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Assessing and addressing health inequities and disparities: The role of health informatics

Edited by
Gulzar H. Shah and Anjum Khurshid

Published in
Frontiers in Public Health

ISSN 1664-8714
ISBN 978-2-83252-088-8
DOI 10.3389/978-2-83252-088-8

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Assessing and addressing health inequities and disparities: The role of health informatics

Topic editors
Gulzar H. Shah — Georgia Southern University, United States
Anjum Khurshid — Harvard Pilgrim Health Care, Harvard Medical School, United States

Topic coordinator
Joanne Chopak-Foss — Georgia Southern University, United States

Citation
Shah, G. H., Khurshid, A., eds. (2023). *Assessing and addressing health inequities and disparities: The role of health informatics*. Lausanne: Frontiers Media SA.
doi: 10.3389/978-2-83252-088-8

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TYPE Editorial
PUBLISHED 21 March 2023
DOI 10.3389/fpubh.2023.1161892

OPEN ACCESS

EDITED AND REVIEWED BY
Peter Kokol,
University of Maribor, Slovenia

*CORRESPONDENCE
Gulzar H. Shah
gshah@georgiasouthern.edu

SPECIALTY SECTION
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

RECEIVED 08 February 2023
ACCEPTED 07 March 2023
PUBLISHED 21 March 2023

CITATION
Shah GH, Khurshid A and Chopak-Foss J (2023) Editorial: Assessing and addressing health inequities and disparities: The role of health informatics. *Front. Public Health* 11:1161892. doi: 10.3389/fpubh.2023.1161892

Editorial: Assessing and addressing health inequities and disparities: The role of health informatics

Gulzar H. Shah[1]*, Anjum Khurshid[2] and Joanne Chopak-Foss[1]

[1]Jiann-Ping Hsu College of Public Health, Georgia Southern University, Statesboro, GA, United States, [2]Department of Population Medicine, Harvard Medical School and the Harvard Pilgrim Health Care Institute, Boston, MA, United States

KEYWORDS

health inequities, health disparities, health informatics, media use, mental health, older adults

Editorial on the Research Topic
Assessing and addressing health inequities and disparities: The role of health informatics

Eliminating health equity and resulting health disparities are at the core of modern population health approaches. Health informatics has been increasingly acknowledged as an essential tool in achieving the desired population health outcomes, but the protective role of informatics may become questionable in the absence of sound scientific evidence about the design and implementation of informatics policies and approaches shown to practically advance the population health and patient-centered healthcare for marginalized population groups (1). The collection of articles in this special topic issue titled *Assessing and Addressing Health Inequities and Disparities: The Role of Health Informatics*, comprised an assortment of topics focusing on the role of various components and processes of health informatics relevant to disparities and inequities in health, directly or as intervening factors. The intent is to showcase health informatics research and empirical evidence that will be instrumental in promoting equitable population health and healthcare outcomes.

The importance of addressing health inequities is increasingly recognized in modern strategies for improving healthcare and public health outcomes. At the same time, improving health and eliminating health disparities requires equitable access to socioeconomic resources known as social determinants of health (SDoH) including assets and income, affordable education, healthy food, clean water, and means to pursue healthy lifestyles. The SDoH data are increasingly used to guide health equity assurance efforts in public health. Recent interest in population health by the healthcare industry and advances in healthcare informatics have fueled their ability to incorporate real-world SDoH data into healthcare information systems to enable EHR-user education and targeted workflow integration (2).

This special topic collection of research studies includes one systematic review and 10 empirical research studies based on primary or secondary data sources. The collection showcases an assortment of geographic coverage, the functionality of informatics, and outcomes. Studies use multi-country data (Qu et al.) as well as national to sub-national geographic coverage. Several studies covered the use of information systems, information technology, and data science in addressing health inequities and disparities in accessing healthcare services by individuals or efficiencies in implementing clinical solutions. The topics and research implications ranged from addressing inequities in access to preventative dental service (Qu et al.), the use of social media during this pandemic (Tegegne et al.), the impact on care coordination by professionals and patients' information exchange (Tegegne et al.; Zhang and Zhang), use of telehealth services for improvements in healthcare services in underserved areas, and in turn, reducing inequities in the distribution of medical resources (Gao et al.; Ganjali et al.), the impact of media use on disparities in physical and mental health among the older people (Wang et al.), and use of modern electronic health records for collection of data for measuring health equity and outcomes for population health (Pesel et al.). Some other studies highlighted the shortcomings of health informatics, including the negative impact of exclusively relying on social media for health communication while excluding traditional media such as TV (Pesel et al.) and the limitation of traditional surveillance systems that do not include data on social determinants of health (Yu et al.). One of the studies tackled best practices in health information system design, with the implications for efficiency in medical resources, improvements in disparities in access to care, improvements in doctor-patient communications, and efficient care coordination (Li et al.). Another study highlighted the lack of policy support in health information systems in health services (Herawati et al.). One of the studies did not establish the linkage between informatics and health equity, though indirect implications can be inferred. The study examined the role of artificial intelligence and machine learning in the individualized prediction of risk factors for high blood loss in the perioperative period of thoracolumbar burst fracture (TBF), which in turn improves clinicians' decision-making and perioperative management (Yang et al.).

In investigating the global effect of COVID-19 mitigation strategies on access to preventable dental care, Qu et al. demonstrated that the COVID-19 mitigation measures in countries across the world created conditions that resulted in an overall decline in the oral health status of people. More critically though, inequities in access the preventive dental care resources worsened the existing disparities in the utilization of dental care. The study findings implied that while containing a pandemic such as COVID-19 can require imposing restrictions that limit people's access to dental care, equitable access to socioeconomic resources becomes even more critical to avoid the spill-over effect of the pandemic on oral health disparities (Qu et al.). Zhang and Zhang used the theory of planned behavior to examine the factors affecting patients' opt-in intention for health information exchange. Detecting health inequities in access to care upstream through data exchanged by health information exchanges (HIEs) can be instrumental in preventing health outcome disparities.

Social media is increasingly considered a valuable and integral part of health informatics, particularly in a pandemic when the timely exchange of accurate information is extremely valuable in curbing the spread of viruses such as SARS-CoV-2. Tegegne et al. studied health professionals' attitudes toward the use of social media for COVID-19-related information. With their study setting in Bahir Dar City public health centers in Ethiopia, they assessed the health professionals' use of social media for COVID-19-related information, concluding that the level of use was moderate. The need for training, education, behavioral change, and knowledge about the usefulness of social media among professionals was emphasized. In addition, enabling factors such as developing trusted social media pages, and social media platforms were recognized to promote the use of social media for COVID-19-related information among health professionals.

Studies have examined the potential of telemedicine in acting as an equalizer in access to care for traditionally underserved populations, and is increasingly gaining popularity in the COVID-19 era. Gao et al. examined telemedicine in China, examining national and regional level necessity, development history, scale and coverage, and operational procedure involving telemedicine. Ganjali et al. conducted a systematic review to study the use of telehealth services for specific functions during the pandemic. They find that telehealth services positively impact patient outcomes in both emergency and outpatient settings. Counseling was the most common functionality observed in the selected studies, followed by monitoring and diagnosing. The authors conclude that telehealth could be effectively adopted in a health emergency, but further research is needed to identify characteristics of successful systems and relevant health outcomes for measurement. The theme emerging from the papers points to the importance of building health informatics systems in public health and population health to capture, share, measure, and analyze data related to inequity as a starting point to address health inequities. Our current systems do a poor job of being able to do so consistently and hence the importance of the examples highlighted in this issue. The examples range from measuring oral healthcare needs in 17 countries, developing electronic patient record systems in Italy, social media impact in Ethiopia and China, and assessing telehealth services during a pandemic. These papers also highlight the challenges of studying socioeconomic, behavioral, and environmental factors, collectively called SDoH, that impact health inequities but the data linking these factors to specific health outcomes in populations is not easily available or collected. This issue is therefore also a call to action to improve the ability to collect, analyze and use richer data using health informatics tools and research to develop better strategies to narrow health equity gaps in the population (Ganjali et al.).

Wang et al. use quantitative methods with a national data sample from the 2017 China General Social Survey. They study the role of media use on the physical and mental health of older adults while controlling for other factors. They find that health disparities due to educational levels which are seen in older adults are narrowed by the use of traditional media but contrarily increase due to internet use. Wang et al. recommend repeated health campaigns through traditional media, like TV, because of its higher use. They also suggest integrating public health messages with media campaigns and advocating policies for narrowing the digital gap to narrow the information gap among older adults.

Pesel et al. present an evaluation of a new electronic patient record system in the Italian healthcare system. The study reminds us of the fact that the digitization of patient records is not a universal phenomenon but one that is a fundamental step in measuring health equity and outcomes for population health (Pesel et al.). In their population-based study of older adults with lung cancer, Yu et al. use cancer surveillance data to develop predictive models for older adults undergoing early-lung cancer treatment.

The study is a good example of the use of data for specific subpopulations, like older adults, but also highlights the limitations of surveillance data in not including socioeconomic factors that are important to understand lung cancer prognosis (Yu et al.).

Herawati et al. describe the problems experienced by the health information system in health services in Indonesia in getting support for policy-making. To effectively address the problems, the study proposed to model a mathematical concept for implementing the health information system in the implementation of JKN in Indonesia. A structural equation model with Lisrel 88 software was used to model the health information system. Structured input components such as governance, human resources, infrastructure, types of information system (IS)(program, JKN, management), and financing; process components: funding, technical guidance, and verification and validation; and output components: open access, standards and quality, utilization, bridging, and security. The concept for strengthening the health information system prioritizes improving the output components (standards, utilization, bridging, open access, and security) in the process components (funding, verification, technical guidance) while the input components (financing, human resources, governance, IS programs, infrastructure, IS JKN, IS management) were included in the structural equation model.

Overall, the collection of articles for this special topic was fairly aligned with the call for papers announcement. However, to our surprise, studies in this collection were predominantly concerned with equitable access to healthcare, quality of healthcare, and improvements in healthcare interventions, and the role of information technology and information systems in addressing promoting these aspects of healthcare. There remained a dearth of studies on the role of health informatics in addressing inequities in public health and population health outcomes. A future call for a special topic may want to solicit studies to address this gap. Anyway, the research evidence generated by the collection of articles in this special topic issue concerning the ways health information technology (HIT) can be leveraged to support improvements in healthcare outcomes and health equity is particularly important in this era of emerging public health threats and patient-centric, evidence-based healthcare.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Acknowledgments

The guest editors sincerely thank the authors of the manuscript included in this special issue for their high-quality submissions.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 31 May 2022
doi: 10.3389/fpubh.2022.890469

Effect of the COVID-19 Mitigation Measure on Dental Care Needs in 17 Countries: A Regression Discontinuity Analysis

Xing Qu[1], Chenxi Yu[2], Qingyue He[3,4], Ziran Li[5], Shannon H. Houser[6], Wei Zhang[1,7] and Ding Li[8]**

[1] Institute of Hospital Management, West China Hospital, Sichuan University, Chengdu, China, [2] College of Economics and Management, Sichuan Normal University, Chengdu, China, [3] Southwest Medical University, Chengdu, China, [4] Center of Health Care Management, Chengdu First People's Hospital, Chengdu Integrated TCM & Western Medicine, Chengdu, China, [5] School of Public Finance and Taxation, Southwestern University of Finance and Economics, Chengdu, China, [6] Department of Health Services Administration, University of Alabama at Birmingham, Birmingham, AL, United States, [7] West China Biomedical Big Data Center, Med-X Center for Informatics, Sichuan University, Chengdu, China, [8] Institute of Development Studies, Southwestern University of Finance and Economics, Chengdu, China

OPEN ACCESS

Edited by:
Gulzar H. Shah,
Georgia Southern University,
United States

Reviewed by:
Jeffrey Fellows,
Kaiser Permanente Center for Health Research, United States
Matheus Lotto,
University of São Paulo, Brazil

***Correspondence:**
Wei Zhang
weizhanghx@163.com
Ding Li
liding@swufe.edu.cn

Specialty section:
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

Received: *06 March 2022*
Accepted: *11 May 2022*
Published: *31 May 2022*

Citation:
Qu X, Yu CX, He QY, Li ZR, Houser SH, Zhang W and Li D (2022) Effect of the COVID-19 Mitigation Measure on Dental Care Needs in 17 Countries: A Regression Discontinuity Analysis. Front. Public Health 10:890469. doi: 10.3389/fpubh.2022.890469

Objectives: The effect of COVID-19 mitigation measures on different oral health care needs is unclear. This study aimed to estimate the effect of COVID-19 mitigation measures on different types of oral health care utilization needs and explore the heterogeneity of such effects in different countries by using real-time Internet search data.

Methods: Data were obtained from Google Trends and other public databases. The monthly relative search volume (RSV) of the search topics "toothache," "gingivitis," "dentures," "orthodontics," and "mouth ulcer" from January 2004 to June 2021 was collected for analysis. The RSV value of each topics before and after COVID-19 was the primary outcome, which was estimated by regression discontinuity analysis (RD). The effect bandwidth time after the COVID-19 outbreak was estimated by the data-driven optimal mean square error bandwidth method. Effect heterogeneity of COVID-19 on dental care was also evaluated in different dental care categories and in countries with different human development index (HDI) rankings, dentist densities, and population age structures.

Results: A total of 17,850 monthly RSV from 17 countries were used for analysis. The RD results indicated that advanced dental care was significantly decreased (OR: 0.63, 95% CI: 0.47–0.85) after the COVID-19 outbreak, while emergency dental care toothache was significantly increased (OR: 1.54, 95% CI: 0.99–2.37) 4 months after the COVID-19 outbreak. Compared to the countries with low HDI and low dentist density, the effect was much more evident in countries with high HDI and high dentist density.

Conclusions: COVID-19 mitigation measures have different effects on people with various dental care needs worldwide. Dental care services should be defined into essential care and advanced care according to specific socioeconomic status in different countries. Targeted health strategies should be conducted to satisfy different dental care needs in countries.

Keywords: COVID-19, oral health, Google Trends, regression discontinuity analysis, global health care, health service

INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic has unpredictably and continuously disrupted the delivery of global health care utilization and disrupted essential health services in many countries (1). During the beginning of the pandemic, worldwide lockdown, quarantine, and redistribution of medical resources profoundly impacted the health care utilization of patients with chronic or urgent diseases. One England study reported that the substantial increases in the number of avoidable cancer deaths were expected due to diagnostic delays due to the COVID-19 pandemic (2). A US study showed that the COVID-19 pandemic had affected US psychiatry physicians by raising personal, financial, and ethical concerns (3). Daily increasing cases and deaths in the first wave of COVID-19 at the beginning of 2020 have led to fearing COVID-19 in many countries, and the number of patients who needed and sought emergency medical care services sharply dropped (4). Some patients with severe disease might even experience additional mortality if left untreated (5).

Oral disease is one of the most prevalent chronic diseases globally but is usually neglected (6). More than 3.5 billion people worldwide suffer from untreated dental caries or another oral condition (7). People with oral conditions would like to search online for similar symptoms or disease information on the Internet to relieve symptoms (8, 9). Therefore, this large volume of data generated from online searching behaviors could be analyzed following the concepts of infodemiology and infoveillance, first defined by Eysenbach (10), to identify previous knowledge and concerns of health seekers on a specific issue and to support health strategy planning (11). For example, interest in dental trauma, broken teeth, chipped teeth, knocked-out teeth, avulsed teeth and oral and maxillofacial surgery has shown a general increase in recent years (12, 13). In the dental health field, the most popular queries were markedly associated with symptoms and treatments, with little interest in prevention (14, 15). This phenomenon may be more pronounced during the pandemic. During the COVID-19 pandemic, it is a challenge for many people who seek regular dental examinations and dental cleaning appointments and those with more serious oral health problems to receive dental care in person, since many dental offices worldwide closed during the spring of 2020, given the risk of virus transmission (16). Interest in toothache-related digital information increased significantly after restriction measures were implemented in most countries (17). The search terms “bruxism,” “molars,” “toothache,” “dentist,” and “staying at home” were also increased (18, 19).

People with different oral conditions may have different online health information-seeking motivations and goals during the pandemic. To identify the individual goals of health information seeking, there are many theories to explain the context in which the search for information takes place. The broad and well-known concept of coping encompasses an individual’s efforts to prevent or deal with distress, harm, or threat (20). Following the theory of problem- and emotion-focused coping initially proposed by Folkman and Lazarus (21), the goal of information-seeking between people with toothache and orthodontics-need was supposed to be different. People with toothache may tend to search for information about symptom relief or solution (22), while people with orthodontic needs may tend to compare dentists or treatment consequences. In addition, social determinants, including health culture, dentist supply (23), socioeconomic status (24), and aging structure (25), may also impact dental care service utilization, which may impact online health information-seeking behaviors. Analyzing this information may help us to understand the changes in dental health needs during the pandemic.

This study aimed to identify the effect of COVID-19 mitigation measures on different categories of dental care needs, evaluate the influence duration, and explore the heterogeneity of such effects in countries with different characteristics with Google Trends search topics by using a quasi-experimental method.

METHODS

Data Source and Variable Measures

Relative Search Volume of Dental Care

This longitudinal retrospective study evaluated dental care-related computational metadata using Google Trends. After reviewing related articles and consulting senior dental experts, five search topics were included (26–29). The relative search volume (RSV) and the main related queries were obtained from the topics “Toothache—Search term,” “Gingivitis—Search term,” “Dentures—Search term,” “Orthodontics—Search term,” and “Mouth ulcer—Search term,” adopting the inclusion criteria of “all categories and sources,” between Jan 2010 and June 2021. The RSV indicates the proportion between the search volume of a specific query by the volume of overall queries performed by users on Google Search, normalized by the maximum value observed in a timeline (RSV = 0–100) and presented on a weekly or monthly basis. Only the countries with complete RSV information during each year were included in the analysis.

Dental care topics were divided into emergency dental care, basic dental care, and advanced dental care for a better understanding of the effect of COVID-19 on different dental care types. Although agreement on the concepts and definition of urgent and basic care is missing in dentistry, particularly in the COVID-19 pandemic context (30), following the concept of a previous study (31), we attempted to classify “toothache,” “gingivitis,” and “mouth ulcers” as basic dental care and “dentures” and “orthodontics” as advanced dental health care. Toothaches represent emergency dental care in basic dental care.

Human Development Index

The human development index (HDI) is a social indicator associated with dental services (32). The HDI is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and having a decent standard of living. The HDI is the geometric mean of normalized indices for each of the three dimensions,

Abbreviations: COVID-19, coronavirus disease 2019; RD, regression discontinuity; RSV, relative search volume; HDI, human development index; OR, Odds ratios; CI, confidence intervals.

drawn from the United Nations Development Programme open database (33). Having a higher HDI means a higher standard of living. The HDI was ranked "very high," "high," "medium," and "low" in each country by the UNDP. In this study, we set the original "very high" and "high" rank as the "High HDI group" and "medium" and "low" as the "Low HDI group" in the subgroup analysis.

Dentist Density

A lack of sufficient dental service providers is one of the barriers to accessing oral health care (23). Dentist density is defined as the number of dentists per 1,000 population in each country by the World Health Organization (WHO), which describes the convenience of dental care access. We used annual statistical data of dentist density drawn from the WHO from 2006 to 2020 to represent dental service providers. This study categorized the countries with a higher dentist density than the median of sum into the high dentist density group.

Population Age Structure

Dental care is different among populations with different age structures (25). The population age structure was drawn from World Bank demographic data from 2006 to 2019 (34). Following the definition of aged countries from the World Bank, we considered countries with a population over 65 years old above 14% as aged countries (35), while 65 years old below and equal to 14% were considered non-aged countries.

Study Design

Sharp regression discontinuity (RD) was used to analyze the effect of the COVID-19 mitigation measures on dental care needs. RD is a quasi-experimental study design that identifies causal effects by deterministically exploiting a treatment assignment practice based on a continuously measured variable (36, 37). In this study, let L represent the treatment variable. $L = 1$ means the mitigation measures of COVID-19 (and $L = 0$). After March 2020, many countries imposed a national lockdown as a mitigation measure for COVID-19 to control coronavirus spread.

Let C represent the potential outcome (RSVs). For each country, we defined the potential outcome variables C^1 and C^0, corresponding to L^1 and L^0. The difference in dental disease RSVs before and after the COVID-19 outbreak was:

$$(C/L = 1) - E(C/L = 0) = \frac{E(C^1 - C^0/L = 1)}{\tau} + \frac{E(C^1/L = 1) - E(C^0/L = 0)}{\varepsilon}$$

$\frac{E(C^1 - C^0/L = 1)}{\tau}$ is the average treatment-on-the-treated effect of RSVs in various countries. Such an effect depends on the impact of COVID-19 pandemic mitigation measures. $\frac{E(C^1/L = 1) - E(C^0/L = 0)}{\varepsilon}$ is selection bias, which summarizes all kinds of potential factors correlated with RSVs. Such bias should tend to zero when we restrict our sample to applicants close enough to the cutoff, while the incidence of dental healthcare still changes (discontinuously) at the cutoff. Therefore, comparing dental healthcare within a sufficiently narrow bandwidth of the cutoff but on opposite sides of it identifies the treatment effect of COVID-19 mitigation measures.

Let X represent the forcing variable, which denotes the timing of the pandemic outbreak with $X = 0$ at the cutoff, so $L = 1$ after $X = 0$ is a "treatment assignment" that is equal to 1 for RSVs after the cutoff. We set March 2020 as the cutoff point because from March 1st, 2020 to April 1st, 2020, new cases of COVID-19 sharply increased from 1,734 to 57,655. In March 2020, the World Health Organization declared COVID-19 to be a global pandemic (38). Then, the difference in limits $\lim_{X \to 0} \left[E(C/X > 0) - E(C/X < 0)\right]$ identifies the effect of L on RSVs near the cutoff. The bandwidth of all dental care services around March 2020 was determined using the data-driven optimal mean square error bandwidth method (39).

Statistical Analysis

The descriptive analysis presented the characteristics of the participants against discount eligibility. Then, we adopted the RD approach to estimate the effect of the COVID-19 mitigation measures on different categories of dental care needs during a specific period. Graphical analysis was used to describe the RSV changes on both sides of the cutoff timing, conditional on the fixed effect of timing, country, and dental diseases. We also conducted placebo tests using outcomes that occurred during March 2019 and thus could not have been affected by the COVID-19 outbreak. A t-test was performed to demonstrate the differences in RSV between 12 months before and 12 months after COVID-19 onset through P-Values. Then, we estimated the heterogeneity of the COVID-19 impact on dental care needs among countries with different HDIs, dentist densities, and population age structures in the subgroup analysis. Odds ratios (ORs) and 95% confidence intervals (95% CIs) were reported. $P < 0.05$ was considered statistically significant. All analyses were performed by STATA 14.0 (Stata Corporation, College Station, TX, United States).

RESULTS

Descriptive Information

Figure 1 shows the RSV trends of five search topics in all countries from Jan 1st 2010 to Dec 31st 2021. Seventeen countries with sufficient monthly RSV information remained for analysis. These countries included Australia, Canada, France, Germany, India, Ireland, Malaysia, New Zealand, Pakistan, the Philippines, Saudi Arabia, Singapore, South Africa, Spain, the United Arab Emirates, the United Kingdom, and the United States of America. During 2010–2021, the RSV curves of "orthodontics," "toothache," and "dentures" gradually increased over time, while the curves of "gingivitis" and "mouth ulcers" seemed flat. However, during March 2020, the curve showed a fluctuation.

Table 1 reports descriptive information on the RSVs, HDI, dental density, and population age structure for the overall sample. A total of 17,850 RSV samples were analyzed in the total sample, and each dental type contained 3,570 samples. The mean RSVs of toothache, gingivitis, dentures, orthodontics, and mouth ulcers were 13.91, 9.13, 9.94, 16.14, and 7.74, respectively. The HDI mean was 0.767, and the mean dentist density was 4.093. The mean population aged >65 years was 10.47%.

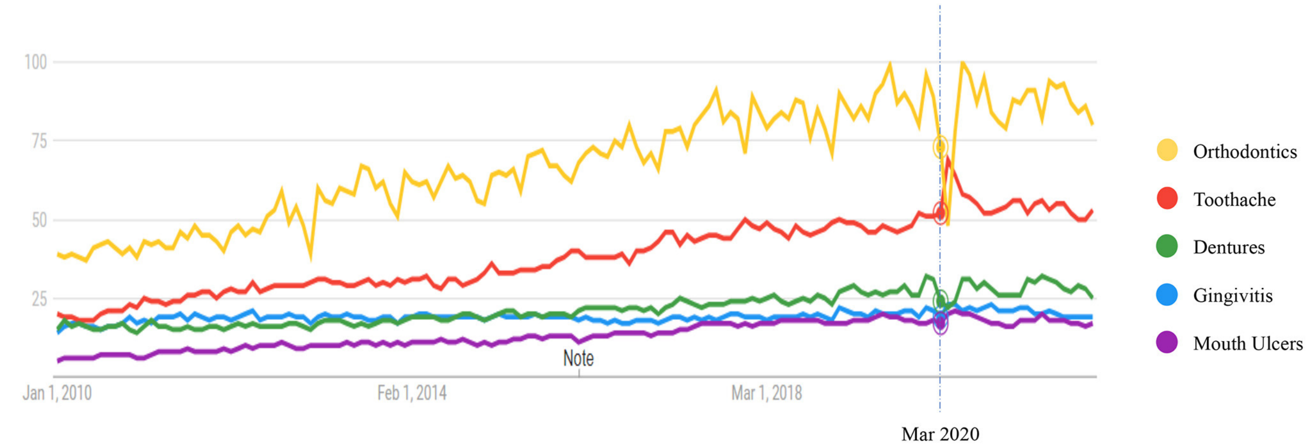

FIGURE 1 | Search volume index of different dental care keywords using Google Trends, 2010–2021.

TABLE 1 | Descriptive information of search volume index, human develop index, dentist's density, and age structure.

	(1) *N*	(2) Mean	(3) SD	(4) Min	(5) Max
Search volume index					
Total samples	17,850	11.38	14.21	0	100
Toothache	3,570	13.91	15.16	0	100
Gingivitis	3,570	9.13	11.43	0	100
Dentures	3,570	9.94	11.54	0	100
Orthodontics	3,570	16.14	19.39	0	100
Mouth ulcer	3,570	7.74	9.48	0	100
Human develop index	14,400	0.767	0.16	0.33	0.96
HDI rank	14,400	61.06	57.43	2.00	185
Dentist's density	9,120	4.09	2.46	0.02	8.58
Percent of aged >65	16,320	10.47	6.12	0.69	21.56

HDI, human development index. SD, standard deviation.

Table 2 shows the country category information in different groups of HDIs, dentist densities, and population age structure classifications. For instance, Australia is a country with high HDI, high dentist density and an aged population.

Heterogeneous Effects of COVID-19 on Different Dental Care Utilization Needs

First, we separately analyzed the effect of COVID-19 on each specific dental care in all sampled countries. **Table 3** shows regression continuity estimates using the residual RSV (log) as the dependent variable, adjusted by the fixed effect of month and time trend. The RSV of "dentures" (OR: 0.60, 95% CI: 0.37–0.94) and "orthodontics" (OR: 0.63, 95% CI: 0.40–0.97) were significantly reduced during the bandwidth. Comparatively, the RSV of "toothache" (OR: 1.54, 95% CI: 0.99–2.37) was significantly increased in the COVID-19 mitigation measures at a significance level of 0.1. RSV of "gingivitis" (OR: 0.86, 95% CI: 0.52–1.42) and "mouth ulcer" (OR: 1.06, 95% CI: 0.59–1.89) had no clear discontinuities. Such an RD plot is reported in **Figure 2**. **Figure 2** plots the discontinuities of the RSV, conditional on the timing of the COVID-19 mitigation measures. The curves were the averages of the logarithmic value of RSV across bandwidth bins of X to the left and right of the cutoff. The vertical solid lines are the predicted outcomes and associated confidence intervals based on a polynomial regression. Following Gelman and Imbens (40), we considered a quadratic polynomial in X in the baseline specification. The bandwidth was approximately 4 months. The sensitivity analysis of bandwidth is shown in **Supplementary Figure S1**. The discontinuity in the predicted RSV at the cutoff equals the changeable effects of RSV before the cutoff.

Impact of COVID-19 Mitigation Measures on Categorized Dental Care Needs

Then, we analyzed the impact of COVID-19 on all types of dental health care and basic and advanced dental care needs in 2020 and in placebo time 2019 in all sampled countries separately. First, T-tests showed that there was no significant RSV difference before 12 and 12 months after the onset of COVID-19 (**Table 4**), which indicated that the 4-month fluctuation of RSV was associated with COVID-19 mitigation measures. In addition, after adjusting for country and disease fix effects (**Table 5**), advanced dental care significantly declined (aOR: 0.63, 95% CI: 0.47–0.85) due to COVID-19 mitigation measures, while there was no significant change in placebo time in 2019. The corresponding RD plots are reported in **Supplementary Figure S2**. The effect of COVID-19 on advanced dental care and basic dental care in different countries is shown in **Supplementary Figure S3**.

Subgroup Analysis in Categorized Countries With Different HDI Ranks, Dentist Densities, and Age Structures

In the countries with a high HDI rank (**Table 6**), the RSV of dentures (OR: 0.61, 95% CI: 0.37–0.97) were significantly

TABLE 2 | Country categories in HDI, dentist density, and population age structure.

	HDI		Dentist density		Population age structure	
	High	**Low**	**High**	**Low**	**Aged**	**Non-aged**
Australia	√		√		√	
Canada	√		√		√	
France	√		√		√	
Germany	√		√		√	
India		√		√		√
Ireland	√		√		√	
Malaysia	√			√		√
New Zealand	√		√		√	
Pakistan		√		√		√
Philippines		√		√		√
Saudi Arabia	√			√		√
Singapore	√			√		√
South Africa		√		√		√
Spain	√		√		√	
United Arab Emirates	√		√			√
United Kingdom	√		√		√	
United States of America	√		√		√	

HDI, human development index. The HDI was ranked "very high," "high," "medium," and "low" in each country by the UNDP. In this study, we set the original "very high" and "high" rank as the "High HDI group" and "medium" and "low" as the "Low HDI group" in the subgroup analysis.
This study categorized the countries with a higher dentist density than the median of sum into the high dentist density group. The mean dentist density equals 5.
This study categorized the countries with a population over 65 years old above 14% to be aged countries.

TABLE 3 | Regression continuity estimates of COVID-19 on five dental care searching topics.

	Advanced dental care		Basic dental care		
	Denture	**Orthodontics**	**Toothache**	**Gingivitis**	**Mouth ulcer**
In all samples					
OR	0.60**	0.63**	1.54*	0.86	1.06
95% CI	0.37–0.94	0.40–0.97	0.99–2.37	0.52–1.42	0.59–1.89
P-Value	<0.05	<0.05	<0.1	0.56	0.847
Bandwidth	3.93	4.52	3.83	6.57	5.73

*The RSV of "dentures" (OR: 0.60, 95% CI: 0.37–0.94) and "orthodontics" (OR: 0.63, 95% CI: 0.40–0.97) were significantly reduced during the bandwidth. Comparatively, "toothache" (OR: 1.54, 95% CI: 0.99–2.37) were significantly increased in the COVID-19 mitigation measures at a significance level of 0.1. RSV of "gingivitis" (OR: 0.86, 95% CI: 0.52–1.42) and "mouth ulcer" (OR: 1.06, 95% CI: 0.59–1.89) had no clear discontinuities. ***P < 0.01, **P < 0.05, *P < 0.1.*

reduced, while the RSV of toothaches (OR: 1.61, 95% CI: 1.07–2.39) were increased. The RSV of dentures (OR: 0.55, 95% CI: 0.31–0.97) and orthodontics (OR: 0.61, 95% CI: 0.38–0.96) were significantly reduced, and toothache was significantly increased (OR: 1.85, 95% CI: 1.14–3.01) in countries with high dentist density. The RSV of orthodontics (OR: 0.61, 95% CI: 0.34–1.08) and gingivitis (OR: 0.56, 95% CI: 0.31–0.98) were significantly reduced in countries with a low percentage of the aged population. However, all the RSVs of toothache increased in all types of countries, with different significance. The corresponding RD plot was reported in appendix **Supplementary Figure S4**.

DISCUSSION

This primary finding of this study showed that the RSV of toothache increased by 1.54 times in approximate 4 months after the COVID-19 mitigation implementation in March 2020, while the need for orthodontics and dentures decreased by nearly 40% among 17 countries in the world, using Google Trends searching topics with a quasi-experimental analysis. Such trends are more evident in countries with a high HDI and high dentist density than in countries with a lower HDI and low dentist density.

This finding observed that the sudden effect time of COVID-19 mitigation measures on global dental health care needs lasted about 4 months, which means such online dental care searching interest fluctuation lasted till July, 2020. The results were consistent with but more generalized than those of previous studies in estimating the effect of COVID-19 on dental care utilization. A study from the United States showed that in the first few days of June, 71% of dental clinics were open, but the number of patients was less than usual (41). By June 20, the number of weekly visits rebounded sharply (42). Another survey indicated

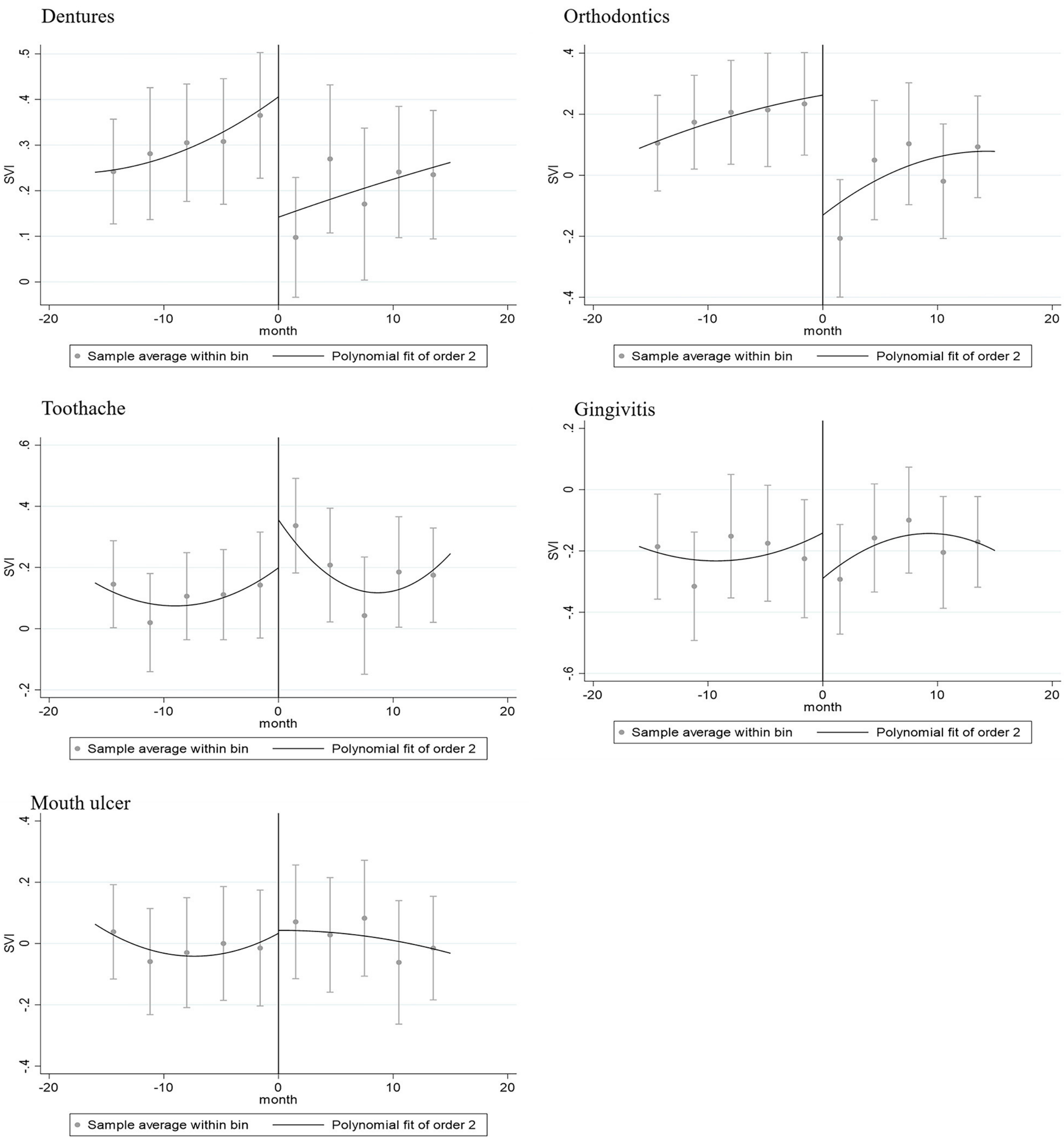

FIGURE 2 | Regression discontinuity plot of topics of dentures, orthodontics, toothache, gingivitis, and mouth ulcer in March 2020.

that 71.1% of dentists would reopen dental clinics on May 20, 2020 (43). The present findings indicated that the estimated effect duration of the COVID-19 mitigation measure on dental care needs was longer than expected. Compared to cardiovascular diseases and diabetes that recovered in early April 20 (44), the recovery time of dental care needs seems to be longer than that of other severe chronic diseases. This may be related to the fact that a lower priority of dental care was in most people's minds, and it is believed that dental disease is not harmful to general health compared to severe chronic diseases. In the present study, the estimation of the time discontinuity of dental care needs is essential for all stakeholders when confronting a similar situation because of the continuous impact of COVID-19, such as new wave outbreaks caused by the Omicron Variant at the end of 2021 (45).

TABLE 4 | Differences of RSV between pre-pandemic period with the pandemic period (12 months before and 12 months after onset) using *T*-Test.

	Pre-onset	Post-onset	Mean difference	*P*-Value
	Mean (SD)	**Mean (SD)**		
Five-diseases	17.83 (17.25)	18.45 (19.57)	−0.61 (−2.22 to 0.98)	0.45
Basic diseases	15.38 (14.24)	16.67 (16.92)	−1.29 (−3.04 to 0.46)	0.14
Advanced diseases	21.49 (20.45)	21.10 (22.74)	0.39 (−2.27 to 3.37)	0.79
Toothache	22.95 (17.26)	26.71 (21.75)	−3.75 (−7.58 to 0.06)	<0.1
Gingivitis	10.91 (10.36)	11.11 (10.30)	−0.20 (−2.21 to 1.81)	0.84
Mouth ulcer	12.29 (10.85)	12.20 (11.39)	0.08 (−2.08 to 2.25)	0.93
Denture	17.29 (13.79)	17.50 (15.67)	−0.20 (−3.08 to 2.67)	0.70
Orthodontic	25.70 (24.76)	24.70 (27.67)	1.00 (−4.11 to 6.11)	0.93

The findings of this study identified the heterogeneous effect of COVID-19 mitigation measures on different dental care categories. The search term "toothache" was significantly sharply increased after mitigation of COVID-19, which was consistent with previous studies (17, 19). The sharp increase in the need for emergency dental care may be related to stress, changes in diet patterns and oral hygiene behaviors during the pandemic, and delayed care (46). These changes predicted that the burden of untreated dental diseases would increase rapidly in a short time (47, 48). Dental professionals should be prepared to face the increasing demand for emergency dental care and adverse clinical outcomes in a short time after the outbreak of the COVID-19 epidemic (49). Comparatively, this finding observed a similar decline in the need for orthodontics (50). This phenomenon could be explained by the different motivations for searching activities online in the context of the pandemic. The decline in orthodontics and dentures may be related to the lower priority of non-urgent oral health during the pandemic. Dental professionals who specialized in such fields should prepare for facing short term financial stress of clinics operation.

Interestingly, COVID-19 mitigation had a greater effect on increasing toothache in countries with a high human development index and high dentist density. This phenomenon indicated that the prevalence of dental disease onset, especially emergency dental diseases, did not decline even in countries with better socioeconomic backgrounds. This may be related

TABLE 5 | Estimates coefficients of regression discontinuity of dental care SVIs at baseline and after adjusting fix effect of country and disease.

	Baseline estimates			Adjusted by country and disease fix effect		
	All type	**Basic dental care**	**Advanced dental care**	**All type**	**Basic dental care**	**Advanced dental care**
Observations	13,512	7,984	5,528	13,512	7,984	5,528
COVID-19 and index (crude)						
SVI (log)	0.91	1.09	0.69*	0.91	1.08	0.66***
95% CI	0.67–1.24	0.75–1.59	0.44–1.08	0.73–1.15	0.81–1.43	0.49–0.90
P-Value	0.57	0.39	<0.10	0.45	0.58	<0.001
Bandwidth (month)	5.39	9.16	6.34	5.54	9.21	5.97
COVID-19 and index (adjusted by fix effect of month and time trend)						
SVI (log)	0.87	1.06	0.66*	0.87	1.03	0.63***
95% CI	0.65–1.18	0.72–1.56	0.42–1.04	0.69–1.09	0.76–1.39	0.47–0.85
P-Value	0.39	0.74	<0.10	0.24	0.83	<0.001
Bandwidth (month)	6.03	7.68	6.74	5.26	6.90	5.91
Placebo tests (in March 2019)						
SVI (log)	1.02	0.99	1.11	1.04	1.02	1.06
95%CI	0.77–1.35	0.70–1.41	0.70–1.76	0.85–1.26	0.77–1.34	0.80–1.41
P-Value	0.87	0.97	0.65	0.72	0.87	0.66
Bandwidth (month)	10.92	10.04	13.10	9.27	8.70	10.75

*Quantitative measures of COVID-19 impact on basic dental care and advanced dental care were reported in this table. We firstly analyzed the association between COVID-19 and SVIs without controlling any other effect, the coefficients in baseline estimates were not significant. After adjusting the fix effect of country and dental care type, lower SVIs of advanced dental care was associated with COVID-19 mitigation measures (OR: 0.66, 95%CI: 0.49–0.90). Then we controlled the fix effect of month and time trend, lower SVIs of advanced dental care was associated with COVID-19 mitigation measures (OR: 0.63, 95%CI: 0.47–0.85) after controlling the fix effect of country and disease. Column 1–3 showed the RD estimates without taking any treatment on logarithmic value of SVIs, column 4–6 showed the RD estimates after adjusting fix effect of country and disease. Comparatively, there was no statistically significant difference of RD estimates in the placebo test. ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.*

TABLE 6 | Regression continuity estimates of COVID-19 on five dental care keywords in countries with different backgrounds.

	Advanced dental care		Basic dental care		
	Denture	**Orthodontics**	**Toothache**	**Gingivitis**	**Mouth ulcer**
Categorized by HDI rank					
Low HDI					
OR	0.74	0.59	1.36	0.67	1.30
95% CI	0.41–1.29	0.29–1.16	0.55–3.37	0.39–1.15	0.37–4.46
P-Value	0.28	0.12	0.67	0.15	0.41
Bandwidth	6.03	4.31	2.90	6.35	7.68
High HDI					
OR	0.63*	0.61**	1.61**	1.02	1.08
95% CI	0.37–1.05	0.37–0.97	1.07–2.39	0.51–2.01	0.55–2.09
P-Value	<0.1	<0.05	<0.05	0.96	0.82
Bandwidth	4.00	3.14	3.55	5.77	3.71
Categorized by Dentists Density					
Countries with density <5 (medium) per 1,000 persons					
OR	0.65*	0.61	1.19	0.76	0.88
95% CI	0.40–1.05	0.32–1.14	0.65–2.17	0.48–1.17	0.38–2.01
P-Value	<0.1	0.12	0.56	0.21	0.76
Bandwidth	6.49	4.96	9.85	5.02	6.60
Countries with density ≥5 per 1,000 persons					
OR	0.55**	0.61**	1.85***	1.04	1.28
95% CI	0.31–0.97	0.38–0.96	1.14–3.01	0.44–2.47	0.60–2.70
P-Value	<0.05	<0.05	<0.01	0.92	0.51
Bandwidth	3.63	5.32	3.82	5.85	4.82
Categorized by age structure					
Countries with aged 65 < 14%					
OR	0.44	0.61*	1.22	0.56**	1.17
95% CI	0.15–1.26	0.34–1.08	0.69–2.15	0.31–0.98	0.36–3.69
P-Value	0.12	<0.1	0.49	<0.05	0.79
Bandwidth	2.74	3.42	3.60	2.73	3.65
Countries with age 65 ≥ 14%					
OR	0.56**	0.58***	1.43	0.91	1.00
95% CI	0.31–1.00	0.37–0.87	0.68–2.97	0.41–2.03	0.45–2.19
P-Value	<0.05	<0.01	0.34	0.82	0.99
Bandwidth	3.77	3.07	5.83	6.43	5.35

****P < 0.01, **P < 0.05, *P < 0.1.*

to the traditional dental care always focused on treating symptoms of dental diseases rather than emphasizing prevention (51). Shifting more toward prevention-centric approaches to care and away from surgical interventions should be considered in the future (52). This finding also reflect the socioeconomic disparities of dental care that are profoundly persistent in the world (53). People from countries with a high human development index and high dentist density may have more conveniently routine dental care accessibility and better oral health perception. Their urgent dental needs could be instantly satisfied due to sufficient dental care supplies before mitigation (54). Therefore, they felt more affected and had more online dental health information seeking behaviors during the pandemic. This may be related to the existing inequalities and heterogeneity in dental care between countries rather than the lower priority of oral health care during the pandemic. The COVID-19 pandemic seems to have revealed such inequalities (53). Eliminating socioeconomic disparities in dental care should be considered when developing public health strategies. In a short period, dental professionals should implement different health management strategies for primary dental care and advanced dental care during the lockdown period to satisfy different dental needs. Increasing preventive dental intervention to reduce acute dental disease should be persistently encouraged in the long run. Essential oral health care should be given priorities according to specific development status in countries when considering oral health care in the primary care system (30).

There are several limitations to this study. First, countries that do not use Google or lack sufficient data are excluded. Therefore, these results may reflect a potential trend of countries using Google, but they are not representative of all countries. Second, the RSV of dental care can provide us with a broad perspective to analyze real-time global health care demand. However, due to repeatedly searching of the same user, RSV may be higher than the actual dental needs. Third, we used five specific dental diseases to represent the different dental care, which only represents a part of dental diseases. Other dental diseases may be overlooked in the analysis. Future research may consider using an extensive database to evaluate more accurate results. Fourth, we assessed the short-term impact on dental health. Considering that the pandemic is still ongoing, researchers should use longitudinal data to evaluate the long-term effect on dental care. Future studies need to summarize our findings.

Despite these limitations, this research shows several advantages. First, we used a quasi-experimental method to estimate the causal effect of COVID-19 on global dental care. To the best of our knowledge, this is the first article to analyze the causal impact of COVID-19 mitigation measures on global dental care needs by using Internet search data. Second, we gave quantitative estimates of the sudden impact of COVID-19 on dental care. The estimates, including the duration and a specific disease, could provide a reference for the recovery time after the pandemic. By using this data-driven estimation time, dentists could prepare for shutdown hours and reduce economic pressure (55). Third, health care decision-makers could redistribute different dental resources to reduce harmful consequences caused by the unexpected pandemic on the dental care market.

CONCLUSION

The influence of COVID-19 mitigation measures was different in dental care categories and different countries. The mitigation measure of COVID-19 exposed the existing disparities in dental care utilization and insufficient preventive dental care. Eliminating socioeconomic disparities in dental care should be considered when developing public health strategies.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: Dental care SVIs are available at https://trends.google.com/trends/?geo=US. HDI rank is available at http://hdr.undp.org/en/content/human-development-index-hdi. Dentist density is available at https://www.who.int/data/gho/data/indicators/indicator-details/GHO/dentists-(per-10-000-population). Age structures are available at https://data.worldbank.org/indicator/SP.POP.1564.TO.ZS.

AUTHOR CONTRIBUTIONS

XQ contributed to the conception, design, data acquisition, analysis, interpretation, drafted, and critically revised the manuscript. CXY contributed to the analysis and critically revised the manuscript. QYH and ZRL contributed to the analysis and interpretation and critically revised the manuscript. SH contributed to the conception, data interpretation, drafted, and critically revised the manuscript. WZ contributed to the conception, acquisition and analysis, and critically revised the manuscript. DL contributed to the design, acquisition, drafted the manuscript, and critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work ensuring integrity and accuracy.

FUNDING

This study was supported by the National Natural Science Foundation of China, No. 71904136 and the Sichuan Science and Technology Agency, No. 2020YFS0582. The funding organization had no role in the study design, implementation, analysis, or interpretation of the data.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.890469/full#supplementary-material

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 17 June 2022
doi: 10.3389/fpubh.2022.900293

Health Professionals' Attitude Toward the Use of Social Media for COVID-19 Related Information in Northwest Ethiopia: A Cross-Sectional Study

*Masresha Derese Tegegne[1]**, *Berhanu Fikadie Endehabtu[1]*, *Habtamu Alganeh Guadie[2]* *and Tesfahun Melese Yilma[1]*

[1] Department of Health Informatics, Institute of Public Health, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia, [2] Department of Health Informatics, School of Public Health, College of Medicine and Health Sciences, Bahir Dar University, Bahir Dar, Ethiopia

Background: Social media platform is one way to share online information regarding pandemic prevention. However, there is no study regarding the attitude of health professionals toward social media use for the COVID-19-related information. This study aimed to assess health professionals' attitudes toward using social media for COVID-19-related information.

Methods: An institution-based cross-sectional study was conducted among 355 health professionals in Bahir Dar city public health centers, Northwest Ethiopia. A pretested self-administered questionnaire was used to collect the data. The data were entered by EPI-data version 4.6 and analyzed using SPSS version 23 software. Descriptive statistics, bivariable, and multivariable logistic regression analysis were used to describe respondents' attitudes toward using social media for COVID-19 information and identify associated factors. An adjusted odds ratio (*OR*) and a *p*-value with a 95% *CI* were calculated to measure the strength of the association and assess statistical significance.

Result: Out of 341 participants, about 73% of the participants had a good attitude toward the use of social media for COVID-19 information. Age $\leq$ 24 [adjusted odds ratio (*AOR*) = 3.74, 95% *CI*: (1.53–9.13)] and age group 25–34 years [*AOR* = 2.25, 95% *CI*: (1.04–4.86)], computer training [*AOR* = 2.03, 95% *CI*: (1.03–4.00)], usefulness of social media [*AOR* = 3.25, 95% *CI*: (1.58–6.67)], and trustworthiness [*AOR* = 3.57, 95% *CI*: (1.93–6.60)] were enabling factors for attitude toward the use of social media for COVID-19 related information.

Conclusion: Health professionals had a moderate attitude toward using social media for accessing COVID-19-related information. This implies that after considering positive attitude predictors, such as providing basic computer training, emphasizing the usefulness of social media, and building trusted social media pages, social media platforms can be used as a source of COVID-19-related information for health professionals.

Keywords: social media, attitude, COVID-19, Ethiopia, COVID-19 information

Edited by:
Gulzar H. Shah, Georgia Southern University, United States

Reviewed by:
Wondesen Teshome Bekele, Dire Dawa University, Ethiopia
Ho-Jui Tung, Georgia Southern University, United States

****Correspondence:***
Masresha Derese Tegegne
masresha1derese@gmail.com

Specialty section:
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

Received: *20 March 2022*
Accepted: *18 May 2022*
Published: *17 June 2022*

Citation:
Tegegne MD, Endehabtu BF, Guadie HA and Yilma TM (2022) Health Professionals' Attitude Toward the Use of Social Media for COVID-19 Related Information in Northwest Ethiopia: A Cross-Sectional Study. Front. Public Health 10:900293. doi: 10.3389/fpubh.2022.900293

INTRODUCTION

The World Health Organization (WHO) declared coronavirus diseases 2019 (COVID−19) as a public health emergency of international concern on 11 March 2020 (1, 2). Reports reveal that the number of confirmed COVID-19 cases is exponentially increasing (3, 4). As a result of the exponential increase in cases and deaths, the current COVID-19 pandemic is threatening global health. It is vital to prevent pandemics from further spreading in community and healthcare settings through promotion and education. Social media platforms are a means of pandemic prevention and are used by health professionals for communication purposes (5).

Social media is defined as automated communication through mobile and web-based technologies (6). Evidence showed that social media helps in crisis communication, such as natural disasters and pandemics (5), and it also played a significant role during the COVID-19 pandemic (7, 8).

The use of social media in the era of pandemics warrants greater scrutiny because of its consequences for public understanding of COVID-19 issues. The internet and social media are used as reference guides for accessing COVID-19-related information for health professionals (9). Moreover, health professionals can provide access to valid information about the pandemic to the community using social media sites (10).

Evidence suggests that social media platforms encourage the exchange of current information to improve community and healthcare workers' knowledge, practice, and attitude (11). In a previous Egyptian study, more than half of the respondents said that social media is their primary source of COVID-19-related information (12). Similarly, Karasneh et al. (13) found that social media networking sites and the internet were the primary means for sharing COVID-19-related information. Furthermore, an international study has been undertaken on health professionals' attitudes toward using social media for accessing health information (14–18). Jordanian evidence revealed that nursing students were enthusiastic about using social media to access COVID-19 information (15, 19). Similar studies identified that health professionals' use of social media platforms had been considered an efficient instrument for education, exchange, and communication in the COVID-19-related information (20, 21).

According to the study, issues, such as a lack of training, a negative perception of social media sites' usefulness, and a lack of access to the internet and electronic devices contribute to a negative attitude about using social media to receive health information (14, 17). Besides this, the legality and trustworthiness of information shared on social media are limited, resulting in fake news, professional identity, and privacy violations.

Health practitioners were recognized to be on the front lines of raising community awareness and preventing the spread of the COVID-19 pandemics. It is difficult for healthcare providers to teach patients face to face and offer them accurate information about COVID-19 transmission and preventative strategies because of the nature of COVID-19 transmission. The lack of a well-integrated system to combat COVID-19 makes prevention challenging in developing nations (22). According to research, traditional media were revealed to be sources of COVID-19 information in Ethiopia (23). Conventional methods of communication do not reach a large number of people quickly or obtain an immediate reaction. As a result, social media networking platforms have become health professionals' only method of connection in their communities.

As we have seen in different countries of the world, a few studies have explored health professionals' behavior in using social networking sites for accessing COVID-19-related information (15). Similarly, there is limited evidence on health professionals' attitudes regarding using social media platforms to share COVID-19-related information in Ethiopia. As a result, the current study aimed to determine health professionals' attitudes toward using social media for COVID-19-related information and its associated factors in Bahir Dar town health centers in northwestern Ethiopia. The findings of this study could add to our understanding of health professionals' attitudes toward using social media to learn about COVID-19. Our results can also help health administrators, policymakers, and planners in implementing effective pandemic response systems. These initiatives may assist them in implementing new pandemic prevention mechanisms.

METHODS

Study Design and Setting

A cross-sectional study was carried out among health professionals from 25 January to 20 February 2021, to assess the attitude of health professionals toward the use of social media for accessing COVID-19 related information in Bahir Dar town health centers, which is the objective of this research. Bahir Dar is the capital of the Amhara Region and is situated in the northwestern part of Ethiopia, which is 490 km far from the capital, Addis Ababa (24). In the city, there are 10 health centers, namely, Abay health center, Bahir Dar health center, Minilik Health Center, Han Health Center, Meshenty Health Center, Shimbit Health Center, Shumabo Health Center, Tis Abay Health Center, Zegie Health Center, and Zenzelma Health Center, which serve approximately 750,991 population.

Study Subject

The population included in this study consisted of all health professionals who had at least one social media account in Bahir Dar town health centers. This population had experience in social media practices and could give adequate data on the research questions. However, health professionals who were severely sick and on annual leave during the data collection period were excluded.

Sample Size and Sampling Procedure

The calculated sample size for this study using the single population proportion formula was 423, while the total number of health professionals in Bahir Dar town health centers who had

Abbreviations: COVID-19, Coronavirus diseases 2019; AOR, Adjusted odds ratio; CI, Confidence interval; Epi-Data, Epidemiological Data; ICT, Information Communication Technology; SMNs, Social media networks; SPSS, Statistical Package for Social Science; WHO, World Health Organization.

at least one social media account was only 355. Therefore, all health professionals meeting the eligibility criteria were included.

Study Variables and Outcome Measurement

The study's primary outcome variable was health professionals' attitudes toward using social media for COVID-19-related information. This study's tools were adapted from a review of related studies (14, 17). Some independent variables include socio-demographic parameters, technological-related variables, and behavioral variables.

Attitudes toward social media usage for COVID-19-related information were measured by using a 5-point Likert scale from "strongly disagree" (score 1) to "strongly agree" (score 5) (14). The item scores for each composite variable were added and divided by the number of items to create a composite variable ranging from scores 1 to 5 for data analysis (25, 26). As a result, final scores of three or more (strongly disagree, disagree, and neutral) were labeled as "Good attitude." In contrast, final scores of three or less (strongly disagree, disagree, and neutral) were categorized as "Poor attitude" (27).

Data Collection Tools and Quality Assurance

A self-administered, structured, and pre-tested questionnaire in English was used to collect data from the study population. The data were collected by ten health informatics technicians with excellent communication skills, with two health informatics professionals with prior study experience in supervising the data collection process. In addition, 1 day of training was given to data collectors. A pre-test was done out of the study area, at Gondar town in Gondar health center with 10% of the study population to avoid unclarity before actual data collection. The researchers attempted to reduce response bias based on survey replies during the pre-test. This was done by looking over the questions and making sure they were balanced, avoiding any that would provoke a strong emotional response in one direction or the other. The pre-test results were also used to evaluate the data collection instrument's validity and reliability. Cronbach's alpha result was used to assess the data collection instrument's internal consistency, and the score on attitude toward social media usage for COVID-19 was 0.86.

Data Processing and Analysis

The data entry and cleaning were performed by using Epi-data version 4.6. After that, the data were exported to SPSS version 25 software for analysis. Descriptive statistics and percentages were computed to describe the socio-demographic variables and attitudes toward social media usage for COVID-19 information. Bivariable and multivariable binary logistic regression analyses were used to measure the association between the dependent and independent variables. In the bivariable regression analysis, factors having a p-value of <0.2 were included in the multivariable regression analysis. The odds ratio (*OR*) with 95% *CI* and p-value were calculated to evaluate statistical significance. For all statistical significance tests, the cut-off value was $p < 0.05$. Multicollinearity assumptions were evaluated before running the logistic regression model, and all the variance inflation factor (VIF) values were <3, indicating no multicollinearity between variables. Since our outcome variable is not normally distributed, we have fitted a multivariable binary logistic regression. The model fitness was assessed by Hosmer and Lemeshow test, which indicates that it was well-fitted where the p-value was >5% (i.e., p-value = 0.596).

TABLE 1 | Socio-demographic characteristics and computer and internet access at Bahir Dar city health centers ($n = 341$).

Socio-demographic characteristics	Frequency	Percentage
Gender		
Male	185	54.3
Female	156	45.7
Age		
≤24	36	10.6
25–34	235	68.9
≥35	70	20.5
Profession		
Nurse	123	36.1
Midwives	67	19.6
Health officer	52	15.2
Laboratory	46	13.5
Pharmacy	38	11.1
Other*	15	4.4
Educational level		
Diploma	108	31.7
BSc. Degree	209	61.3
Masters	24	7.0
Years of experience on social media networks		
≤5 years	222	65.1
6–10 years	73	21.4
>10 years	46	13.5

Environmental health and nutrition.

RESULTS

Socio-Demographic Characteristics

The questionnaire was completed by 341 (96%) of the 355 participants. The respondents' average age was 31.49 (SD ± 6.42) years. As shown in (**Table 1**), 235 (68.9%) of health professionals belonged to 25–34 years age group. More than half (54.3%) of the respondents were men. The majority of the responders (61.3%) had a bachelor's degree, and more than half (55.7%) were nurses or midwives. The majority of the respondents, 222 (65.1%), had <5 years of experience with social media networks (SMNs).

Computer and Internet Access

Table 2 shows that 321 (94.1%) health professionals owned at least one electronic device, with smartphones 87.1%, laptops 22.9%, and desktops 15%. Of all respondents, 206 (60.4%) have access to the internet, and approximately 48.7% of respondents have basic computer training.

The Attitude Toward the Use of Social Media for COVID-19 Related Information by Health Professionals

Of the total respondents, 248 (72.7%) (95% *CI*: 67–77%) had a good attitude toward using social media for accessing COVID-19-related information. **Table 3** shows that 43.1% of health professionals believe that using social media to share COVID-19-related information and knowledge is an essential use of time. About 45.7 and 41.9% of the total respondents believe that sharing COVID-19 information and knowledge *via* social media is valuable and engaging. Furthermore, 47.2% of them thought using social media to stay up to date on COVID-19 was a good idea.

Of all respondents, 239 (70.1%) healthcare providers were daily users of social media. As shown in **Table 4**, Facebook (87.1%) and Telegram (59.2%) were found to be the two most widely used platforms for accessing COVID-19-related information among health professionals working at Bahir Dar town health centers. Health professionals' main reasons for using social media to seek COVID-19-related information were to know COVID-19 treatment 174 (51%) and for global and local death reports 177 (51.9%) (**Table 4**).

While using social media to access COVID-19-related information, about 74.5% of health professionals concluded that COVID-19-related information released on SMNs was trustworthy. Furthermore, 81.8% of health professionals argued that COVID-19-related information published on SMNs was useful, and 194 (56.9%) had privacy concerns while using SMNs for COVID-19-related information.

TABLE 2 | Computer and internet access among health professionals working at Bahir Dar city health centers (n = 341).

Computer and internet access	Frequency	percentage
Computer access*		
Smartphone	297	87.1
Laptop	78	22.9
Desktop	51	15.0
Don't have access	20	5.9
Internet access		
Yes	206	60.4
No	135	39.6
A stable power supply to use the internet		
Yes	198	58.1
No	143	41.9
Did you take any kind of computer training?		
Yes	166	48.7
No	175	51.3

**Multiple responses possible.*

TABLE 4 | Social media usage for COVID-19-related information in Bahir Dar city health centers (n = 341).

Frequency of social media use	Frequency	Percentage
Frequency of using social media networks.		
Daily	239	70.1
Not daily	102	29.9
Used platform*		
Facebook	297	87.1
Telegram	202	59.2
WhatsApp	70	20.5
YouTube	124	36.4
Twitter	8	2.3
Others**	19	5.5
Reasons for using social media to seek COVID-19*		
For diagnosis	166	48.7
For treatment	174	51.0
For global and death reports	177	51.9
For global and local case reports	169	49.6
To find updates on the prevention methods	139	40.8
To find updates on the mode of transmission	127	37.2
Privacy concern of while using SMN to seek COVID-19 information		
Concerned	194	56.9
Not concerned	147	43.1
Trustworthiness of COVID-19 information posted on SMN		
Trustworthy	254	74.5
Not trustworthy	87	25.5
Usefulness of SMN to seek COVID-19 information		
Useful	279	81.8
Not useful	62	18.2

**Multiple responses possible, **(Instagram and Tik Tok).*

TABLE 3 | Health professionals' attitude toward the use of social media for COVID-19-related information (*n* = 341).

Attitude statements	SD (%)	*D* (%)	*N* (%)	*A* (%)	SA (%)
Sharing COVID-19 information and knowledge by using social media is an essential use of time	31 (9.1)	54 (15.8)	65 (19.1)	147 (43.1)	44 (12.9)
Sharing COVID-19 information and knowledge by using social media is very beneficial	20 (5.9)	51 (15.0)	55 (16.1)	156 (45.7)	59 (17.3)
Using social media for accessing COVID-19 updates make me very engaging	21 (6.2)	56 (16.4)	86 (25.2)	143 (41.9)	35 (10.3)
Using social media is a good way to get current information for COVID-19	13 (3.8)	32 (9.4)	34 (10.0)	161 (47.2)	101 (29.6)
Using social media is returns high quality information regarding COVID-19	17 (5.0)	64 (18.8)	44 (12.9)	137 (40.2)	79 (23.2)

SD, strongly disagree; D, disagree; N, neutral; A, agree; SA, strongly agree.

TABLE 5 | Factors associated with health professional's attitude toward the use of social media for COVID-19-related information at Bahr Dar city health centers ($n = 341$).

Characteristics	Attitude		COR (95% CI)	AOR (95% CI)
	Good (%)	Poor (%)		
Age				
≤24 years	85 (24.9)	21 (6.2)	3.75 (1.81–7.73)	3.74 (1.53–9.13)*
25–34	136 (39.9)	47 (13.8)	2.69 (1.41–5.06)	2.25 (1.04–4.86)*
≥35 years	27 (7.9)	25 (7.3)	1	
Educational level				
Master's degree	20 (5.9)	6 (1.8)	1.69 (0.62–4.57)	1.81 (0.48–6.75)
BSc Degree	157 (46.0)	51 (15.0)	1.56 (0.93–2.60)	1.20 (0.64–2.25)
Diploma	71 (20.8)	36 (10.6)	1	1
Experience on SMN				
>10 years	36 (10.6)	9 (2.6)	1.94 (0.89–4.25)	1.39 (0.56–3.47)
6–10 years	62 (18.2)	11 (3.2)	2.74 (1.36–5.52)	1.95 (0.85–4.46)
≤5 years	150 (44.0)	73 (21.4)	1	1
Device access				
Yes	238 (69.8)	83 (24.3)	2.86 (1.15–7.13)	1.75 (0.55–5.56)
No	10 (2.9)	10 (2.9)	1	1
Internet access				
Yes	166 (48.7)	49 (14.4)	1.81 (1.11–2.95)	1.01 (0.55–1.88)
No	82 (24.0)	44 (12.9)	1	1
Frequency of using SMN				
Daily	189 (55.4)	50 (14.7)	2.75 (1.66–4.54)	1.39 (0.74–2.63)
Not-daily	59 (17.3)	43 (12.6)	1	
Electricity availability				
Yes	170 (49.9)	47 (13.8)	2.13 (1.31–3.47)	1.04 (0.56–1.95)
No	78 (22.9)	46 (13.5)	1	1
Basic computer training				
Yes	143 (41.9)	23 (6.7)	4.14 (2.43–7.07)	2.03 (1.03–4.00)*
No	105 (30.8)	70 (20.5)	1	1
Privacy				
Concerned	137 (40.2)	56 (16.4)	0.81 (0.50–1.32)	0.79 (0.43–1.44)
Not-concerned	111 (32.6)	37 (10.9)	1	1
Trustworthiness				
Trustworthy	210 (61.6)	44 (12.9)	6.15 (3.60–10.49)	3.57 (1.93–6.60)*
Not-trustworthy	38 (11.1)	49 (14.4)	1	1
Usefulness				
Useful	224 (65.7)	55 (16.1)	6.44 (3.57–11.63)	3.25 (1.58–6.67)*
Not-useful	24 (7.0)	38 (11.1)	1	1

Significance at p-value < 0.05.

Factors Associated With Health Professionals' Attitude Toward Using Social Media for COVID-19 Related Information

In both bivariable and multivariable analysis age, basic computer training, the usefulness of SMN to seek COVID-19-related information, and the trustworthiness of COVID-19 information posted on SMN were significant variables in the attitude of health professionals toward the use of social media for COVID-19 related information (**Table 5**).

Health professionals who were younger (Age ≤24 and 25–34 years) were approximately [adjusted odds ratio (*AOR*) = 3.74, 95% *CI*: (1.53–9.13)] and [*AOR* = 2.25, 95% *CI*: (1.04–4.86)] times more likely to have a good attitude toward using social media for COVID-19-related information when compared with those who are >35 years of age. Health professionals taking basic computer training were [*AOR* = 2.03, 95% *CI* = (1.03–4.00)] times more likely to have a good attitude toward using social media for COVID-19-related information. Similarly, health professionals who perceived social media as helpful in seeking COVID-19 information were [*AOR* = 3.25, 95% *CI*: (1.58–6.67)] times more likely to have a good attitude toward using social media for COVID-19-related information than those who perceived it not helpful. Respondents argued that COVID-19 information posted on SMN trustworthy were [*AOR* = 3.57, 95% *CI*: (1.93–6.60)] times more likely to show a good attitude toward using social media for COVID-19 related information than their counterparts.

In other words, educational level, experience with SMN, device access, internet access, frequency of using SMN, electricity availability, and privacy concern were found to be non-significant variables (p-value > 0.05) in the attitude of health professionals toward using social media for accessing COVID-19-related information (**Table 5**).

DISCUSSION

The study aimed to assess health professionals' attitudes toward social media use for COVID-19-related information and its associated factors in Bahir Dar city health centers in Northwestern Ethiopia. As far as we know, this is the first study in Ethiopia to look into health professionals' perspectives on using social media for COVID-19 information.

This study showed that three-fourths (72.7%) of health professionals had a favorable attitude toward using social media for accessing COVID-19-related information in this study. The possible explanation for the high attitude level in this study may be COVID-19 pandemic makes health professionals have a good attitude toward the technology (28). Furthermore, another reason may be that health professionals have more information needed due to the nature of the COVID-19 pandemic (29, 30).

This study showed that Facebook and Telegram were the most frequently used social media platforms for accessing COVID-19-related information. This finding supports previous research (31, 32) that found Facebook and WhatsApp to be the most popular platforms for accessing COVID-19 data. However, in this study, Telegram is more popular than WhatsApp. The difference may be due to cross-country differences in the preferences of social media platforms. Another reason might be that the availability of government-related sites on Telegram forced health professionals to utilize this platform, such as the Ethiopian Public Health Institute.

The multivariable model revealed that respondents' age, basic computer training, the usefulness of social media for accessing COVID-19 information, and the trustworthiness of COVID-19 information posted on social media were all significant factors associated with health professionals' attitudes toward using social media to access COVID-19 related information.

Among the factors, younger health professionals were more likely to have a good attitude toward using social media for COVID-19 information. This conclusion has been supported by previous research on the subject (17, 33). Younger health professionals are more eager to accept and use social media networking sites for COVID-19-related information than older groups. This suggests that older employees need more assistance in adapting to and using social media as sources of COVID-19-related information.

This study also indicated that taking basic computer training was found to have a significant association with the attitude of health professionals toward the use of electronic health information sources, such as social media. This may be justified that computer-related training was more likely to increase health professionals' familiarity with using digital media, including social media platforms for accessing health information. Study findings from Ethiopia (34, 35), Saudi Arabia (36), and the United kingdom (17) support these findings.

The findings also showed that the perceived usefulness of social media networking sites was positively associated with health professionals' attitudes toward using social media to seek COVID-19-related information. This result is consistent with other studies where health professionals who did not believe in the possible advantages of social media were less inclined to use social media for accessing health information (33, 36, 37). This might be because health professionals who believe digital platforms as vital for sharing information may emphasize and seek information from them. This suggests that, in the delivery of health information by social media, there is a need to guarantee that social media will enhance the intended health outcomes.

In this study, respondents who trusted COVID-19 information on SMN were more likely to have a positive attitude toward using social media to seek COVID-19-related information. This finding is consistent with other studies (38). This implies that in the delivery of pandemic information through social media pages, it is better to use more trusted sites than other non-professional pages (34).

As a result, interventions to improve health professionals' basic computer skills, such as training on how to access and use electronic health information sources and emphasizing individual factors, such as usefulness and trustworthiness, may have a positive impact on health professionals' use of social media in combating the COVID-19 pandemic.

CONCLUSION

In general, health professionals had a moderate attitude toward using social media for accessing COVID-19-related information. Being young, having computer training, perceived usefulness, and trustworthiness of SMN contributes to a positive attitude toward using social media for COVID-19 information.

Providing comprehensive digital platform training, improving health professionals' expectations of the usefulness of social media networking sites, and implementing more trusted information sources are necessary measures to increase the health professionals' attitude toward using social media for accessing pandemic-related information.

LIMITATION

Since this study was an institution-based cross-sectional survey, only health professionals who came during the data collection period were interviewed, thus excluding those who were absent during data collection time. Additionally, the information collected was self-perceived, which might have reporting bias.

DECLARATION

Ethical Considerations

The ethical clearance and approval letter for this study was obtained from the Institutional Review Board (IRB) of the University of Gondar. Communication with officials was made through a formal letter received from the University of Gondar. A supporting letter was also obtained from the Amhara Regional Health bureau. All additional explanations about the research's objective and method were given with the assurance that any information contributed by study participants would be kept private. Written consent was obtained from each study participant. Participation was voluntary, and participants could withdraw from the study if they were not comfortable with the questionnaire.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Considerations. The ethical clearance and approval letter for this study was obtained from the Institutional Review Board (IRB) of the University of Gondar. At all level communication with officials was made through a formal letter obtained from the University of Gondar. A supporting letter was also obtained from the Amhara Regional Health bureau. All additional explanations about the purpose of the research and its procedure were explained with the assurance of confidentiality of any information provided by study subjects. Written consent was obtained from each study participant. Participation was voluntary and participants can withdraw from the study at any time if they were not comfortable with the questionnaire. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MT made significant contributions in conception, design, data collection supervision, data analysis, interpretation, and write up of the manuscript. TY, BE, and HG have contributed in extensively revising the manuscript, analysis, and interpretation. All authors have approved the final version of this manuscript.

ACKNOWLEDGMENTS

We are grateful to the Institute of Public Health at the University of Gondar for allowing us to conduct this research. We also like to thank the Bahir Dar town administration and health centers for providing all required information and assistance. We also want to express our gratitude to the project's participants, data collectors, and supervisors.

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 06 July 2022
doi: 10.3389/fpubh.2022.916303

Telemedicine Is Becoming an Increasingly Popular Way to Resolve the Unequal Distribution of Healthcare Resources: Evidence From China

Jinghong Gao[1,2,3†], Chaolin Fan[1†], Baozhan Chen[1,2,3†], Zhaohan Fan[1,2], Lifeng Li[1,2], Linlin Wang[1,2,3], Qianqian Ma[1,2,3], Xianying He[1,2,3], Yunkai Zhai[2,4] and Jie Zhao[1,2,3*]*

[1] The First Affiliated Hospital of Zhengzhou University, Zhengzhou, China, [2] National Engineering Laboratory for Internet Medical Systems and Applications, Zhengzhou, China, [3] Henan Province Telemedicine Center of China, National Telemedicine Center of China, Zhengzhou, China, [4] Management Engineering School, Zhengzhou University, Zhengzhou, China

Background: Few studies focused on the general situation of telemedicine in China.

Objectives: The purpose of this review is to investigate telemedicine in China, from the aspects of necessity, history, scale, and operation procedure, to improve the further development and implementation of telemedicine service.

Methods: A literature search for peer-reviewed studies was conducted using the primary electronic databases. Additional documents from the official websites of Chinese government departments involved telemedicine was also collected. We extracted telemedicine related information focused on China from the final retrieved materials, and the general situation of telemedicine was drawn.

Results: In China, telemedicine offers a feasible solution to the unequal allocation of healthcare resources, which makes telemedicine increasingly become an important alternative to close the gap between rural and urban in the capability and quality of medical services. China initiated telemedicine in the late 1980s. In 2018, China's telemedicine network has covered more than 3,000 hospitals across the country. As of 2019, almost all of the 31 provinces and municipalities in mainland have established regional telemedicine centers, and the market size of telemedicine reached about USD 2.68 billion. Based on the telemedicine network, remote rural patients can apply for healthcare services of top-tier urban hospitals through local county-level medical institutions.

Conclusions: Through improving the capacity, quality, and efficiency of healthcare in underserved areas, and reducing the unequal distribution of medical resources, telemedicine can help solve the problems of the difficulty and high cost to access to medical services in China.

Keywords: telemedicine, necessity, development history, scale, operation procedure

OPEN ACCESS

Edited by:
*Gulzar H. Shah,
Georgia Southern University,
United States*

Reviewed by:
*Al Asyary,
University of Indonesia, Indonesia
Ricardo Valentim,
Federal University of Rio Grande do Norte, Brazil*

***Correspondence:**
*Jie Zhao
zhaojie@zzu.edu.cn
Jinghong Gao
fccgaojh@zzu.edu.cn*

† These authors have contributed equally to this work

Specialty section:
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

Received: *09 April 2022*
Accepted: *10 June 2022*
Published: *06 July 2022*

Citation:
Gao J, Fan C, Chen B, Fan Z, Li L, Wang L, Ma Q, He X, Zhai Y and Zhao J (2022) Telemedicine Is Becoming an Increasingly Popular Way to Resolve the Unequal Distribution of Healthcare Resources: Evidence From China. Front. Public Health 10:916303. doi: 10.3389/fpubh.2022.916303

INTRODUCTION

A major challenge faced by both developed and developing countries today is the inequity of access to healthcare resources. Based on information and communication technologies (ICTs), telemedicine offers a potential solution to the problem by providing cross-regional, accessible, and high-quality healthcare services (1, 2). Telemedicine can overcome geographical and temporal barriers, and help healthcare professionals exchange valid information and deliver medical services (1, 3). Telemedicine, a term firstly coined in the 1970s, which generally refers to the use of modern ICTs to increase the access of medical institutions, physicians, and patients to healthcare resources and medical information for the prevention, diagnosis, and treatment of diseases, response of major public health emergency, continuous education of medical staff, interdisciplinary research, administration and effectiveness assessment, and others in the interests of improving public health (1, 4, 5).

In general, there are two basic forms of telemedicine: synchronous and asynchronous, which are classified based on the timing of information transmission and the relationships between the individuals involved (1, 3). The former requires that the involved clinicians and patients are connected at the same time and exchange information simultaneously, such as live two-way interactive videoconferencing. In contrast, the latter involves the asynchronous communication and exchange of pre-recorded medical information, such as clinical examination reports, images, and video recordings, between different individuals separated by distance and time, as in the case of email or text message (1, 6). This latter approach is known as "store-and-forward." For both synchronous and asynchronous telemedicine, necessary information can be transmitted in a variety of media, such as figure, audio, video, still picture, and text. In practice, these two telemedicine forms may be employed one or both with or without intermittent in-person consultations based on clinical and individual needs, which have been applied to various services in diverse settings, including teleconsultation, teleradiology, telemonitoring, teledermatology, and telepathology (1–3, 7). For instance, as one of the typical telemedicine service that use of ICTs to transmit medical information (e.g., photos or videos) concerning skin conditions for the purpose of teleconsultation and interpretation, teledermatology may be classified into two main modalities (1). In the modality store-and-forward, the local referring doctor firstly sends materials and description of a medical case to an expert of top-tier hospital, who sends back an interpretation and opinion regarding diagnosis advice and optimal treatment after a variable time interval. For the synchronous modality, individuals involved can exchange information and conduct dermatological teleconsultation through real-time two-way interactive videoconferencing.

As an open, sharing, and continuously evolving science, telemedicine constantly incorporates new advancements in ICTs and adapts to the contexts of socioeconomic development and changing public health needs to achieve the key purpose that the cross-regional and without time limited delivery of medical services and exchange of information (1, 8). Compare to traditional medical patterns, telemedicine with some typical elements should be highlighted, including (1) various types of ICTs are employed; (2) main purpose is to provide clinical support; (3) can overcome area and temporal limitations, and allow physicians to reach patients in different physical locations; (4) with the potential to enhance access to healthcare and improve patients' outcomes; (5) may alleviate the shortage of healthcare professionals and medical resources; (6) is usually, although not always, brings cost saving for both patients and healthcare facilities (1, 2, 7, 9). With these characteristics, to date, telemedicine has been used to a wide array of services in radiology, dermatology, cardiology, endocrinology, obstetrics, nephrology, neurology, gastroenterology, psychiatry, cardiovasology, and ophthalmology (8, 10–15). In recent years, the simultaneous advance and maturation of multiple ICTs has provided an unprecedented opportunity for further development and implementation of telemedicine. These technology innovations, including artificial intelligence (AI), wearable and implantable sensing technologies, 5th generation mobile networks (5G), Internet of Things, cloud computing and platform, and block-chains, are creating an inter-dependent ecosystem for new opportunities in telemedicine (2, 7, 16–18).

It is increasingly realized that telemedicine generally has the potential to increase access to healthcare services, make the most of scarce medical resources, improve clinical diagnosis, treatment and care of diseases, and advance the health of individuals. This is particularly true for the regions that traditionally suffer from lack of access to healthcare, such as remote villages, mountainous areas, isolated islands, or underserved communities, especially in developing countries (1, 19). In the United States, a non-profit American Telemedicine Association (ATA) was founded in 1993, which is committed to ensuring that everyone has opportunities and access to safe, affordable, and appropriate healthcare services when and where they need it. To date, the ATA has included more than 400 partner organizations and alliances, and there are more than 60% of health service organizations and 50% of hospitals have integrated telemedicine into routine medical services (20). In Europe, telemedicine has also been becoming one of the priority areas on the political agenda. It has been reported that more than 50 countries in Europe have established telemedicine systems, and the application fields include cardiology, radiology, ophthalmology, stomatology, emergency, monitoring, and health management (4, 21). In Brazil, telemedicine has been emerged since the early 1990s in a decentralized and fragmented manner in health, teaching, and research (22, 23). Due to the expansive geographies, with thousands of isolated, difficult-to-access locations, unequal distribution of medical resources, and uneven levels of health professionals, Brazil becomes a country

Abbreviations: COVID-19, novel coronavirus 2019; ECG, electrocardiograms data; EMR, electronic medical records; HPHC, National Bureau of Statistics, Henan Province Health Commission; HTCC, Henan Province Telemedicine Center of China; LIS, laboratory information system; NHCC, National Health Commission of China; NHFPC, National Health and Family Planning Commission of China; PACS, picture archiving and communication system; PLA, People's Liberation Army; WHO, World Health Organization.

of unique opportunities for telemedicine development and application (24–26). In order to minimize regional inequalities in the distribution of medical resources and specialists, reduce unnecessary referrals, establish continuing education for medical staff and, thus, obtain better cost-effectiveness and services quality, in 2007, the Ministry of Health formed the Telehealth Brazil Program, which was renamed National Telehealth Program Brazil Networks in 2011 (23, 27). Currently, for the program there are 26 Telehealth centers in 23 states serving 3,417 cities, involving teleconsultation, telediagnosis, telemonitoring, and tele-education (24, 27, 28). However, in Brazil, direct communication with patients such as teleconsultation remains forbidden. This situation only recently changed due to the outbreak of coronavirus disease 2019 (COVID-19). By the middle of April 2020, the Ministry of Health published a specific ordinance to authorize the use of telemedicine, during the COVID-19 pandemic, in any healthcare activities in Brazil (23, 29). Given the continuous pandemic of COVID-19, similar situations of quantum leap development and applications of telemedicine were also observed in many other countries around the world (30–32).

In China, telemedicine is a relatively new approach to healthcare delivery that is under rapidly developing. Various telemedicine networks covered different level hospitals have been launched to provide telemedicine services, such as teleconsultations, remote specialty diagnoses (e.g., tele-diagnosis of imaging results, tele-pathology, and tele-electrocardiograms), and remote education of medical staff (5, 33, 34). Telemedicine in China has been improving the dissemination of high-quality healthcare resources from the cities to remote rural areas, providing equivalent healthcare services in cities and underserved regions, and promoting China's hierarchical medical systems (34). However, to date there has no study tried to investigate the situation of telemedicine comprehensively in China, especially from the perspectives of both national and regional levels. Thus, in the current scoping review, we first investigate the necessity, development history, and scale of telemedicine in China at a national level. Second, we summarize the general operation procedure of telemedicine services in healthcare facilities in China, focusing on the information from provincial telemedicine centers. Lastly, taking the Henan Province Telemedicine Center of China (HTCC) as an example, from regional level we examine the specific telemedicine services and the corresponding effectiveness. To the best of our knowledge, this is the first comprehensive account of telemedicine in China, at both national and regional levels, and we hope the findings will help improve the further development and implementation of telemedicine service in China and provide significant references for other regions worldwide.

METHODS

Study Design

This scoping review was conducted consistent with the guidance of the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) checklist (35, 36). A scoping review was selected to identify and summarize the existing evidence about the development and implementation of telemedicine in China because it allows a general and comprehensive approach to the subject.

Search Strategy

A literature search for peer-reviewed studies published up to 2020 was conducted using the electronic databases PubMed, China National Knowledge Infrastructure (CNKI), and Wanfang Data. Relevant reports from the World Health Organization (WHO) were also searched for further information. Our search used the following Medical Subject Headings (MeSH terms) from the US National Library of Medicine and key words: "telemedicine," "telehealth," "teleconsultation," "health unfairness," "healthcare distribution," "remote specialty diagnoses," "remote education," "China," and "developing country." In order to facilitate an effective search, the search terms were adapted to the different databases. In addition, a comprehensive search from the official websites, government reports, public documents, yearbooks, and announcements of the National Health Commission of China (NHCC), National Bureau of Statistics, Henan Province Health Commission (HPHC), and HTCC was performed on 15 April 2020. References in the retrieved materials were examined and necessary manual searches were further performed.

Eligibility Criteria

Both English and Chinese language articles were included in the initial search. The PICO criteria described in PRISMA was followed in this study. The identified materials were screened and selected in accordance with the pre-specified inclusion criteria, including (1) the development and implementation of telemedicine was involving the public in China; (2) telemedicine services such as teleconsultation, remote specialty diagnoses, or distance education were the studied factor(s); (3) the characteristics, advantages, or effectiveness of telemedicine compare to traditional medical services were investigated; and (4) the necessity, history, scale, or operation procedure of telemedicine were discussed.

Data Extraction and Synthesis

For the retrieved materials, the telemedicine related information focused on China was extracted using a pre-designed data extraction form. Two authors (JHG and CLF) extracted data independently from the final selected references and the following key information was obtained: issues of medical services, the distribution of healthcare resources, necessity, development history, and scale of telemedicine, procedure of telemedicine service, challenges faced by telemedicine, and future work and directions of telemedicine. The information was then cross-checked and discrepancies were discussed by the data extractors and resolved through consensus among all authors. A comprehensive summary of the situation of telemedicine in China was finally drawn, at both the national and provincial levels.

RESULTS

A total of 5,442 peer-reviewed records were identified from the databases, 45 official and government reports and documents were obtained, and 21 additional articles or documents were retrieved through references. After removing duplicates, the titles and abstracts of the preliminary identified materials were scanned for relevance. Based on the PICO criteria and topics of this review, materials that did not involve the aspects of necessity, history, scale, operation procedure, challenges, and future directions of telemedicine in China were excluded. Then, 121 materials were screened for a full-text examination and 57 articles or documents were retained (**Figure 1**).

The Necessity of Telemedicine

China's development gap between urban and rural regions is huge. For example, although 42.65% of China's population lives in rural areas, about 80% of China's medical resources are concentrated in the cities, two-thirds of which are in megacities (37). This geographically uneven distribution of medical resources has created relatively poor healthcare in remote rural areas. In 2018, compared with the figure 4.01 in the urban, the number of practicing (assistant) physicians per thousand in rural regions in China was only 1.82 (**Figure 2**) (38). Rural patients with intractable diseases often need to go to distant top-level hospitals for treatment. In addition to the problems regarding physical distance, travel to urban specialty healthcare services imposes financial burden on the patients and their families, since they have to pay for transportation, accommodation, and somehow make up for wages lost because of time taken off work (1, 3, 39). Besides, the transfer roads are often bumpy, which is uncomfortable for patients, and might influence, even exacerbate, certain medical conditions. Diagnosis and treatment are likely delayed for patients without the means to travel to specialty healthcare services in cities, resulting a further physical and mental adverse influence on both the patients and their family members (40, 41).

Patients in China are free to choose their healthcare facilities and doctors, then even for minor symptoms, lots of people tend to travel to municipal or provincial level hospitals for diagnosis and treatment (34). Although many diseases can be cured at primary hospitals at affordable prices with convenient access, many patients hesitate to use these facilities because they lack confidence in the local healthcare professionals and the quality of healthcare services provided there (34, 42). Indeed, skilled doctors in China tend to avoid working at remote rural facilities for both financial and professional reasons (34, 43). The preference for the top-tier urban hospitals has increased the bed tension and business burden, whereas the local county-level hospitals have plenty of available beds, which creates the contradictory co-existing phenomena of unequal geographical distribution and polarization between urban and rural healthcare resources, healthcare inefficiencies, and lack of access to specialty healthcare services (**Figure 3**) (33, 43). Telemedicine offers a feasible solution to the unequal allocation of medical resources, rural/urban gap in the capability and quality of disease diagnosis and treatment, and meets the public's urgent needs for high-quality healthcare services (1, 33, 34). In China, telemedicine is gradually becoming a key approach to respond to these problems.

The History of Telemedicine

China initiated telemedicine in the late 1980s. In 1986, Guangzhou Ocean Shipping Company's hospital provided emergency transoceanic consultations for its ships' crews *via* radiotelegraphy, which was believed to be the first telemedicine practice in China (1). In 1988, the People's Liberation Army (PLA) General Hospital in Beijing conducted a remote neurosurgery case discussion *via* network satellite with a German hospital (3). Shanghai Medical University launched a pilot telemedicine project in 1995, and established one of the earliest telemedicine center in China (44). Since about that time, people began to search for medical help through the Internet. In the same year, there was a well-known instance that has become a classic telemedicine case at the international level. A Peking University student became ill for unknown reasons. Her classmates wrote her symptoms in English and emailed relevant foreign organizations for help through the Internet. They received more than 1,000 replies from 18 countries and regions around the world, which ultimately helped Chinese doctors to determine that the patient was afflicted with thallium poisoning (3).

In the late 1990s, from the theoretical exploration to gradual application, telemedicine in China experienced a rapid development period, and the representative milestones, namely, initiated telemedicine firstly or with the largest annual number of telemedicine services at national or provincial level, were summarized in **Table 1**. In 1997, the NHCC established the Chinese Jin-Wei Telemedicine Network, which provided teleconsultation and remote education services through satellite communication for hospitals in 21 provinces (3). The PLA and the National Health and Family Planning Commission of China (NHFPC) set up the Jun Wei II project (telemedicine network) in 2001. Since then, with the recognition and support of the central and local government, there were lots of telemedicine programmes initiated in other provinces, including Henan, Guizhou, Guangdong, and Fujian. Organizations such as the government, medical universities, hospitals, and even some private companies, sponsored their own telemedicine networks in succession, and made telemedicine a routine healthcare service (1, 3, 45). It has been reported that as of 2019, almost all of the 31 provinces and municipalities in mainland of China have established their own regional telemedicine centers (33, 46, 47).

Scale and Coverage of Telemedicine Services

In 2001, the Jun Wei II telemedicine network covered approximately 300 hospitals across the whole country, which performed about 1,800 teleconsultation cases per year (48). By the end of 2003, the telemedicine network had carried out teleconsultation and remote education services for more than 1,000 patients and 50,000 medical staff, respectively (3). Between 2003 and 2010, lots of provinces in China launched their own regional telemedicine networks, including the Xinjiang, Gansu,

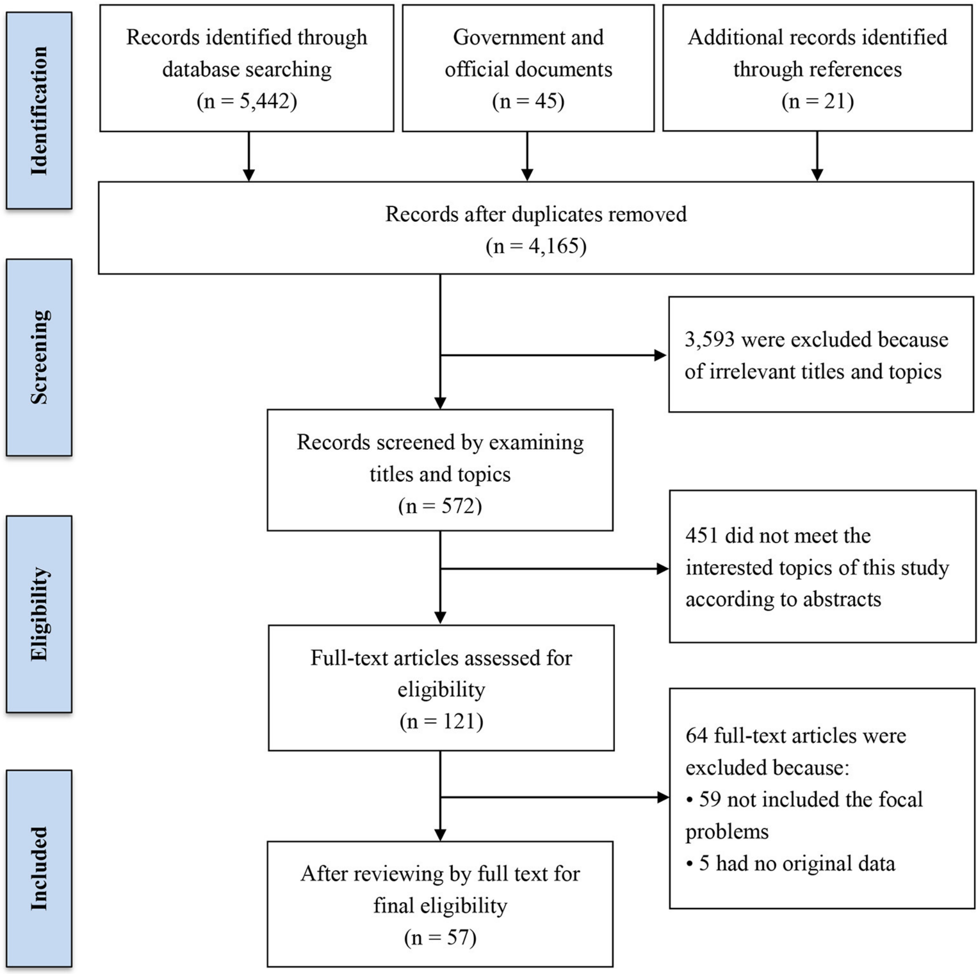

FIGURE 1 | Flow chart of screening process of the literature search.

Ningxia, Fujian, and Yunnan (**Table 2**). All these provincial telemedicine platforms were supported by local government and are still in operation nowadays. Since 2010, the government has invested about USD 12.25 million in deploying and operating local telemedicine systems in 22 central and western provinces. During this process, 12 western provinces and 12 subordinate hospitals of the National Health Commission were brought together to establish a top-tier telemedicine network that included 110 tertiary hospitals, three secondary hospitals, and 726 county-level hospitals (49).

According to the NHFPC, in 2013, 2,057 healthcare facilities sponsored telemedicine services throughout China, and regional top-tier hospitals of many provinces established separate telemedicine platforms themselves (49). In 2017, 22 provinces had provincial telemedicine platforms comprised of about 13,000 healthcare facilities in more than 1,800 counties, which conducted about 60 million person-time telemedicine services (33). As of 2018, China's telemedicine network had covered more than 3,000 hospitals across the country, with more than 60 specialty areas, and there were six provincial telemedicine centers have completed business interconnection with each other (50). The appointment period of teleconsultation was shortened from 7 days to 2 days, and for the emergency and critical cases the time was not more than 2–4 h. For emergency rescue, a brand new remote collaborative information channel can be established within 30 min. It has been suggested that, in 2019, the market size of telemedicine in China reached about USD 2.68 billion (51).

Cui et al. investigated the general implementation and application of telemedicine in 29 provinces, autonomous regions, and municipalities across China. The authors reported that in 2017, among the investigated 185 tertiary hospitals, 253 secondary hospitals, and 26 primary hospitals, there were 161 (87.03%), 187 (73.91%), and nine (34.62%) hospitals have conducted telemedicine services, respectively (47). As of June 2020, the number of Internet medical users in China had reached 276 million, accounting for 29.4% of the total Internet users, and 26.4% of Internet users had purchased medicines and health equipment online (52, 53). For example, in 2020, the revenue of the teleconsultation business carried out by Alibaba Health reached 5.93 million dollars, implying a year-on-year

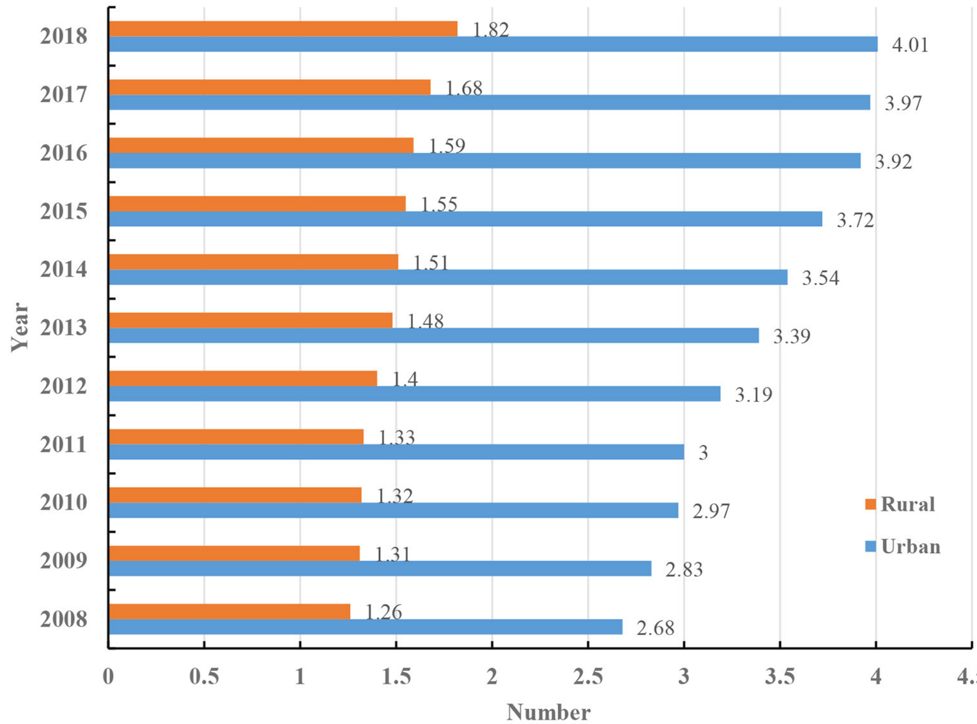

FIGURE 2 | The number of practicing (assistant) physicians per thousand in urban and rural regions in China.

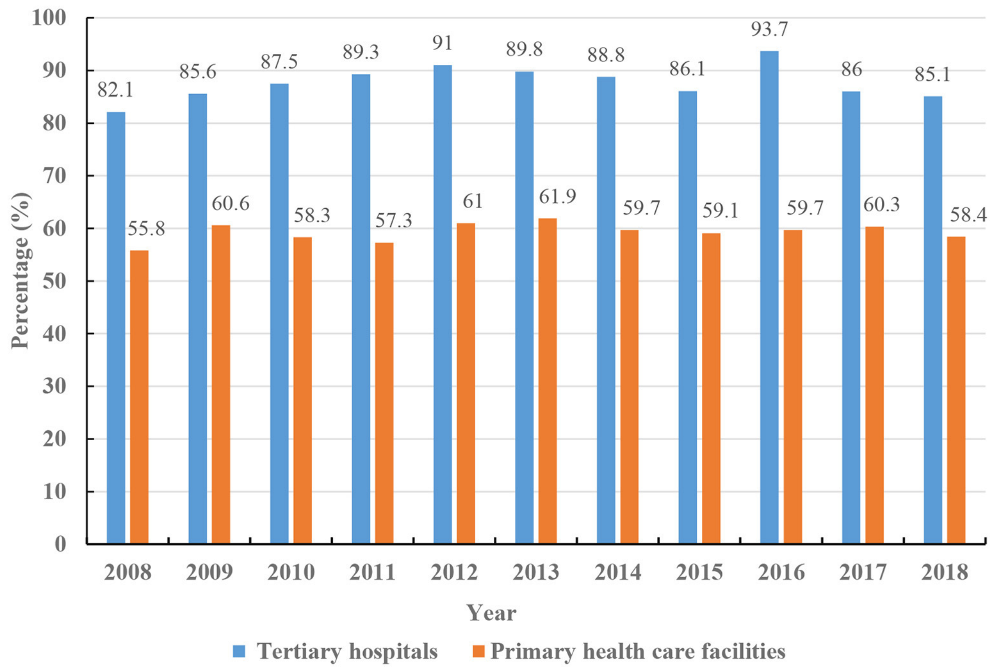

FIGURE 3 | The bed use rate in urban tertiary hospitals and local primary healthcare facilities.

increase of 221.2%. During the COVID-19 epidemic, 17.9% of Internet users have used telemedicine services such as remote registration and teleconsultation. Affected by the epidemic, the remote health consultation, diagnosis and treatment services of

TABLE 1 | The development history of telemedicine in China.

Year	Telemedicine milestone(s)
1986	Guangzhou Ocean Shipping Company's hospital provided emergency transoceanic consultations for its ships' crews *via* radiotelegraphy
1988	The People's Liberation Army (PLA) General Hospital conducted a remote neurosurgery case discussion *via* network satellite with a German hospital
1994	Shanghai Medical University successfully carried out a teleconsultation between the Huashan hospital and the Shanghai Jiaotong University
1995	In Beijing, a student named Ling Zhu became ill for unknown reasons and searched for help *via* the Internet, which helped her to prove that she was afflicted with thallium poisoning; in Shanghai, the Shanghai Medical University launched a pilot telemedicine project and established a telemedicine center; in Shandong Province, a girl named Xiaoxia Yang suffered from an unidentified disease and asked for help through the Internet, then she was diagnosed as a phagocytic bacterial infection in the muscles
1996	The First Affiliated Hospital of Zhengzhou University initiated the first telemedicine center in Henan Province
1997	The International Medical Network Committee was established by China Medical Foundation to promote the development of medical information and telemedicine; the Chinese Jin-Wei Telemedicine Network was established to provide telemedicine services through satellite communication for hospitals in 21 provinces
1999	The Ministry of Health developed a set of rules to regulate and supervise telemedicine services
2001	The PLA and the National Health and Family Planning Commission of China (NHFPC) set up the Jun Wei II project (telemedicine network); the NHFPC launched the Shuang-wei telemedicine network to provide remote medical education services for doctors and nurses all over the country
2010	The NHFPC issued a guidance document about the development of teleconsultation services for tumor pathology and the construction of a network for quality control
2014	The NHFPC published the opinions on promoting telemedicine services in medical institutions
2015	The NHFPC carried out pilot work of telemedicine policy in five provinces: Ningxia, Yunnan, Inner Mongolia, Guizhou, and Tibet
2018	Office of the State Council published the opinions on promoting the development of Internet & medical health; the NHFPC issued the Standard of Telemedicine Service Management; the NHFPC approved the construction of the National Telemedicine Center.

telemedicine platforms in China increased by more than 20 times, and the number of remote prescriptions increased by nearly 10 times (52).

Procedure of Telemedicine Service

Telemedicine is an increasingly popular way to reduce the unequal distribution of healthcare resources in China. Generally, there are three common telemedicine service modes worldwide: medical institution-to-medical institution (B-B), medical institution-to-patient (B-C), and medical institution-to-telemedicine enterprise-to-patient (B-B-C) (4, 47). In China, the telemedicine service model is mainly B-B (47). For B-B model in China, although the operation procedures of telemedicine services in different telemedicine platforms may discrepant, the general process of a telemedicine service is similar as following (**Figure 4**). Through local sub-center (county-level hospital) of the telemedicine network, patients (applicants) can apply for top-tier urban hospital (provider) healthcare services, and the local medical institution uploads the patients' electronic medical records (EMR) and set teleconsultation appointments. After receiving the materials, the top-tier hospital being consulted verifies the information, arranges for experts and teleconsultation activities, and prepares the site and facilities for telemedicine services. Then, through the telemedicine system jointly driven by real-time videoconferencing and data exchange, physicians of the patients side report the medical histories and transfer relevant materials to the experts.

Based on the information from the EMR data, picture archiving and communication system (PACS), laboratory information system (LIS), electrocardiograms (ECG) data, and the physicians' statements, the experts diagnose the patients and provide treatment advice (5). Multi-center teleconsultation and case discussion are performed for complex cases or intractable diseases. Last, diagnostic conclusions and treatment plans are recommended, and necessary feedback is provided to the local physicians. When the process is complete, all relevant information and records are organized and filed. The superior hospital continuously communicates with the local doctors using follow-up system of the telemedicine platform to regularly assess patients and update treatment plans in time. During the telemedicine services, for the business processes of relevant subjects from different levels, such as local healthcare facilities, referral system, and the top-tier hospitals were summarized in **Table 3**.

Henan Province Telemedicine Center (HTCC)

HTCC began developing its platform and practical operations in 1996, and was set as the National Telemedicine Center in January 2018. Currently, it has firstly developed and applied the "nation-province-city-county-township-village" six-level telemedicine network in China, covering the entire Henan and connecting with several other provinces across the country (5). As an open and sharing comprehensive platform, HTCC provides various telemedicine services to 35 tertiary hospitals, nearly 300 secondary hospitals in Henan Province, and, with more than 1,000 teaching and coordination networks and teleconsultation sub-centers throughout the country, which enables the smooth dissemination of healthcare resources to underserved areas (5, 39).

To date, the HTCC has annually performed almost 30,000 teleconsultations, more than 1,000,000 remote specialty diagnoses, trained about 300,000 medical staff in approximately 300 remote education venues, and achieved remarkable

TABLE 2 | The time and organization that firstly initiated telemedicine network/center in the 31 provinces and municipalities in mainland of China.

Year	Provinces/municipalities	Organization(s)
1996	Hunan	Xiangya Hospital Central South University
1996	Henan	The First Affiliated Hospital of Zhengzhou University
1997	Beijing	The People's Liberation Army (PLA) General Hospital, Beijing Union Medical College Hospital
1998	Shandong	Shandong Provincial Hospital
2000	Fujian	PLA Fuzhou General Hospital
2001	Sichuan	West China Hospital of Sichuan University
2001	Jiangxi	Jiangxi Provincial People's Hospital
2002	Shanghai	Huashan hospital
2002	Tibet	PLA Tibet Military Region General Hospital
2005	Guizhou	Affiliated Hospital of Zunyi Medical University
2006	Yunnan	SUNPA Telemedicine
2007	Gansu	Gansu Provincial Hospital
2007	Ningxia	General Hospital of Ningxia Medical University, People's Hospital of Ningxia Hui Autonomous Region
2008	Xinjiang	The First Affiliated Hospital of Xinjiang Medical University
2008	Zhejiang	The Second Affiliated Hospital of Zhejiang University School of Medicine
2010	Guangdong	Nanfang Hospital of Southern Medical University
2011	Anhui	The First Affiliated Hospital of Anhui Medical University
2011	Chongqing	The Second Affiliated Hospital of Chongqing Medical University
2011	Hubei	Union Hospital affiliated to Tongji Medical College of Huazhong University of Science and Technology
2011	Qinghai	Qinghai University Affiliated Hospital
2012	Guangxi	The First Affiliated Hospital of Guangxi Medical University
2012	Jilin	Jilin Province People's Hospital
2012	Inner Mongolia	Inner Mongolia People's Hospital
2012	Shaanxi	Shaanxi Provincial People's Hospital
2013	Hainan	Hainan General Hospital
2013	Liaoning	Dalian Municipal Central Hospital
2014	Hebei	Hebei General Hospital
2014	Jiangshu	Nanjing Drum Tower Hospital
2014	Tianjin	Tianjin Medical University, Tianjin University of Traditional Chinese Medicine
2016	Heilongjiang	Qiqihar Medical University
2018	Shanxi	The Second Hospital of Shanxi Medical University

implementation effects and socioeconomic benefits (5, 39, 54). For example, in 2017, in terms of hospitalization costs and food- and travel-related expenses, compared with transferring to top-tier hospitals for treatment, patients remained at primary hospitals for treatment with the help of telemedicine can save them approximately USD $17.5 million (5).

DISCUSSION

Based on telemedicine networks, the connections and information exchanges between top-tier hospitals and their subordinate facilities enable high-quality healthcare resources to be transmitted across space and time. Thus, telemedicine has become increasingly popular in recent years, especially for developing countries and regions. In the present study, the necessity, development history, scale and coverage, operation procedure of telemedicine in China were investigated, from both national and regional levels. According to our knowledge, this is the first time that the comprehensive account of telemedicine in China was explored.

Telemedicine enables people in underserved areas to overcome geographical and temporal limitations and obtain specialty healthcare services similar to those they would receive in cities. The main pattern of telemedicine service in China is B-B model, based on telemedicine networks, lower-level healthcare facilities are connected with those upper-level ones, and patients make the appointment of telemedicine services through the doctors of the primary medical institutions. Patients just need to visit to the local community health service centers or county-level hospitals to apply for and receive teleconsultations and specialty diagnoses from skilled experts at tertiary hospitals (5, 47). Teleconsultation specialists spend 10 or more minutes discussing the materials from patient's EMR, PACS, LIS, and ECG with the local physician, then, provide diagnosis and treatment advice. Oppositely, most of the in-person clinic consultations of patients at top-tier hospitals last only a few minutes, which might be too short to fully understand and accurately diagnose a patient. This characteristic of telemedicine

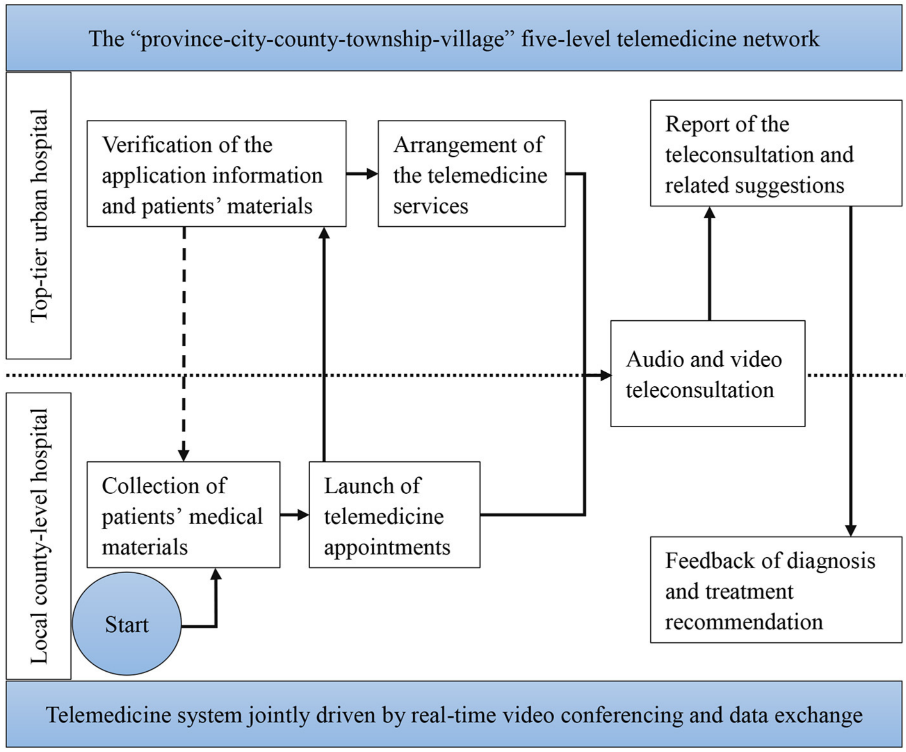

FIGURE 4 | The general operation procedure of telemedicine services in China.

may increase the satisfaction of patients with healthcare services (34, 39, 47).

Telemedicine is often a less expensive, more convenient, and timesaving way to obtain healthcare without indirect costs than in-person hospital visits (1, 3, 55). Through telemedicine network, local healthcare facilities can directly diagnose and treat common diseases with the assistance of the professionals from tertiary hospitals. Thus, the top-tier hospitals have more time and attention to focus on the serious and intractable cases, which can help improve the appropriate dissemination of high-quality healthcare resources (33, 43, 56). For instance, telemedicine has been playing a particularly salient role in the COVID-19 epidemic in China (18). The COVID-19 limited the ability of healthcare specialists to work on site, while telemedicine was not restricted by this situation (57, 58). Besides, during the telemedicine services such as teleconsultation, specialty diagnoses, surgical techniques teaching, and occupational education, primary hospitals' staff might learn advanced experience and techniques used at top-tier hospitals. This may improve the quality and capacity of their services, shrink the gap between urban and rural healthcare, increase the use rate of local hospitals' beds, and rationalize the distribution of patients throughout the telemedicine network, which could ultimately help strengthen China's hierarchical medical system (18, 39, 46, 54).

Challenges Faced by Telemedicine

In recent years, although telemedicine in China has developed rapidly in terms of system development, network connection, and scale expansion, it is still in the exploratory stage, and many problems remain. First, the telemedicine systems built in different regions vary in their technical framework, data transmission protocols, and application programming interfaces, which makes it challenging to effectively integrate multi-source heterogeneous data across regions and healthcare facilities (5, 59). This problem might create "data islands" that limit information sharing and cross-regional telemedicine services (4, 8, 33). Second, telemedicine service procedures and models vary across medical institutions, non-uniform standards may restrict the regional, national or international communication and popularization of telemedicine (8, 60). Third, it is difficult to clarify and unify the costs of various telemedicine services across the country, and most of these services are not covered under health insurance, this may prevent people from choosing telemedicine services (8, 34, 61). Fourth, in some provinces, the existing telemedicine networks and services heavily rely on government or project funding, the return on investment is relatively long term, and the mechanisms of long-term sustainable operation of telemedicine are not clear (2, 3, 34).

It has been discussed that there are four types of digital divide barriers, mental, material, skill, and usage, that may limit the further applications of telemedicine (62, 63). The authors

TABLE 3 | The business processes of relevant subjects from different levels during the telemedicine services.

Subject	Role	Business process
Local healthcare facilities	Applicants	①According to the patient's actual condition and personal requirements, apply for teleconsultation to the top-tier hospitals through telemedicine network ②After the invitee accepts the application, the doctor in charge of the patient in the local healthcare facilities uploads the patient's EMR to the top-tier hospitals ③The doctor discussed the patient's condition with the consultation experts, and formulates and optimizes the patient's treatment plan ④After telemedicine services, make a record of the teleconsultation, and provide feedback on the follow-up patient treatment effect and outcome to the top-tier hospitals
Referral system	Coordinator /administrator	①It is a functional module of the telemedicine platform ②For the local healthcare facilities, it receives teleconsultation applications, sets and notifies teleconsultation appointments, and coordinates the referral of serious or intractable cases to the top-tier hospitals ③For the top-tier hospitals, it invites teleconsultation experts, coordinates teleconsultation appointments, and arranges the reception of patients referred from the local healthcare facilities
The top-tier hospitals	Providers	①Through the telemedicine network, accept teleconsultation applications from the local healthcare facilities, organize specific experts and arrange venues for the teleconsultations ②Guiding the doctor in charge of the patient in local healthcare facilities to develop and improve the patient's treatment plan ③Making necessary records for the teleconsultation, and following-up the treatment effect and outcome of the patient ④Evaluating the quality and effectiveness of the teleconsultation, and based on which to further improve the capabilities of telemedicine service.

suggested, to date, many people are still reluctant to choose telemedicine services because of at least six factors, including lack of trust, lack of support, lack of accessibility, user-unfriendly platforms, digital illiteracy, and inequalities related to gender, age and social groups (62). However, this situation may be somewhat different in China. Due to the great progress of education popularization in recent years, in 2020, there were only 37.75 million illiterate people in China, with an illiteracy rate 2.67% (37). According to the report on China's Internet development, as of December 2021, the number of Internet users in China was 1.032 billion, and the Internet penetration rate reached 73.0% (64). Among the Internet users, the ratio of males to females was 51.5:48.5, which is basically the same as the ratio in the overall population (64). For telemedicine in China, the software and hardware facilities involved in telemedicine are usually purchased and configured uniformly by the regional top-tier public hospitals relying on the support of national or local governmental projects, meaning that the infrastructure required for telemedicine is well guaranteed. Besides, since the B-B model of telemedicine services is adopted mostly in China, during a telemedicine service, patient is with the help of local doctors to apply for telemedicine services to top-tier hospitals through primary healthcare facilities (5). Thus, strictly speaking, the service process is an expert-to-expert approach, and there are fewer restrictions on patients. In this context, it has been reported that the majority of both medical practitioners (68.4%) and patients (60.0%) hold positive attitudes toward telemedicine services (65). Accordingly, in terms of the coverage and scale of telemedicine services in recent years, the abovementioned four types of digital divide barriers may play a limited role in the further development and implementation of telemedicine in China.

Due to the relatively time-consuming and sophisticated process of telemedicine services, many clinicians are reluctant to spend time to understand and master telemedicine related technologies and operational procedures, which limits the application of telemedicine in more medical institutions. Thus, realistically feasible and clinically appropriate telemedicine systems and related applications should be developed and deployed. To date, in different hospitals or even in one medical institution for different diseases, the length of waiting time for telemedicine service appointments varies greatly. How to standardize the service process and promote the efficiency of telemedicine appointments has become a key to further improve the quality of telemedicine services (9, 66). Besides, current telemedicine services have not developed applicable ways to protect patients' privacy or ensure healthcare data security, and the rights of relevant stakeholders and allocation of responsibilities in the event of a medical dispute or malpractice are also immature (5, 34, 67). Lastly, during telemedicine services, the scope of the business, the appropriate disease types, supervision, assessment, and quality control need to be further considered. These concerns reveal the future directions for further development and implementation of telemedicine in China.

Limitations

Several limitations of this study must be acknowledged. For each of the 31 provinces and municipalities in mainland of China, there are more than one healthcare facilities that have developed and implemented telemedicine services. However, in the present study, only the provincial organizations that firstly initiated telemedicine network or center were investigated. The telemedicine systems built in different regions and even in the same province are usually discrepant. Thus, only the general situations, such as the content, operation procedure, and scale of telemedicine services, were discussed. Further studies are needed to address these issues.

Future Work

Because of ICTs improvement and the increasing public need for lower medical costs, telemedicine has important practical significance for China where high-quality healthcare resources are concentrated in megacities and remote rural areas have little, if any, healthcare resources. In terms of both the challenges and necessity of telemedicine in China, the future development and implementation directions of telemedicine include but not limited to the followings. Firstly, the price standards for specific telemedicine services should be introduced or improved, at least at regional level, and the government should include telemedicine in the scope of medical insurance. Secondly, the operation procedure of telemedicine should be optimized to adapt to the doctors' time, for example, the teleconsultation site not being restricted by fixed places, and physicians can perform telemedicine services at any place where they are convenient (9, 68). Thirdly, medical institutions can encourage doctors to use telemedicine through establishing relevant incentive mechanism, such as performance appraisal, social prestige, or financial bonuses. Fourthly, AI could be integrated into the existing telemedicine system to assist the early screening of diseases and diagnosis of patients from remote areas as well as realize intelligent triage when the applications of telemedicine service are submitted by primary hospitals (17, 66). This can reduce the workload of coordinators and doctors in charge of telemedicine services. Last but not the least, in addition to single teleconsultation, ideally, telemedicine should be employed as an intermediate bridge to achieve bidirectional referral, and connect local healthcare facilities with top-tier hospitals more closely. Therefore, with the assistance of telemedicine, common and mild diseases should be diagnosed, treated, and rehabilitated directly at local primary hospitals, while intractable cases can be referred quickly to top-tier tertiary hospitals for treatment.

Implications

In terms of the mentioned challenges and future directions of telemedicine in China, progressive leadership at the national, provincial, and local levels should develop or improve policies that coalesce standards and regulations into coherent visions for telemedicine. At the national level, the departments of healthcare management can set comprehensive regulatory and legal frameworks for telemedicine services that across provincial borders. Provincial or local governments could supplement such policies to accord with local medical, socioeconomic, legal, and cultural needs. These measures will shift telemedicine in China from its current fragmented systems, various service procedures and models, limited or even null reimbursement mechanisms, and poor information security of development and implementation to one that benefits from uniform standards, procedures, and management within which stakeholders such as governments, funders, healthcare facilities, and patients can enjoy more welfare from telemedicine services. Besides, such environments with uniform regulations will also help researchers of different provinces in China better perform scientific studies, and then the improved evidence base can in turn refine policies. Thus, in China, the changes or updates of top-down telemedicine related policies and guidelines in the near future are necessary to further develop, implement, and evaluate need-based telemedicine services.

Similar to the situations in China, the major issues in the development and implementation of telemedicine may be also faced by other countries around the world. Specifically, aforementioned problems such as the "data island" between different telemedicine system due to disparate technology architectures and information transmission standards, data intercommunication and integration of heterogeneous medical information, cross region intercommunication of telemedicine services with various procedures and models, weak reimbursement mechanisms, and poor privacy and information security of patients, are all the global common issues that need to be addressed to further promote the development and popularization of telemedicine. Thus, the challenges, future directions, potential response policies, and suggestions discussed in the present study may provide significant references and inspirations for other regions or countries worldwide.

CONCLUSIONS

Telemedicine is one positive response to China's Internet & Medical innovation strategy by reducing the unequal distribution of medical resources, improving healthcare in remote and impoverished areas, and meeting public's demands for superior healthcare services in different regions, especially for the remote underserved areas. Telemedicine is also an encouraging initiative that promotes the implementation of Healthy China strategy, and it is recognized as an effective way to ensure that everyone enjoys the equal rights to and opportunities for high quality healthcare services. Through improving the capacity, quality, and efficiency of healthcare in underserved areas and reducing the unequal distribution of medical resources, telemedicine can support the development of China's hierarchical medical system that offers initial diagnosis at the community, bidirectional referrals, acute and chronic treatment classifications, and upper and lower medical institution linkages, which plays an active role, at the regional or even national level, in solving the problems of the difficulty and high cost to access to medical services.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found at: National Bureau of Statistics. The 2019/2020/2021 China Statistical Yearbook [In Chinese]. China statistics press. Internet: www.stats.gov.cn/tjsj/ndsj/ (accessed April 2, 2022).

AUTHOR CONTRIBUTIONS

JG conceptualized, designed, and initiated the study. JG, CF, and BC drafted the initial manuscript. ZF, LL, LW, QM, XH, and YZ involved in the development of methodology and discussion of article structure. JG and JZ reviewed and revised the manuscript. All authors read and approved the final manuscript as submitted.

FUNDING

This work was supported by Natural Science Foundation of Henan Province of China (202300410409), Joint construction project of the Henan Province medical science and technology research plan (Grant Nos. 2018020120 and LHGJ20200331), and special funds of major science and technology project in Henan province (Grant No. 201400210400). The funders played no role in the design, development, or interpretation of the present work. The views expressed in the article are those of the authors and do not necessarily reflect the position of the funding bodies.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers | Frontiers in Public Health

TYPE Review
PUBLISHED 22 July 2022
DOI 10.3389/fpubh.2022.937207

Telemedicine solutions for clinical care delivery during COVID-19 pandemic: A scoping review

Raheleh Ganjali[1,2]*, Mahdie Jajroudi[2,3], Azam Kheirdoust[2], Ali Darroudi[4] and Ashraf Alnattah[2,3]

[1]Clinical Research Development Unit, Emam Reza Hospital, Mashhad University of Medical Sciences, Mashhad, Iran, [2]Department of Medical Informatics, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran, [3]Pharmaceutical Research Center, Mashhad University of Medical Sciences, Mashhad, Iran, [4]Department of Health Information Technology, Faculty of Paramedicine, Mashhad University of Medical Science, Mashhad, Iran

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EDITED BY
Gulzar H. Shah,
Georgia Southern University, United States

REVIEWED BY
Snehil Gupta,
All India Institute of Medical Sciences Bhopal, India
Chao-Yu Guo,
National Yang Ming Chiao Tung University, Taiwan

*CORRESPONDENCE
Raheleh Ganjali
GanjaliR2@mums.ac.ir

SPECIALTY SECTION
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

RECEIVED 05 May 2022
ACCEPTED 24 June 2022
PUBLISHED 22 July 2022

CITATION
Ganjali R, Jajroudi M, Kheirdoust A, Darroudi A and Alnattah A (2022) Telemedicine solutions for clinical care delivery during COVID-19 pandemic: A scoping review. *Front. Public Health* 10:937207. doi: 10.3389/fpubh.2022.937207

Background: The unexpected emergence of coronavirus disease 2019 (COVID-19) has changed mindsets about the healthcare system and medical practice in many fields, forcing physicians to reconsider their approaches to healthcare provision. It is necessary to add new, unique, and efficient solutions to traditional methods to overcome this critical challenge. In this regard, telemedicine offers a solution to this problem. Remote medical activities could diminish unnecessary visits and provide prompt medical services in a timely manner.

Objective: This scoping review aimed to provide a map of the existing evidence on the use of telemedicine during the COVID-19 pandemic by focusing on delineation functions and technologies, analyzing settings, and identifying related outcomes.

Methods: This review was conducted following the Arksey and O'Malley framework and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) checklist. PubMed and Scopus databases were systematically searched based on specific eligibility criteria. The English publications included in this study focused on telemedicine systems implemented during the COVID-19 pandemic to provide clinical care services. Two independent reviewers screened the articles based on predefined inclusion and exclusion criteria. The relevant features of telemedicine systems were summarized and presented into the following four domains and their subcategories, including functionality, technology, context, and outcomes.

Results: Out of a total of 1,602 retrieved papers, 66 studies met the inclusion criteria. The most common function implemented was counseling, and telemedicine was used for diagnosis in seven studies. In addition, in 12 studies, tele-monitoring of patients was performed by phone, designed platforms, social media, Bluetooth, and video calls. Telemedicine systems were predominantly implemented synchronously (50 studies). Moreover, 10 studies used both synchronous and asynchronous technologies. Although most studies were performed in outpatient clinics or centers, three studies implemented a system for hospitalized patients, and four studies applied telemedicine for emergency care. Telemedicine was effective in improving 87.5% of health resource utilization outcomes, 85% of patient outcomes, and 100% of provider outcomes.

Conclusion: The benefits of using telemedicine in medical care delivery systems in pandemic conditions have been well–documented, especially for outpatient care. It could potentially improve patient, provider, and healthcare outcomes. This review suggests that telemedicine could support outpatient and emergency care in pandemic situations. However, further studies using interventional methods are required to increase the generalizability of the findings.

KEYWORDS

telemedicine, information technology, setting, outcomes, function, context, COVID-19

Introduction

The coronavirus disease 2019 (COVID-19) pandemic has greatly challenged and overwhelmed economic and health systems, leading to the deaths of more than 1 million people, although many countries have controlled the initial outbreak, there is still the risk of resurgence (1–3). In order for continuous surveillance, risk management, disease mitigation, and complete containment, health systems need to reorganize resources and rearrange clinical services at the population level so that they could meet the public health requirements and minimize the risk of transmission by providing timely healthcare services (3, 4). To overcome this critical challenge, new, unique, and efficient solutions must be added to traditional methods. In this regard, technology offers a solution to this problem. While researchers are trying to early diagnose and treat the disease and develop vaccines for the virus, technologists have applied technology to reduce the spread of the disease and provide healthcare. Remote medical and health activities could decrease unnecessary visits and provide prompt medical services in a timely manner (1). With the development of technology and the Internet and incrementing the video-based communication potential over the last decade, a new and effective paradigm has been formed to provide telehealth and telemedicine (2, 3). Telehealth refers to the utilization of information and communication technologies (ICTs) to deliver remote healthcare-related services, while telemedicine is defined as the use of electronic data and telecommunication technologies to improve clinical healthcare delivery to patients at long distances (3–6). Given the purpose of telemedicine and the model of clinical care delivery, we preferred to use the term "telemedicine" in this article to refer to all forms of ICT-based medical care. In telemedicine, professionals may use videoconferencing to provide real-time counseling (synchronous modality) or "store-and-forward" technologies to transfer medical data (e.g., images, notes, and diagnostic test results) to healthcare providers so that they could later use them for disease diagnosis and management (asynchronous modality) (7). Telemedicine could be used as a tool to increase patients' access to quality care services in both developing and developed countries. It is specifically effective in situations where there is a barrier to receiving treatment (8). During the COVID-19 pandemic, telemedicine was the best and safest method for patients and providers to maintain their physical distance when patients needed prompt and affordable care. Various configurations, including text messages, email, smartphone applications, and wearable devices, could be applied to perform virtual visits and share information between different subjects (9). Telemedicine could become a useful asset in routine care settings and offer many benefits to the entire healthcare delivery spectrum, such as reducing resource use, enhancing access to healthcare, and reducing the risk of direct person-to-person transmission of COVID-19 (7, 8).

Many studies have been performed to evaluate telemedicine systems in pandemic situations (10–12). Some of these studies have reviewed barriers and facilitators of telehealth, and some of them have investigated telehealth services for a special field during the COVID-19 pandemic (13, 14). None of these studies have focused on clinical care, while the use of telemedicine in pandemic conditions is more critical and complex for infected patients requiring rapid interventions. This study could help healthcare managers and providers in planning and designing telemedicine in clinical care settings. This study could also help healthcare managers in evaluating telemedicine systems.

Therefore, the main purpose of this scoping review was to identify the applications of telemedicine in medical care delivery during the COVID-19 pandemic. The first objective was to characterize the functionality of telemedicine services in clinical care delivery. The second objective was to characterize the technologies used in current clinical practices. The third objective was to describe the results of telemedicine studies and their effects on clinical care.

Methods

Review studies allow further analysis of possible gaps for potential innovation. Accordingly, we believed that a scoping review using the most recent guidelines (the Arksey and

TABLE 1 Keywords and MeSH terms used in literature search.

COVID-19	**Keywords**	**Severe acute respiratory syndrome coronavirus, Wuhan coronavirus, Wuhan seafood market pneumonia virus, COVID19 virus, COVID-19 virus, coronavirus disease 2019 virus, SARS-CoV-2, SARS2, 2019-nCoV**
	MeSH terms	-
Telemedicine	Keywords	Telemetry, telemedicine, mobile health, m-health, telehealth, telecare, e-health
	MeSH terms	Telemedicine

O'Malley framework and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews [PRISMA-ScR] checklist) was the most appropriate method to (1) address the research questions, (2) identify related studies, (3) choose relevant studies, (4) chart data, and (5) collate and summarize results (15, 16).

Research questions

The research questions were as follows:

- Which functionalities of telemedicine systems have been described in the context of COVID-19?
- Which technologies have been used in clinical practices?
- Which outcomes have been evaluated in clinical care during COVID-19?

Identification of relevant studies

PubMed and Scopus databases were searched to identify potentially relevant studies published, followed by the World Health Organization (WHO) initial announcement regarding a cluster of pneumonia cases in Wuhan from 31 December 2019 to 19 September 2020. The search was conducted in the third week of September, and the collected data were exported to Microsoft Excel for screening and charting. Search terms selected for the literature search included telemedicine domains and the target pandemic context of its implementation along with Boolean operators (OR/AND). The final detailed search strategy is included in Supplementary Materials 1. Table 1 shows keywords and MeSH terms related to telemedicine and COVID-19. We defined telemedicine as the application of remote telecommunication technology to treat, diagnose, counsel, and follow-up or mentor patients in the COVID-19 context.

Selection of relevant studies

Search results were screened in a reference manager by two authors (RG and MJ), and publications unrelated to the domain of this research were removed based on a review of their titles and abstracts. If the articles were not satisfactorily removed based on the information available in their title, abstract, or both, their full text was retrieved and reviewed for more clarity. Disagreements were resolved by including the articles in an in-depth analysis.

Inclusion criteria used during the article screening process were as follows: (1) studies aimed at improving at least one treatment or management outcome during the COVID-19 pandemic; (2) articles about applying telemedicine; (3) randomized studies, including quasi-experimental studies and randomized controlled trials, and non-randomized studies, including cohort, case–control, and cross-sectional studies; (4) studies published in English; (5) studies published in scientific journals; and (6) studies published from 2019 to 2020.

Exclusion criteria were as follows: (1) articles whose title, abstract, or full text were not related to COVID-19; (2) thesis, book chapters, letters to editors, editorials, short briefs, reviews or meta-analyses, case studies, conference papers, and study protocols; (3) articles whose full text was not available; (4) studies that used telemedicine in primary care; (5) survey studies that investigated attitudes toward telemedicine without implementation; and (6) studies that described only the implementation phase.

Data charting

To chart the data, information was collected and categorized into extraction sheets according to four domains, namely, functionalities, technology, setting, and outcomes (17).

The functionality domain incorporated all aspects of the medical care process, including diagnosis, treatment, follow-up, and rehabilitation. This dimension was divided into four categories, namely, (1) counseling, (2) diagnosis, (3) monitoring, and (4) mentoring. The components of the technology dimension were grouped into two sets of variables, including synchronicity and network design. Open Internet and social networks were subcategories of network design/configuration, in which information is posted and shared.

10.3389/fpubh.2022.937207

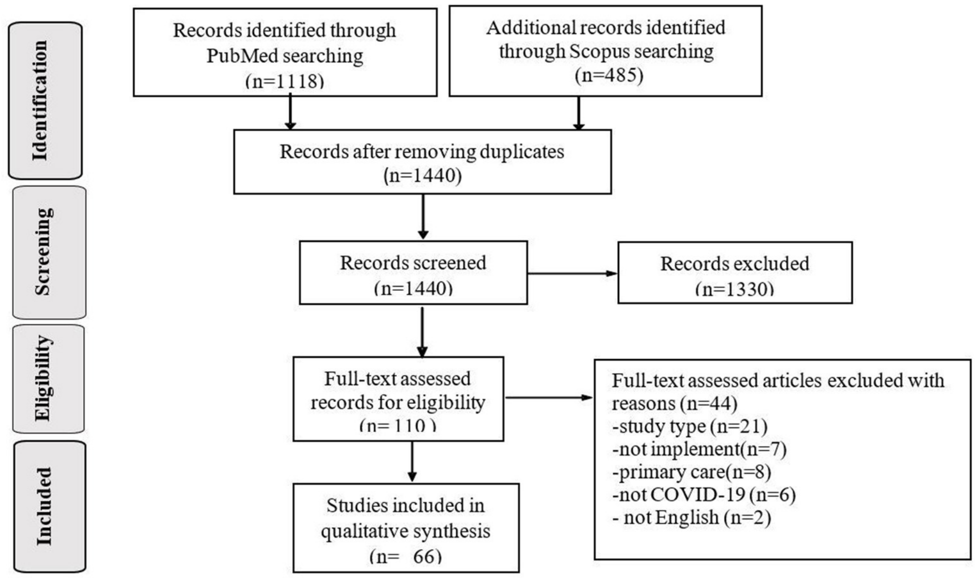

FIGURE 1
PRISMA Flowchart.

The third domain was a setting that contained a site for providing care or needed care and was divided into three groups, namely, emergency care, outpatient care, and inpatient care.

Telemedicine outcomes were the fourth domain. They were divided into three groups, namely, healthcare resource utilization, patient, and healthcare provider outcomes.

Data collation and summarization

Data extracted from the studies were about study sample, study type, objective, function, technology, network, sample size, outcomes, findings, and conclusion. We summarized and presented the features related to telemedicine systems.

The effect of telemedicine was defined as (1) positive (i.e., its effect was statistically significant or more than 50%) and (2) no effect (i.e., its effect was not statistically significant or < 50%).

Results

Selection of relevant studies

Figure 1 illustrates the articles obtained by searching the literature in a flowchart. A total of 1,602 articles were retrieved, of which 163 were duplicates. After screening, 110 documents were qualified for full-text analysis, and 66 were included in the final analysis.

Characteristics of telemedicine studies included in this scoping review

All 66 studies reviewed in this research were published in 2020. Out of the 66 articles, 21 (32%) articles were related to the implementation of telemedicine systems in the United States, and the remaining articles were related to telemedicine systems implemented in China (17%), Italy (12%), India (6%), and the United Kingdom (6%) (Figure 2). Regarding the research methods used in these studies, it was found that 49 (74%) articles used a cross-sectional design, 11 (17%) articles used a cohort design, and six (9%) studies used a pre-post comparison design.

Results related to data charting

The charting results of data related to the four research domains (domains A to D) evaluated in the reviewed studies and the definitions related to each category are presented in Table 2. Most telemedicine studies had functionality (domain A) in the form of counseling ($n = 59$, 90% of the studies). As shown in Table 3, technologies used for counseling included phones, social media platforms, special platforms, videoconferencing, smartphones, and video calls. In addition, seven studies designed telemedicine to diagnose diseases using technologies such as social media platforms, specific platforms, videoconferencing, and phones. In these studies, primary physicians were fully responsible for patients ($n = 7$, 11%). Moreover, in 12 studies, tele-monitoring of patients was performed by phone, designed platforms, social media, Bluetooth devices, and video calls.

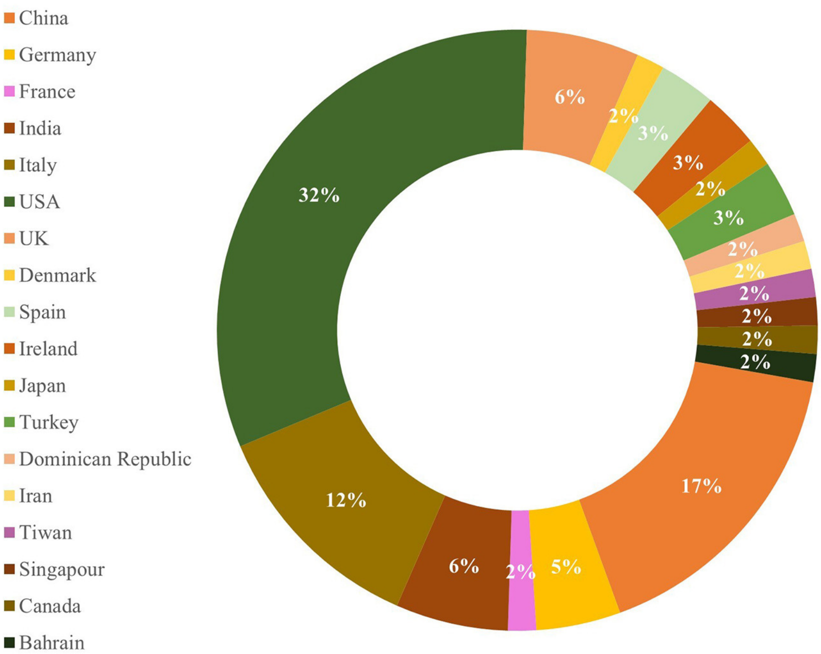

FIGURE 2
Distribution of the reviewed studies based on country.

As shown in Table 3, mentoring was mostly performed using phones, followed by special platforms, social media platforms, Bluetooth, and video calls.

Regarding domain B, telemedicine systems were predominantly implemented synchronously ($n = 50$, 76%), and 10 studies (15%) used both synchronous and asynchronous technologies. Technologies employed in this domain included phones (14 studies), social media platforms (11 studies), special platforms (six studies), videoconferencing (five studies), video calls (seven studies), smartphone (two studies), Bluetooth (one study), and multiple technologies (four studies).

Most telemedicine studies used the Internet and other telemedicine networks. However, a large number of studies used social media networks, such as WhatsApp, Line, and other video and audio communication networks (19 studies).

Out of the 66 studies, 11 (17%) studies reported descriptive results related to domain D and thus were not included in the outcome analysis. A total of 58 outcome variables were evaluated in 55 studies and grouped into three categories (i.e., resource utilization, patient, and healthcare provider outcomes). First, out of the 55 studies, 21 (38%) studies provided data on resource utilization outcomes. Out of the 55 studies, patient and healthcare provider outcomes were reported by 24 (43%) and 6 (11%) studies, respectively. Four remained studies investigated patient and health resource utilization outcomes. Second, 25 studies investigated healthcare resource utilization outcomes, including hospital discharge, visit rate, hospital admission, no-show rate, rate of canceled visit, and stroke alert volumes. The most frequent outcomes evaluated in this category were visit rate and no-show rate, which were investigated in 13 and five studies, respectively. Third, 28 studies evaluated patient outcomes in this review. Patient outcomes evaluated in these studies included usage rate, satisfaction, attitude, acceptance rate, patient compliance, mortality rate, glucose management indicator (GMI), tinnitus handicap inventory scoring, travel time, and total ischemia time (TIT). Results about usage rate and satisfaction were reported in more studies. Forth, in terms of provider outcomes, six studies provided results regarding activity rate, physician and hospital staff satisfaction, managing patients, and accuracy of diagnosis. Physicians' satisfaction was evaluated in four studies.

Regarding domain C, six studies provided no information about the services or care delivered to patients and thus were not included in the setting analysis. Out of the 60 studies, 51 (85%) studies provided outpatient or follow-up services. Three (5%) studies designed telemedicine for inpatient care delivery. Emergency care was delivered in four (7%) studies through telemedicine, and two (3%) studies designed telemedicine for a quarantined traveler and long-term facilities.

Telemedicine based on care delivery

Telemedicine for emergency care

Four studies reported how the telemedicine system was used to address specific events related to emergency

TABLE 2 Results based on data charting.

Domain and Category		Definitions	Studies ($N = 66$), N(%)
Functionality (A)		Contains all aspects of the medical care process.	
Counseling		A remote appointment with a doctor or patient in order to seek advice	59 (90)
Diagnosis		Remote diagnosis by a radiologist, pathologist, cardiologist, or other specialists based on transferred images, records, and laboratory results	7 (11)
Monitoring		Controlling patients at home with various forms of telemetry	12 (18.5)
Mentoring		Giving remote guidance typically by surgeons and other specialists to other surgeons	4 (6)
Technology (B)			
Synchronicity	Synchronously	Concurrent interaction of participants present in different places	50 (76)
	Asynchronously	In the asynchronous (store-and-forward) method, participants do not interact in real-time.	6 (9)
	Mix method	Use of both methods mentioned above	10 (15)
Network design	Social networks	Use of Internet-based social media sites to communicate with patients	19 (29)
	Other networks	Only use internet, a virtual private network, and other tools to communicate with patients	47 (71)
Setting (C)			
Emergency	Providing emergency inptient and outpatient hospital services to patients to prevent death or severe health impairment		4 (7)
In-patient	Providing any services or treatments to patients hospitalized, either for a short time or for a long time.		3 (5)
Outpatient	Providing any services or treatments to non-hospitalized patients		51 (85)
Other	Any care other than those mentioned above		2 (3)
Outcomes (D)			
Healthcare resource utilization	Outcomes that measure the use of healthcare resources		24 (41)
Patient	Outcomes that evaluate prospective and clinical characteristics of patients and their family		27 (47)
Healthcare provider	Outcomes that assesse the function and satisfaction of healthcare providers		7 (12)

TABLE 3 Applied technology in telemedicine systems based on functionality.

	Phone	Video conferencing	Special platform	Social Media platform	Smart phone	Online	Bluetooth	Video call	Multiple technology
Consultation	16 (27 %)	5 (9 %)	10 (17 %)	14 (24 %)	2 (3 %)	3 (5 %)	-	4 (7 %)	5 (8 %)
Diagnosis	1 (14 %)	1 (14 %)	1 (14 %)	2 (29 %)	1 (14 %)	-	-	-	1 (14 %)
Monitoring	6 (46 %)	-	3 (23 %)	1 (8 %)	-	-	1 (8 %)	1 (8 %)	-
Mentoring	-	-	2 (50 %)	2 (50 %)	-	-	-	-	-

TABLE 4 Classification of outcome measures based on clinical care.

Type of clinical care	Outcome categories	Outcome	*N* (%)	Effect *N* (%)	No effect *N* (%)
Outpatient care	Health resource utilization	Hospital discharge	1 (2 %)	1 (2 %)	
		Visit rate	12 (24 %)	10 (20 %)	2 (4)
		Hospital admission	2 (4 %)	2 (4 %)	
		No-show rate	4 (8 %)	3 (6 %)	1 (2 %)
		Rate of canceled visit	1 (2 %)	1 (2 %)	
	Patient	Usage rate	4 (8 %)	2 (4 %)	2 (4 %)
		Satisfaction	11 (22 %)	11 (22 %)	
		Attitude	1 (2 %)	1 (2 %)	
		Acceptance rate	1 (2 %)	1 (2 %)	
		Patient compliance	2 (4 %)	2 (4 %)	
		Mortality rate	1 (2 %)	0 (0 %)	1 (2 %)
		Glucose management indicator (GMI)	1 (2 %)	1 (2 %)	
		Travel time	1 (2 %)	1 (2 %)	
		Tinnitus handicap inventory scoring	1 (2 %)	1 (2 %)	
		Total ischemia time	1 (2 %)	1 (2 %)	
	Provider	Physician and hospital staff satisfaction	4 (8 %)	4(2 %)	
		Managing patient	1 (2 %)	1 (2 %)	
	Sum		49 (100 %)	43 (88 %)	6(12%)
In-patient care	Health resource utilization	Visit rate	1 (33 %)	1 (33 %)	
		No-show rate	1 (33 %)	1 (33 %)	
	Provider	Activity rate	1 (33 %)	1 (33 %)	
	Sum		3 (100 %)	3 (100 %)	
Emergency care	Health resource utilization	Stroke alert volumes	1 (17 %)	1 (17 %)	
		Hospital admission	1 (17 %)	1 (17 %)	
	Patient	Usage rate	1 (17 %)	1 (17 %)	
		Satisfaction	1 (17 %)	1 (17 %)	
		Mortality	1 (17 %)		1 (17 %)
	Provider	Accuracy of diagnose	1 (17 %)	1 (17 %)	
	Sum		6 (100 %)	5 (83 %)	1 (17 %)

care delivery during the COVID-19 pandemic. A recent study used tele-ophthalmology to evaluate eye emergency conditions; in this study, phone, simple smartphone, or web applications were used to deliver care (18). According to the results, the misdiagnosis rate was only 1%, which led to delays in care delivery. Another study implemented a tele-stroke network to assess patients *via* video calls, which led to a decrease in inpatient mortality and stroke alert volumes (19). In addition, pediatric patients with COVID-19 were assessed in a study *via* telephone and then hospitalized if needed (20). In another study, tele-emergency care delivery through a designed platform increased the usage rate of telemedicine and satisfaction in pregnant women (21).

Telemedicine for hospitalized patients

Two studies used telemedicine to provide inpatient and outpatient care. These studies were conducted with the aim of tele-monitoring and tele-psychiatry *via* special platforms designed by investigators (22) and the InTouch platform (23), respectively. Another study used a real-time telemetry system in an isolation ward (24).

Telemedicine for outpatient care

Telemedicine was implemented in 51 (85%) studies to provide outpatient or follow-up services. Out of the 51 studies, 18 (35%) studies implemented telemedicine systems *via* telephone for counseling and follow-up (25–42). Among which two studies added asynchronous technology (voicemail and website) to the care delivery process (26, 32). 14 outcomes were investigated in these 18 studies (five healthcare resource utilization outcomes, one provider outcome, and eight patient/caregiver outcomes). This technology was effective in improving all provider and patient outcomes and some healthcare resource utilization outcomes. Three studies reported outcomes *via* the number that were not considered (35, 38, 40).

Some patients used messaging applications of social media as an alternative. These mobile applications could help make quick decisions by providing instant communication based on text messages and images. Out of the 51 studies, 13 (25%) studies accepted social media and messaging applications as technologies that could be used in telemedicine systems (43–55). The most widely used online application in five studies was WhatsApp (44, 45, 53–55). WeChat was used in China during the COVID-19 outbreak as a telemedicine communication tool for counseling and disease diagnosis (47, 51, 52). The other applications were Zoom, Skype, and FaceTime (43, 46, 48–50).

Videoconferencing was used in six (12%) studies to facilitate patient–provider communication (56–61). Out of the seven outcomes investigated in these six studies, five outcomes were related to patients, and two outcomes were related to healthcare resource utilization. This technology had no effect on mortality (56) and no-show (58) rates. Five studies used video visits without providing any information about this technology (62–66), which was effective in improving patient and healthcare resource utilization outcomes. Six studies used a special platform to provide telemedicine services (67–72). This technology could improve provider, patient, and healthcare resource utilization outcomes; however, in one case, the use of this platform had no effect on the visit rate (71). Two studies applied smartphones to provide outpatient services *via* online visits (73) and social media (74). Other studies employed online technology. Table 4 shows more details about the outcomes.

Other care

Two studies reported the use of social media and video counseling to measure the cost of quarantine (75) and the number of visits to long-term facilities (76).

Discussion

The COVID-19 pandemic had healthcare systems to suspend or drastically reduce in-person service delivery for non–urgent patients to minimize the various transmissions through this way, which increased the use of alternatives, the best one being telemedicine for maintaining social distancing and limiting contagion. The primary purpose of this scoping review was to present an overview of the literature on telemedicine services in clinical care services during the COVID-19 pandemic.

A total of 66 studies of telemedicine by different modalities emerged in this review. There are still serious gaps in the evidence base for telemedicine. The heterogeneity of studies concerning study designs, populations, locations, and / or measures makes challenges. The type of articles included in our review also varied. A vast majority (49 / 66; 74%) were observational or descriptive articles, with the remainder being cohort studies (18, 19, 33, 48, 51, 56, 57, 59, 60, 63, 75, 77) or before–after studies (40, 58, 78–80).

Functionalities

Most of the included studies were conducted to reduce the number of patients referring to health centers to receive face-to-face healthcare services like visits, assessments, and care. The most common function in the reviewed studies was counseling. Healthcare workers could contact patients through telecommunication tools like videoconferencing or a simple call to collect their required information and provide further counseling and follow-up services if patients could monitor symptoms at home. The second most common function in the reviewed studies was monitoring (22–24, 28, 31, 32, 37, 39, 65, 74, 78, 80). Regular monitoring of data, such as blood glucose level, respiration rate, and oxygen level, could also be performed through telecommunication tools.

Technology

Telemedicine could be synchronous or asynchronous. Synchronous telemedicine provides platforms for patients and physicians to exchange vital data simultaneously through a real-time video session. Physicians could also use these platforms to perform remote visual examinations of patients without direct contact. Telemedicine employs a wide range of electronic communication media, ranging from phone and teleconferencing to image-sharing and remote patient surveillance. Diverse technologies could be used for different functions. In this regard, social media platforms and phones could be employed for counseling (77), monitoring, and diagnosis. Telecommunications have been proven to be similar to face-to-face contact when used to promote health and assist in the long-term management of chronic diseases (78). Furthermore, the strategic use of synchronous telemedicine when visual assessment is required may be more effective in improving healthcare resource utilization outcomes (85).

Setting

Modern technologies, smartphones, and popular mobile applications that provide end-to-end encryption, like WhatsApp and Viber, could be effectively used in telemedicine and could also satisfy patients further through video calls.

The role of telemedicine in managing epidemics and pandemics has been described previously (79), and health systems have expanded this technology in response to COVID-19 to provide outpatient, emergency, and inpatient care. In this review, most of the reviewed studies used this method to provide outpatient care. In this method, real-time interactive visual, textual, audio, and data communication tools are employed to deliver medical care, provide counseling, diagnose diseases, give guidance, transfer medical data, and treat patients. Telemedicine is available in the form of telephone, videoconferencing, and social media platforms. Telemedicine limits exposure to vulnerable patients while simultaneously allowing medical practitioners to provide care. In addition, it allows outpatients to communicate remotely with their physicians and allows physicians to screen patients before they have to refer them to the hospital. This could significantly reduce unnecessary patient visits and encourage patients to quarantine themselves and maintain social distance. Increased use of telemedicine has been shown to reduce in-person visits by two-thirds during the COVID-19 pandemic, which is now declining. These virtual consultations could reduce unnecessary in-person referrals to specialists, waiting times for their feedback, and unnecessary travel.

Store-and-forward is a common technology used in hospital-based telemedicine, especially in radiology departments to send images from smaller hospitals to distant locations for interpretation during nights and weekends. However, the store-and-forward technology was reported in none of the tele-emergency care studies. However, due to the nature of emergency medicine, if images were transmitted to this ward, it was for immediate review and consultation. All studies employed simultaneous audio and video transmission tools. Telemedicine applications in emergency rooms (tele-emergency) are a prime example. In this study, it was found that the most frequently used services were emergency care provided for pregnant women, children, and patients in stroke programs.

Outcome

The popularity of telemedicine is often due to its ability to improve access to health services while remaining efficient in terms of the resources required. Healthcare resource utilization outcomes, especially visit rate and no-show rate, were variables measured by several studies. Telemedicine was able to improve visit rates for new patients (23, 42, 43, 46, 50, 52, 62, 63, 71, 73) and follow-up rates for previous patients (44, 58, 63, 67). It could increase the rate of visits. Increased healthcare utilization could represent over-care or reflect widespread access to care. These results are consistent with the results of previous studies (79). The most common reason for the decline in telemedicine visits in some studies was the lack of physical examination (45). This review showed a mixed effect of telemedicine on no-show rates. Telemedicine potentially increased the efficiency of healthcare resources by significantly reducing patient no-show rates (23, 41, 62, 67). Due to the nature of COVID-19, the no-show rate increased for surgical providers (58). Telemedicine offers significant benefits to the healthcare system, which strongly supports its widespread utilization during and following the COVID-19 pandemic (80).

Out of 27 patient outcomes, five outcomes were clinical outcomes, such as mortality (2 studies), GMI, TIT, and tinnitus handicap inventory score. Telemedicine was effective in improving GMI, TIT, and tinnitus handicap inventory score using special platform, smartphone, and telephone, respectively, but not in improving mortality. Most studies reported overall satisfaction with telemedicine (20, 26, 27, 29, 32, 40, 43, 48, 50, 65, 76) or compared levels of satisfaction with telemedicine and in-person treatments, such as COVID-19 teleconsultation care (56). This finding is consistent with the findings of other investigations on overall satisfaction with telemedicine in areas such as psychiatry, dermatology, and multi-specialty services (86, 87).

Several studies assessed patient-related clinical outcomes associated with telemedicine (18, 28, 55, 67, 79). However, not all literature supports the positive impacts of telemedicine on patient-related clinical outcomes (18, 55). A review study evaluated the use of real-time "store-and-forward" modalities in various fields of medical services and reported equivocal evidence related to clinical management and telemedicine outcomes (87). Similarly, another review study reported inadequate evidence on the clinical effectiveness of telehealth (81). Telemedicine was shown in another study to potentially increase accessibility to health services *via* removing travel time and cost (55). Telemedicine visits increased patient adherence to treatment by increasing their commitment to telemedicine appointments.

Provider outcomes, such as physician satisfaction, diagnosis accuracy, and patient management, could also be improved by telemedicine. This finding is consistent with the findings of many previous studies in this field (82, 83). Physicians have accepted telemedicine due to time-saving and increased flexibility in scheduling telemedicine visits that modify healthcare delivery.

Limitation

Similar to any other research, this review also has some limitations. Although a systematic literature review in this study led to the identification of 66 quantitative studies, there are still concerns about methodological quality. These concerns are particularly related to the use of different outcome measures, limited reporting, and retrospective data collection methods (due to the observational nature of many of the included studies). This review included only studies published in English, which might have led to publication (language) bias in study selection due to the omission of other relevant articles published in languages other than English. Future work should further explore barriers and facilitators of telemedicine, implications related to costs and reimbursements, and their impact on care delivery. Some important areas for future research include: clearly delineating the requirements of a telemedicine system for a pandemic and providing evidence of improved patient outcomes.

Conclusion

This study suggests that telemedicine could be adopted in health emergencies as a convenient, safe, scalable, effective, and green method to provide clinical care. The use of telemedicine in pandemics improves the medical care delivery system, especially for outpatient and emergency care. It potentially could help improve patient, provider, and healthcare outcomes. However, future research is needed to address the requirements of a telemedicine system for a pandemic, the characteristics of successful telemedicine systems, and the outcome measures that should be used to evaluate the clinical care services delivered.

Author contributions

RG designed this scoping review, search strategy, searched databases, and conducted data analysis and interpretation. RG, MJ, AK, and AD conducted an article screening process. RG and AA drafted the manuscript. All authors reviewed and approved it, contributed to the article and approved the submitted version.

Acknowledgments

The authors thank the Clinical Research Development Unit, Imam Reza Hospital, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran, for supporting the project.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.937207/full#supplementary-material

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frontiers | Frontiers in Public Health

TYPE Hypothesis and Theory
PUBLISHED 03 August 2022
DOI 10.3389/fpubh.2022.919543

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OPEN ACCESS

EDITED BY
Anjum Khurshid,
University of Texas at Austin,
United States

REVIEWED BY
Christopher Pearce,
Outcome Health, Australia
Muhammad Muddassir Ali,
University of Veterinary and Animal Sciences, Pakistan

*CORRESPONDENCE
Filippo Gibelli
filippo.gibelli@unicam.it

SPECIALTY SECTION
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

RECEIVED 13 April 2022
ACCEPTED 18 July 2022
PUBLISHED 03 August 2022

CITATION
Pesel G, Ricci G, Gibelli F and Sirignano A (2022) Electronic unified therapy record as a clinical risk management tool in the Italian healthcare system.
Front. Public Health 10:919543.
doi: 10.3389/fpubh.2022.919543

Electronic unified therapy record as a clinical risk management tool in the Italian healthcare system

Giuliano Pesel[1], Giovanna Ricci[2], Filippo Gibelli[2]* and Ascanio Sirignano[2]

[1]Policlinico Triestino SPA, Trieste, Italy, [2]Section of Legal Medicine, School of Law, University of Camerino, Camerino, Italy

Digitization of health records is still struggling to take hold in the Italian healthcare context, where medical records are still largely kept manually on paper. Besides being anachronistic, this practice is particularly critical if applied to the drug chart. Poor handwriting and transcription errors can generate medication errors and thus represent a potential source of adverse events. In the present study, we attempt to test the hypothesis that the application of a computerized medical record model may represent a useful tool for managing clinical risk and medical expenditure. We shall do so through the analysis of the preliminary results of the application of such a model in two private hospitals in Northern Italy. The results, although preliminary, are encouraging. Among the benefits of digitizing drug records, we recorded a greater accuracy and adequacy of prescriptions, a reduction in the overall workload for nurses (no longer required to manually transcribe the list of drugs from one chart to another), as well as an optimization of the management of drug stocks by hospital pharmacies. The results in terms of clinical risk reduction will be monitored through a prospective cohort study that will take place in the coming months.

KEYWORDS

digitalization, drug chart, electronic medical record, medication error, therapy

Introduction

On the eve of the fourth industrial revolution, seeing the affirmation—including in the healthcare sector—of advanced technologies such as artificial intelligence and robotics, the existence of paper-based drug charts manually filled by healthcare professionals in the hospitals' wards appears to be an anachronism (1). The use of electronic drug prescription systems, in addition to being more consistent with the digitization and technologization that the current healthcare system has been experiencing for years, ensures greater safety in the delivery of care and could represent a valuable clinical risk management tool.

Concerning the U.S. context, the Food and Drug Administration receives more than 100,000 reports per year related to medication errors (2). More than 7 million

US patients are affected by medication errors each year (3). The costs of morbidity and mortality related to prescription drug errors are estimated to be $21 billion annually in the United States (4).

The problem is no less important in the European context. On March 22, 2022, a roundtable debate was organized by the European Alliance for Access to Safe Medicines (EAASM) along with the members of the European Collaborative Action on Medication Errors and Traceability (ECAMET).

The discussion, held virtually with the participation of speakers from European institutions, international organizations and health NGOs, focused on how to prevent medication errors in the European territory. During the debate, the impact of medication errors in the genesis of preventable harm to patients was highlighted, with an estimated 50% of medical service-related harm being attributable to medication-related errors (mainly prescribing and monitoring errors). Among the strategies suggested to curb the spread of the phenomenon, one of the main ones was precisely the use and implementation of technological and IT tools. Within the white paper written in preparation for the event (titled "The Urgent Need to Reduce Medication Errors in Hospitals to Prevent Patient and Second Victim Harm") (5) it is explained how so-called CPOEs (Computerized Provider Entry Systems) can minimize errors related to medication prescription (6, 7). According to a survey conducted by the paper's editors, e-prescribing systems are widespread in Europe, but poorly integrated with the clinical decision-making process, not available in all departments and not always validated by clinical pharmacists.

Regarding the effectiveness of CPOE systems, there are numerous scientific contributions that attempted to precisely define their impact on the quality of medical care. Among the most significant is an overview of systematic reviews on the topic published in 2020 (8). The study showed that the use of CPOE is associated with a significant reduction in medication ordering errors (9–11), in incidence of adverse drug reactions (9, 11, 12), and in intensive care mortality (10). In contrast, no significant benefits of CPOE systems have been documented in terms of absolute mortality (10, 11) and length of hospitalization (10).

These data provide insight into how CPOEs have enormous potential in terms of improving the quality of health care, but how it takes a long way to get to the point of reaping the best benefits. With particular regard to prescription of drugs, a first and significant step forward has been made by adopting the unified paper-based drug chart, so-called because it concentrates all therapeutic prescriptions in a single document, on which several professionals, mainly doctors and nurses, intervene. This tool greatly facilitated the physicians in carrying out the written prescriptions (which therefore replaced the verbal prescriptions) and allowed to avoid the transcription steps between the medical record and the nursing documentation so that nurses could use the same sheet filled in by the doctor to carry out the administration, saving time and reducing the possibility of transcription errors. Therefore, the unified paper-based drug chart allows to keep track on a single document of all the operations carried out on the process, as well as the author of each intervention, dealing with communication problems, the first cause of medication errors (13). However, since the unified paper chart is still paper-based, it is burdened with all the problems and critical issues that this way of compilation entails (first and foremost, the not always adequate intelligibility of the writer's handwriting).

The next stage of evolution of the therapeutic prescription policy is represented by the transition from handwriting to digital writing through computer tools, already in use in some Italian hospitals.

In this sense, the electronic unified therapy record would represent the digitized version of the paper-based drug chart, maintaining the same purposes and prerogatives but being considerably more practical and manageable and involving a greater quality guarantee in the adequacy of therapeutic prescriptions. Such computerization of the drug prescription system accounts for the increasing involvement in the drug dispensing process of the clinical pharmacist, who through electronic monitoring of drug regimens is able to practice adequate surveillance of drug interactions.

Computerization also makes it possible to dispense drugs remotely, another possibility that makes the enormous innovative potential of the new system very clear. It is precisely in the conviction of the need for such innovation that we chose to conduct the present project, which involved the application of a computerized therapeutic prescription system tool in two private hospitals in the Friuli Venezia Giulia region, in north-eastern Italy.

From paper-based drug charts to electronic therapy records

Paper-based drug chart: An obsolete tool?

Although more immediate and practical than the interface with computer systems, the compilation of paper-based drug charts has many drawbacks that may lead to medication errors. The adaptation of diagnostic and therapeutic measures to technological progress is, in fact, a deontological duty of the healthcare professional, as enshrined in the Italian Code of Medical Ethics in Article 78 ("Computer Technologies"): "… the physician must promote the use of information and communication technologies of clinical data for the management of the complexity of medicine and for the improvement of individual and collective prevention tools in particular in the face of clinical and scientific findings that document or justify the preferred choice" (14).

The National Coordinating Council for Medication Error Reporting and Prevention (NCC MERP), an independent international body composed of 27 national organizations with the aim of ensuring safe use of medications and increasing awareness of medication errors by promoting strategies to prevent them, provides the following definition of medication error: "A medication error is any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient, or consumer. Such events may be related to professional practice, health care products, procedures, and systems, including prescribing, order communication, product labeling, packaging, and nomenclature, compounding, dispensing, distribution, administration, education, monitoring, and use" (15).

There are several different classifications of medication errors. One of the most widely used is the one according to which medication errors can be classified into five macro-categories: prescribing errors, transcription errors, dispensing errors, administration errors, and monitoring errors (16). The written compilation of a paper-based drug chart requires a not negligible commitment by both physicians and nurses, especially in terms of time, which can contribute to the occurrence of medication errors belonging to all five categories, above all transcription errors. Transcription errors can be defined as the product of the inadequate transfer of data from one source to the next, such as copying a drug chart from a complete sheet to a new one (17). A particularly delicate phase of the care process, in which transcription errors can more easily occur, is that of the so-called "medication reconciliation", i.e., the transcription in the medical record of the therapeutic regime assumed by the patient before being admitted to the hospital (18). Inadequate filling and storage of the paper-based drug chart can pose a serious threat to the proper management of this critical phase. In fact, it is not uncommon for therapy sheets to be confusedly wrapped together, at best protected by a thin transparent plastic cover.

Often these documents, which form an integral part of the patient's medical record, are in very poor condition, creased, dirty (even with blood) and often written with poor handwriting, which generates difficulties of interpretation by the various professionals involved in the treatment process, with all the easily predictable medical-legal consequences. Unfortunately, this situation still represents the norm in many healthcare facilities throughout Italy. This method of drafting and storing the drug chart certainly does not seem to align with the expected procedures of managing a document of public interest such as the medical record, representing a likely source of adverse events capable of affecting the quality of the care process.

Unified electronic therapy record: The present and future of drug prescriptions

In recent years, more and more healthcare facilities are replacing the paper-based drug chart with its electronic version, the unified electronic therapy record, where "unified" indicates that it can be used by several healthcare professionals, mainly physicians and nurses. This innovative tool, complementary to the electronic medical record, fits within a technological innovation and digitalization process, aiming to lead to an increase in the safety of care (19, 20). Adverse events related to therapy during an inpatient stay are common and costly. Most hospitals identify these events through spontaneous reports (incident reporting).

Computerized approaches to identify such errors seem promising and have been studied since the late 1990s, although it is not easy to compare spontaneous error reporting data with "computerized management" data. In some U.S. studies on this topic, electronic prescribing systems of medical therapies in inpatient wards proved efficient in reducing the risk of major adverse events (21) and also raised the "under-reporting" issue, i.e., a number of spontaneous reports (through incident reporting) significantly lower than reality (22). During the 2000s, even in Italy, experiments with electronic prescribing systems began. They become particularly widespread in recent years thanks to the spread of Wi-Fi networks and, in general, computer systems' progress. In the following years, a heated debate also began in the scientific community, primarily American but also British, about the effectiveness or, on the contrary, the dangerousness of electronic prescription systems. Computerized drug prescribing has long been touted as a significant improvement in patient safety, primarily due to the 1999 American Institute of Medicine report on errors (23).

Although the literature suggests that such systems can improve patient outcomes through decreases in adverse drug events, actual improvements in medical outcomes have not been documented. In fact, according to some authors, the implementation of such systems may increase the number of adverse drug events and result in higher overall medical costs, particularly in the early years of their adoption, which is undoubtedly the downside (24).

The healthcare context within which the project was developed

Clinical risk management and incident reporting in the friuli venezia giulia region

Incident Reporting is a system that allows to detect situations of risk to the safety of operators and users due to critical organizational issues and errors (25). This tool allows to report and describe situations that can potentially result in adverse events (i.e., patients' health problems more likely attributable to treatment errors than to the underlying pathologies) or in near-miss events (i.e., situations in which patients are exposed to potentially dangerous conditions but in which harm does not materialize due to accidental circumstances or implementation of adequate protective measures) (26). The main purpose of this voluntary and anonymous reporting system is to develop a culture of non-guilt on the part of the operator who makes a mistake or reports an error or non-compliance with the culture of safety. The system should raise awareness of risk perception, detection, and management. The possibility of "learning from experience" must be seen as an opportunity to avoid repeating reported events and improve the continuous cycle of safety and quality of care. The collection and analysis of adverse events and events avoided is an essential pool of data and information for the mapping of areas at higher risk at a corporate level. The subsequent analysis of an adverse event or an event avoided is essential to increase awareness of the organization's level of safety and acquire critical information for the management of clinical risk and improvement actions to be taken.

From the clinical risk surveillance activity carried out at the Policlinico Triestino by the Health Departments through the analysis of incident reporting, it has emerged that reports related to the incorrect prescription/administration of drugs represent a significant proportion of all reports. Among these, the use of paper-based drug charts represents a considerable share. The "Safe Care Network", established by regional resolution of the autonomous region of Friuli-Venezia-Giulia No. 1970 of October 21, 2016 (27), coordinates and governs, in an integrated form, the activities related to the safety of care. In addition, through Regional Resolution No. 185 of February 2, 2018 (28), it fulfills the functions of "Center for Health Risk Management and Patient Safety" according to the requirements of Law No. 24 of March 8, 2017 (the latest reform of healthcare liability and safety of care legislation in Italy). The "Safe Care Network" coordinates and governs, in an integrated form, the activities related to the safety of care. Participation is mandatory for all entities belonging to the National Health Service and for private hospitals affiliated with the Regional Health Service. Policlinico Triestino actively participates in the network. The activities carried out by the network, launched in 2010 with the "Clinical governance and patient safety in Friuli Venezia Giulia" program, were officially defined with Resolution No. 1970 of October 21, 2016. The Network consists of the central directorate for health, social policies and disability, the regional coordinating agency for health, the corporate risk managers, the corporate managers of regional programs, the corporate link professionals, the healthcare professionals belonging to the Regional Health System, the citizens.

The program consists of several projects developed to ensure adequate standards of safety and quality shared between hospital and territorial context:

1. Safe use of medications
2. Prevention and control of care-related infections
3. Prudent use of antibiotics (antimicrobial stewardship)
4. Safety of clinical care practices
5. Citizen involvement
6. Prevention of violence against providers

Policlinico triestino: The birthplace of our project

Policlinico Triestino is the most important private healthcare facility in the Friuli-Venezia Giulia Region (North-Eastern Italy). It includes two private hospitals affiliated with the National Health Service in the Province of Trieste and ten medical clinics with a blood drawing center scattered between Trieste and Gorizia and their provincial territories. Concerning the two private hospitals, the first, "Salus", provides outpatient and inpatient healthcare services for medical, surgical and specialist pathologies, has over 400 hospital admissions per year (consisting of 74 beds). It has a testing laboratory that analyses ∼1,000,000 blood samples per year and provides about 60,000 radiological and outpatient services. The second one, "Pineta del Carso", can rely on 70 beds and is divided into a neuro-motor rehabilitation ward, a respiratory rehabilitation ward, a hospice ward and a severely disabled ward (intended for patients with severe central nervous system injuries). It is focused mainly on rehabilitation-type treatments.

Considering the 2 private hospitals and 10 medical clinics, services related to almost all medical and surgical specializations are provided in the private regime and in convention with the National Health System. All healthcare facilities accredited with the National Health System in the Friuli Venezia Giulia Region and the other Italian regions undergo thorough periodic audits to verify the existence of the conditions of eligibility for renewal of accreditation. These audits include the verification of numerous items related to the quality and appropriateness of care. One of the most essential aspects assessed in institutional accreditation with the National Health System in the Friuli Venezia Giulia Region is the monitoring of incident reporting, i.e., the reporting of adverse events related to healthcare, including those resulting from incorrect prescription or administration of drugs.

Policlinico Triestino has undertaken for many years a process of digitalization of the medical record through a program provided by a software-house of national importance.

The latest step in the ongoing innovation is the transformation of the traditional paper-based drug chart into an electronic version (unified electronic therapy record), which is being tested in some wards of one of the two private hospitals and whose use will then be extended to all the facilities of the group. The need underlying this process is the rationalization and speeding up of care processes and the reduction of clinical risk arising from the administration of drugs. There are also numerous advantages in terms of organization and economics, particularly regarding the pharmacy warehouse. In fact, the computerization of the prescription and administration of medical therapy also allows for better management of stocks in the warehouse.

Incident reporting results related to medication errors over the 2015–2020 period

From the constant monitoring activity by the Health Departments involved in this study, 11 reports were recorded from "Salus" private hospital and 14 from "Pineta del Carso" private hospital.

These reports refer to criticalities linked to the use of the paper-based drug chart in the period between 2015 and 2020. Regarding the outcomes, it should be noted that these were primarily near-miss events with early detection and immediate correction or events with no outcome or negligible outcome.

In very few cases there were minor outcomes. However, it is likely that, in the absence of active surveillance of adverse events, the events recorded could also have caused significant consequences on patients.

Within Table 1, the spontaneous reports related to the use of the paper-based drug chart in the period between 2015 and 2020 in the two private hospitals afferent to the Policlinico Triestino are detailed. Level 3 events are those in which there is no harmful outcome to the patient, while Level 4 events are those in which there is a minor, negligible outcome not requiring specific treatment. It should be noted that the "Pineta del Carso" private hospitals became part of Policlinico Triestino only in November 2019. The number of reports from the "Pineta del Carso" private hospital results higher, while the "Salus" private hospital shows a higher severity index (more level 4 events). This is a predictable result, since the "Salus" private hospital treats patients suffering from acute conditions, while the "Pineta del Carso" private hospital mainly treats patients suffering from chronic illnesses.

TABLE 1 Spontaneous reports related to the paper-based drug chart in the period 2015–2020 in the two private hospitals of Policlinico Triestino.

	"Salus" nursing home	"Pineta del Carso" nursing home
Near-miss events	2	3
Level 3 events	5	10
Level 4 events	4	1
Total	**11**	**14**

The unified electronic therapy record adopted in the context of the present study

The features of our IT tool

Given the company's need to switch to an IT tool for therapy management, this program was chosen because it complements the medical records management system already in use at Policlinico Triestino and is supplied by the same software house that has supplied similar systems in use in other Italian hospitals. The application is based on a server platform that is regularly backed up and guarantees data availability. Passwords and sensitive data are protected and are not easily accessible. The separation of data is guaranteed, and the system respects the current legislation on privacy. Referential integrity functions present in all versions of Oracle Databases are activated in the database (referential integrity is a software property that ensures that relationships between different tables are consistent; the Oracle database is one of the most popular database management system software). There is also a module designed to guide the preparation and administration phases of therapies that require dilution by the nurse. The patient dashboard module (dashboard) is the main screen of the program. It immediately highlights the status of patients and clinically relevant activities that are required or scheduled and allows access to further modules. The patient dashboard module has a set of configurable filters that allow to search for patients more quickly. Additional filters can be applied to the subset that identifies "Inpatient Department" patients (admitted and bedridden in the user's department) to select patients based on recorded data or assigned beds. For each selected patient, the relevant personal and clinical information is reported (name, tax code, sex, date of birth, age, hospitalization, bed identification, etc.). For each anagraphic position, allergies/intolerances or other relevant notes recorded in the medical record can be retrieved (configurable according to the specifications provided by the client). This information is configurable depending on the specifications provided by the client (clinic or hospital).

The prescription management module provides for the recording and confirmation of the following information:

- Identifier of the prescribed drug
- Route of administration
- Dosage and duration of administration for "continuous" prescriptions (e.g., intravenous, transdermal, etc.)
- Type of prescription (at exact times; at time slots; as needed)
- Frequency of repetition (daily; every other day; on a schedule; etc.)
- Prescription start and end date
- Type of therapy (chronic/acute)

10.3389/fpubh.2022.919543

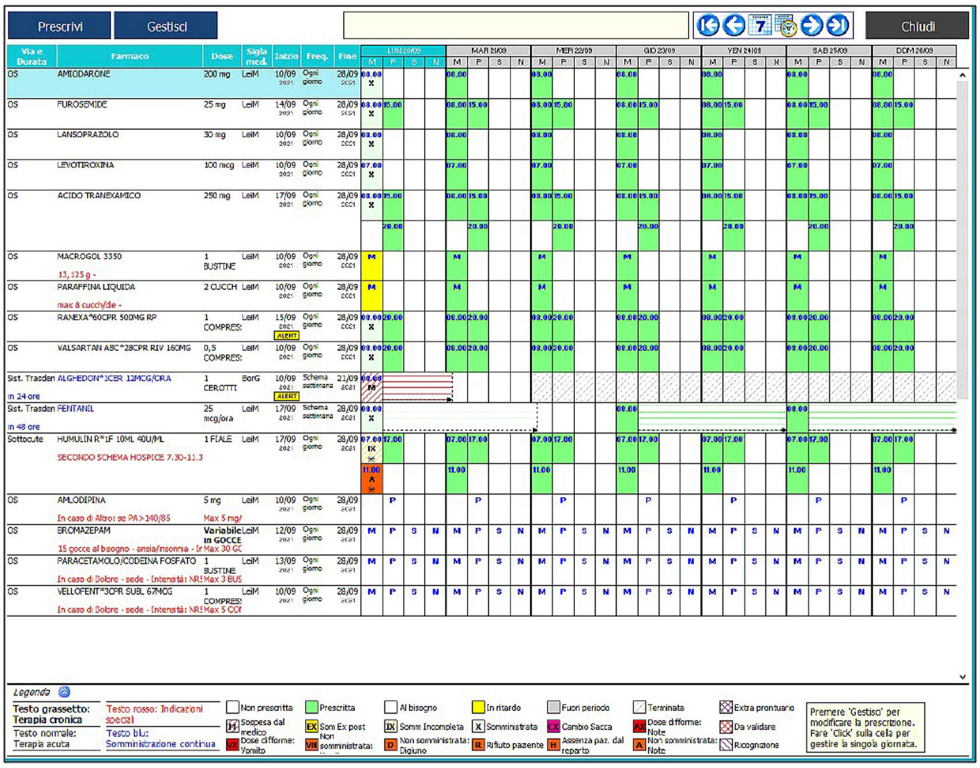

FIGURE 1
The main screen of the unified electronic therapy record employed in the present study.

Numerous alerts allow to monitor various aspects of the prescription/drug administration process. The physician's functions cannot be managed by the nurse and vice versa, and the program is set up to have a clear consequentiality between the actions of the two professionals. All these features make the program a completely reliable and safe tool. Figure 1 illustrates the main screen of the computer program.

The system has 5 basic features:

1. Modularity and customizability: it maintains an incomparable consistency and compactness, adapting to specific clinical and organizational needs.
2. Transactionalness: it manages the granular control of each phase of the process and builds data collections for the control and monitoring of the quality and quantity of the activities carried out, also with the evaluation of costs and results.
3. Completeness and structuring: it manages the completeness of the data, supporting the medical-nursing activity through the management of care protocols and the standardization of information.
4. Openness and transparency: it easily communicates with different equipment and systems, increasing the quantity and quality of immediately available information, for maximum interoperability and reduction of delays and omissions. The system supports the International standards for communication in the health sector (DICOM, HL7, IHE): the integration of the various information systems already present at the customer will take place with standard tools and protocols.

   In detail, the system complies with several open standards:

   - HL7/IHE/Web service for connectivity with systems;
   - HTML5 for viewing on all browsers;
   - Standard SQL DBMS: The Oracle database is a standard and can be queried *via* SQL code in standard SQL-99 core, using Open Source tools, such as SqlTools (available on Sourceforge.net), with the possibility of extracting files in standard CVS format.

   Adherence to these standards allows you to connect the system offered to any other system using open standard formats and to be able to extract data even without resorting to proprietary tools.

5. Flexibility and scalability: it easily adapts to the evolution of processes, new technologies and changes in organizational models, even expanding on a large scale toward territorial solutions.

Operational aspects

The unified electronic therapy record object of this study shows, for each selected patient, unequivocally, the name of the drug and its dosage, the administration route (each marked with a different color card), the days on which it is to be administered, the time and any notes in the notes box (e.g., dilutions). The system informs the doctor during the prescription phase if the drug he is about to insert is already part of the treatment plan, it shows all the drugs on the market for the same active ingredient, being connected to the program. Whether doctor or nurse, each user enters the program after typing in an identification code and a password so that any operation carried out by him, both on the hardware and the software, is traced. Each user has his own operating profile in relation to the role he performs, so a doctor can generally prescribe, modify, and eliminate a therapy. A nurse can administer it but cannot complete the functions attributed to the doctor. It is possible to view the history of prescribed and administered therapies at any time, distinguishing the operator, the day, date, and time when the operation was carried out. This documentation can be printed when the patient is discharged and attached to the medical record. The software also allows the patient's prescription to be filled without re-entering personal data and having the complete sheet of all the therapy. The system can automatically generate periodic and urgent requests for the restoration of pharmaceutical products needed in the warehouse, taking into account the actual need, the values of the minimum limit (the stock value below which the system generates an order), and the reorder threshold (the value to which the system reports the stock of the drug each time a restoration order is generated) based on specific calculations that take into account the individual doses prescribed.

In our opinion, a unified electronic therapy record provided with the features listed can effectively address three of the five categories of medication errors listed above. Concerning the errors most frequently attributable to the manual drafting of the drug chart, the transcription errors, these are substantially annulled since the doctor prescribes the therapy using a computer (desktop computer or portable computer) and the nurse uses both the same source of data and the same technological support for the administration. This implies, on the one hand, time savings for the nursing staff, who no longer have to transcribe from the medical record into special registers or notebooks used for administration, and on the other hand a reduction of reading errors, since the therapies are clearer and more straightforward to read and interpret as they are written through a computer system. The unified electronic therapy record is also able to reduce the incidence of prescribing and dispensing errors. As far as prescription errors are concerned, the computer system is beneficial since it can provide complete information about the therapy (the correct name of the patient, name of the drug, dosage, time of administration, etc.) and since it prevents the prescription from proceeding until all the fields have been entered. It also helps the doctor to restrict the choice of drugs to those belonging to the formulary or available in the hospital. A link to Federfarma's database is even available to clarify any doubts about the active ingredient or commercial name (Federfarma is the national federation of Italian pharmacy owners).

The drug register can be automatically aligned and currently updated to the Federfarma database (National Federation of Italian pharmacy owners), with the possibility of filtering the categories of drugs to be treated. Through a dedicated tool, all the periodical updates of the FEDERFARMA database are loaded directly into the Oracle database on coding tables that contain both active ingredients and commercial drugs. Each active ingredient is identified by the unique identifier code of FEDERFARMA (codpa); each commercial drug is identified by the AIC code (identification code for medicinal products for human use). So, in the prescription modules, when choosing or consulting drugs and therapies, it is always possible to access the detailed sheet showing, in addition to the MINSAN and EMEA code, the following information sections:

- ➢ PRODUCT DATA
- ➢ COMPANY AND SALES DATA
- ➢ MONOGRAPHY
- ➢ INTERACTIONS
- ➢ EQUIVALENT DRUGS

About the administration of drugs, the electronic system does not provide an absolute guarantee of the univocity between the patient and the correct medication to be administered since, by our choice, the electronic reading of the patient's bracelet barcode and the AIC code (identification code for medicinal products for human use) of the drug is not active even though it is predisposed to this operation. To alleviate the difficulties of the change, we decided to postpone the operation to a later stage, gradually getting staff used to the new operating system. Furthermore, the system helps to reduce the likelihood of administering the drug by a different route than the prescribed one, it allows the printing of therapies by selecting the route of administration, it warns the operator if he is administering a drug before the scheduled time, it doesn't allow the administration of a drug outside the scheduled day (or if it had been suspended) and it notifies any therapies to be administered or delayed.

Economic aspects

Another relevant aspect of the problem arising from the correct prescription and administration of drugs during the treatment process is undoubtedly economic. The process of drug management can be improved through different technical choices, such as computerization of operations, computerized cabinets, unit dose distribution, and other forms of customization. Depending on the technical choice made, different degrees of improvement in the entire process are achieved. In the first phase, the immediate activation of the "warehouse-pharmacy management" module is not foreseen. Still, as soon as the healthcare staff is ready (i.e., adequately trained) this module will also be activated, given the proper importance of this aspect. The use of the new IT package in full mode began in late 2021.

In fact, an appropriate use of the drug is crucial to improve the patients' health status and optimize the allocation of economic resources. It is essential to experiment with information technologies that support operators along the whole path from prescription to administration of drugs, to the verification of the administration, up to the traceability in the levels of responsibility. The computerized therapy prescription by doctors is unambiguous, without further transcription, resulting in fewer errors and further levels of control between the prescription and preparation. Nurses can thus save time that they can spend to care for patients, as it is free from repetitive activities that the traditional system imposes, focusing exclusively on administration. On the economic side, the system effectively reduces the consumption of drugs and stocks, entailing a radical change in the organization that requires an articulated training of all actors involved: pharmacists, physicians, and nurses. With the computerized system, stocks and incoming and outgoing flows can be recorded. The system will then provide as a final step the reading of the bar code of the patient's wristband with the AIC code of the drug packages to confirm the correct assignment of the therapy.

Preliminary results

The innovation project based on the unified electronic therapy record application saw the end of experimentation for both private hospitals in March 2022, with the final transition to the new system in all departments. In the "Pineta del Carso" private hospital, where experimentation has begun, the new system became fully operational in late 2021. In the meantime, the new system will be monitored and studied both from the point of view of clinical risk and from the perspective of the management of pharmacy warehouse resources by the pharmacist and the purchasing office. The Policlinico management is also studying the proposal to administer to all personnel involved an anonymous questionnaire to detect the satisfaction with the new IT tool, in two different moments, as at the beginning and end of the experimentation.

The main issue we foresee is the increased risk of errors in the transition phase between the use of the old system and the new system. In recent months, a staff awareness program is being implemented, alongside training in the use of the computer program, regarding the need to report errors. An increase in active error surveillance by risk managers assisted by nurse coordinators is essential in this phase.

In terms of feedback from healthcare professionals, we found a greater tendency for younger nurses and physicians to welcome the innovation, the older ones being more reluctant to use IT tools.

Medico-legal aspects: The nurse's role

In recent years, nurses have assumed an increasingly central role in the therapeutic process offered to patients, mainly as they possess a more and more rich and deep medical background. From the mere task of administering the drug upon prescription (conception of the logic of "job") currently, the nurse is the guarantor of the correct application of diagnostic and therapeutic prescriptions. Within the therapy process, the nurse is required to play a role of "feedback", with a view to a collaborative vision with the physician, but at the same time an antithetical role when the need to protect the patient arises. At this level, an IT tool such as the unified electronic therapy record can provide valuable help. The problem of deaths from medication errors (which are legally qualified as "foreseeable and avoidable" by jurisprudence) has long required risk reduction strategies that involve the therapy process in the totality of its phases: procurement, storage, prescribing, preparation, distribution, administration, and control. In this process, the nursing responsibility finds its first source in the professional guidelines. The postulates of the correctness of action reside in the following rules: correctness of the drug and the dose, correct identification of the patient, right way and time of administration, registration, control. Errors during the various stages of the therapeutic process fall on the nurse in the first instance. In the event of damage caused to the patient, elements of civil (compensatory) and criminal liability may arise.

The jurisprudence (29, 30) emphasized, as a result of the limits of the principle of reliance (corresponding to obvious factual situations that reasonably cast doubt on the occurrence of compliance with the duties of diligence, skill and prudence, by their collaborators), that the nurse must detect obvious inappropriateness of therapeutic prescriptions, in particular for gross errors in the indication of the dosage, posology or prescription of drugs to which the patient is allergic and then report them to the doctor for appropriate revisions. With Judgment No. 1878 of October 25, 2000, the Supreme Court of Cassation declared guilty of manslaughter a physician and a nurse for causing the death of two patients following the administration of an inappropriate dose of potassium chloride. Specifically, the medication initially supposed to be administered (potassium chloride) had been replaced by a similar solution but containing a different potassium concentration. Upon learning of the fact, the ward physician had merely given generic and superficial verbal instructions to the nurse who was about to administer the drug materially. The nurse did nothing to induce the doctor to modify the prescription (recalibrating the dosage of the solution) and proceeded to administer the deadly drug. The judges held that: "… in case of doubts about the prescribed dosage, the nurse must take action not to syndicate the therapeutic efficacy of the prescribed drug, but to draw attention to it and request the written prescription renewal". According to the Supreme Court, the nurse has "… a specific duty to attend the activity of drug administration in a non-mechanistic way (i.e., measured on the level of an elementary fulfillment of tasks merely executive), it is necessary instead to intend the performance in a manner consistent with a form of collaboration with medical staff oriented in critical terms …".

On January 16, 2015, with Judgment No. 2192, the Court of Cassation declared guilty of manslaughter a nurse who, despite being aware of it, had not reported to the doctor an error in the prescription of a drug to a patient allergic to a substance contained therein. The judges reasoned the decision as follows: "… in consideration of the quality and the corresponding content of the relevant professional activity, it is impossible not to recognize the existence, for the nurse, of a precise duty to attend to the activity of drug administration in a non-mechanistic way (i.e., measured on the level of an elementary fulfillment of merely executive tasks); on the contrary, it is necessary to intend its fulfillment according to modalities consistent with a form of collaboration with the medical staff oriented in critical terms; and so much, not already in order to syndicate the work of the doctor (particularly in terms of the therapeutic efficacy of the drugs prescribed), but in order to draw attention to the errors perceived (or otherwise perceivable), or in order to share any doubts about the adequacy or relevance of the therapy established with respect to the hypothesis subject to examination, from these premises resulting in the use of timely legal obligations to activate and solicit time to time specifically and objectively determinable in relation to each concrete case …". The responsibility landscape dictated by the Supreme Court exposes the nurse to a delicate role of verification (in addition to the known panorama of contraindications and post-recruitment events) that is contiguous to the task of translation of what the doctor prescribes (not transgressing the canons of risk management). This results from the fact that the team is horizontal and involves active collaboration between physician and nurse. Instead, there is a real obligation of control, immune from the principle of tempered trust, in the case of delegation of the act of administering oral therapy to support figures (social-health professionals) that requires the nurse (by virtue of the verticality of the performance of the team considered) to verify the correctness of the work of others (in this case the accuracy of the route of administration, the mode of administration and the recruitment).

Conclusions

To date, the innovation project is in the starting phase at the "Pineta del Carso" private hospital, and the first results after 1 month of experimentation are encouraging. There has been no increase in spontaneous reports of therapy-related errors. These preliminary results are interesting, but it is likely that the change is succeeding because the attention of the operators is, at the moment, very high on the subject (also due to pressure from the company management). It still takes time to get a complete perspective.

At the end of the experience of the introduction of the electronic unified therapy record, the nursing staff and the physicians of lower age and seniority proved to be enthusiastic about the change and very cooperative, while the same cannot be said for the "older" staff, traditionally more reluctant to change and to the use of IT tools. The results in terms of clinical risk reduction will be monitored through a prospective cohort study that will start in the coming months, after the adoption of the IT system in all departments. The study will use incident reporting to measure the effectiveness of the innovation system. Preliminary results will be available in late 2022. Initial economic data related to the revamped computerized medication and inventory management will be available simultaneously.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

GP came up with the original idea and followed the developments of the application of the IT system in the two nursing homes. FG wrote the draft article with the support of GR and AS. GR and AS supervised the project. All authors contributed to the article and approved the submitted version.

Acknowledgments

The authors would like to thank Dr. Lucia Calvo, the MEDarchiver specialist who provided the software.

Conflict of interest

Author GP was employed by Policlinico Triestino SPA.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 08 September 2022
DOI 10.3389/fpubh.2022.946299

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OPEN ACCESS

EDITED BY
Anjum Khurshid,
University of Texas at Austin,
United States

REVIEWED BY
Pierpaolo Correale,
Azienda Ospedaliera
'Bianchi-Melacrino-Morelli', Italy
Enwu Long,
Sichuan University, China

*CORRESPONDENCE
Zhongjian Wang
wangzj@pharnexcloud.com

†These authors have contributed equally to this work and share first authorship

SPECIALTY SECTION
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

RECEIVED 17 May 2022
ACCEPTED 19 August 2022
PUBLISHED 08 September 2022

CITATION
Yu G, Liu X, Li Y, Zhang Y, Yan R, Zhu L and Wang Z (2022) The nomograms for predicting overall and cancer-specific survival in elderly patients with early-stage lung cancer: A population-based study using SEER database.
Front. Public Health 10:946299.
doi: 10.3389/fpubh.2022.946299

The nomograms for predicting overall and cancer-specific survival in elderly patients with early-stage lung cancer: A population-based study using SEER database

Gen Yu[1†], Xiaozhu Liu[2†], Yunhe Li[3†], Yang Zhang[4,5], Ruxin Yan[6], Lingfeng Zhu[7] and Zhongjian Wang[7]*

[1]Department of Oncology, Ganxi Cancer Hospital, Pingxiang, Jiangxi, China, [2]Department of Cardiology, The Second Affiliated Hospital of Chongqing Medical University, Chongqing, China, [3]Department of Cardiothoracic Surgery, The Second Affiliated Hospital of Chongqing Medical University, Chongqing, China, [4]College of Medical Informatics, Chongqing Medical University, Chongqing, China, [5]Medical Data Science Academy, Chongqing Medical University, Chongqing, China, [6]Department of Oncology, The First Affiliated Hospital of Army Medical University, Chongqing, China, [7]Artificial Intelligence Laboratory, Pharnexcloud Digital Technology (Chengdu) Co., Ltd., Chengdu, China

Purpose: Lung cancer is the leading cause of death from cancer and the number of operable elderly lung cancer patients is increasing, with advanced age being associated with a poorer prognosis. However, there is no easy and comprehensive prognostic assessment method for these patients.

Methods: Clinicopathological data of patients aged 65 years or older with TNM stage I-II lung cancer from 2004 to 2018 were downloaded from the SEER database. Patients from 2004 to 2015 were randomized into a training group (n = 16,457) and a validation group (n = 7,048). Data from 2016 to 2018 (n = 6,231) were used for external validation. Two nomogram prognostic models were created after independent prognostic factors connected to both overall survival (OS) and cancer-specific survival (CSS) in the training set by using univariate and multivariate Cox proportional hazards regression analysis. In turn, overall survival (OS) and cancer-specific survival (CSS) were predicted for patients at 1, 3, and 5 years. Based on the concordance index (C-index), calibration curves, area under the receiver operating characteristics (ROC) curve (AUC), the time-dependent area under the ROC curve, the validity, accuracy, discrimination, predictive ability, and clinical utility of the models were evaluated. Decision curve analysis (DCA) was used to assess the clinical value of the models.

Results: A total of 29,736 patients were included. Univariate and multivariate analyses suggested that age, race, gender, marriage, disease grade, AJCC stage, T-stage, surgery, radiotherapy, chemotherapy, and tumor size were independent risk factors for patient prognosis. These 11 variables were included in nomogram to predict OS and CSS of patients. C-indexes of OS for the training, validation and external validation sets were 0.730 (95% CI, 0.709–0.751), 0.734 (95% CI, 0.722–0.746), and 0.750 (95% CI, 0.734–0.766), respectively. The AUC results for the training and validation sets indicated good accuracy for this nomogram. The calibration curves demonstrated a high degree of concordance between actual and anticipated values, and the DCA demonstrated that the nomograms had better clinical application than the traditional TNM staging approach.

Conclusion: This study identified risk factors for survival in operable elderly lung cancer patients and established a new column line graph for predicting OS and CSS in these patients. The model has good clinical application and can be a good clinical decision-making tool for physicians and patients.

KEYWORDS

nomogram, elderly lung cancer, SEER, OS, CSS

Introduction

Lung cancer is one of the most popular malignant tumors and the deadliest cancer, with a 5-year survival rate of ∼16% worldwide (1). According to the most recent cancer statistics, it was estimated that 19,300,000 new tumor patients and over 10,000,000 deaths would occur in 2020 (1, 2). With increased awareness of medical screening and improved diagnostic techniques, the early detection rate of lung cancer is increasing, with the proportion of lung cancers presenting as early (operable) at the time of detection increasing from 25 to around 63% (3, 4).

The rate of systemic therapy in lung cancer patients over 65 years old was significantly lower than the rate of treatment in patients under 65 years old, according to a single institution study. Per the recent projections, lung cancer will increase significantly in patients over the age of 65 (5). This is why this study focuses on the elderly population. According to a recent study, elderly patients with lung cancer have substantially higher post-operative problems (26.0 vs. 13.3%) and mortality rate (8.2 vs. 2.2%) than younger patients after surgery (6). Even though surgery might achieve successful resection of the tumor, about half of early-stage lung cancer will recur after surgery, which may lead to death (7). Thus, proper selection of surgery candidates would contribute to an increase in life quality and a decrease in morbidity. To choose surgical patients with a better prognosis, it is advantageous to develop a clinically appropriate and straightforward grading system. Notable heterogeneity exists among patients with early lung cancer in terms of demographic and clinicopathological data, including age, sex, T and N stages, pathological type, tumor stage, and applied therapy strategies. Thus, the prognosis of early lung cancer varies significantly between patients with different characteristics. Adjuvant therapy for patients who have undergone surgery for early lung cancer should be categorized into distinct prognosis groups.

In the United States, nearly 70% of lung cancer cases and >70% of lung cancer deaths occur in patients over the age of 65 (8). However, older adults are underrepresented in clinical trials and making treatment decisions in this population is challenging (9). In general, the available data to guide decision-making in older people is limited. Our study focused on older lung cancer patients aged ≥65.

SEER indicates Surveillance, Epidemiology, and End Results database. Approximately 35% of the U.S. population is covered by this database, which pertain to cancer prognosis. Nomograms provide personalized risk estimates by combining and showing significant prognostic criteria, and they are superior than other existing decision aids for more precisely predicting cancer patient outcomes (10). We used the SEER database to build and verify a web-based model for predicting the survival of elderly patients with early lung cancer, which may be useful for prognostic prediction, treatment strategy selection, and follow-up management of these patients.

Materials and methods

Patients and methods

The SEER*stat software (version 8.3.5; http://seer.cancer.gov/seerstat/) was used to extract all patient data from the National Cancer Institute's SEER database. The National Cancer Institute (NCI) sponsors the SEER database, which collects statistics on cancer incidence and outcomes.

Clinicopathological information on early-stage (operable) elderly lung cancer patients from 2004 to 2018 was selected. Institutional review and informed permission were not necessary for this investigation because no patients were directly involved and no personal identifiable information from the SEER data was used.

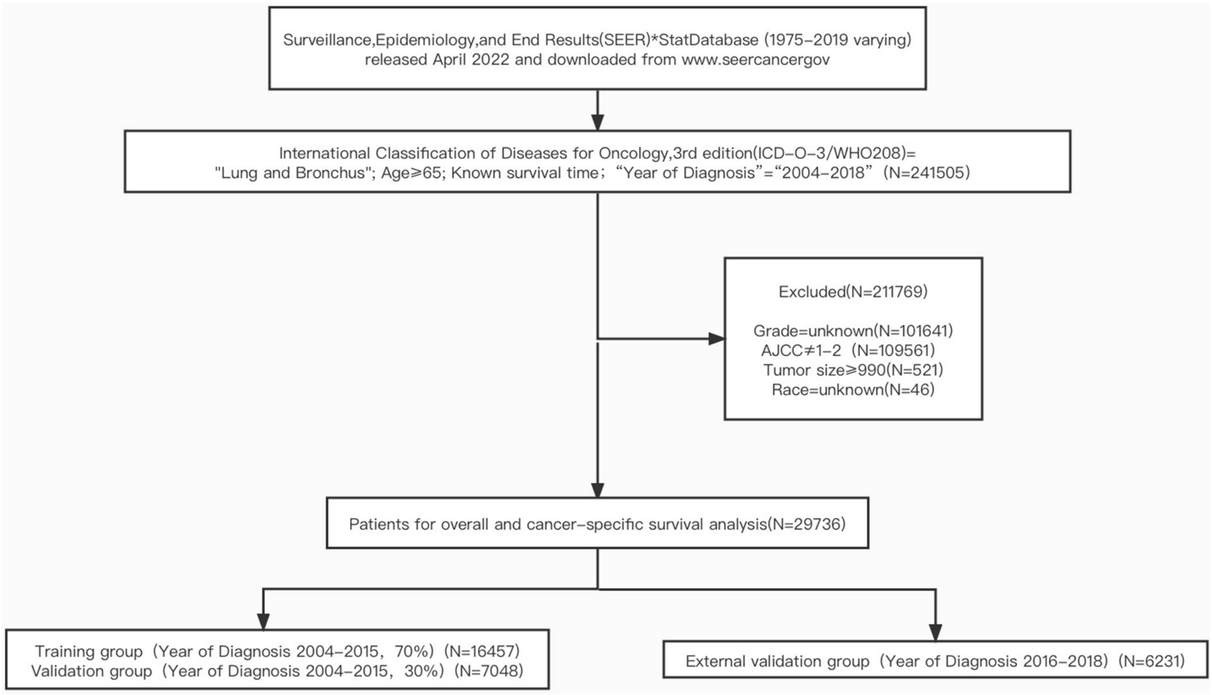

FIGURE 1
The flowchart of including and dividing patients.

Inclusion criteria were as follows: (1) Site recode ICD-10 codes: lung and bronchus (C34.0–C34.3, C34.8, and C34.9); (2) Age ≥65; (3) Known survival time.

The exclusion criteria were as follows: (1) unknown histological grade; (2) AJCC stage IV; (3) Tumor size ≥990; (4) unknown race; (5) Patients with incomplete or unclear data on other indicators. The patient selection process is presented in Figure 1.

Study variables and outcomes

A total of 12 indicators were analyzed in this study, from the clinical and pathological characteristics of the patients, variables included in the study included age (65–69, 70–74, 75–79, 80–84, ≥85), race (black, white, other races), sex (female, male), marital status (married, unmarried), disease classification (grade I, II, III, IV), AJCC stage (IA/IB, IIA/IIB, IIIA/IIIB), T (T1, T2, T3), N (N0, N1), surgery (no, yes), radiotherapy (no, yes), chemotherapy (no, yes), tumor size (<5, 5–10, and ≥10 cm).

Variable correction

Reclassification of T-stage, N-stage and M-stage recorded in the SEER database according to the 8th edition of the American Joint Committee on Cancer Staging manual (11).

Endpoint definition

Primary endpoint one was OS, defined as time from randomization to death due to any cause. Primary endpoint two was CSS, or to say lung cancer-specific survival (LCSS), defined as the time from randomization to death as a result of lung cancer. In addition, the survival rates at 1, 3, and 5 years were examined. The C-index, receiver operating characteristics (ROC) curve, time-dependent area under the ROC curve (AUC), decision curve, and calibration curve were used to evaluate the nomogram's validity, accuracy, discrimination, predictive capacity, and clinical value. In this study, patients who had been alive at the time of their last follow-up were omitted from the data.

Statistical analysis

We randomly assigned 70% (n = 16,457) of patients from 2004 to 2015 to the training cohort and 30% (n = 7,048) of patients from 2004 to 2015 to the validation cohort for nomogram construction and validation. The external validation cohort included 6,231 patients from the SEER database from 2016 to 2018.

Various Cox proportional hazard regression models were used to examine the impact of potential predictors on both overall survival (OS) and cancer-specific survival (CSS). For

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TABLE 1 Clinicopathological characteristics of elderly lung cancer patients—the training group and the validation group.

Characteristic N	Overall 23,505	Training set 16,457	Validation set 7,048	*p*-value
Age (%)				
65–70	6,005 (25.55)	4,149 (25.21)	1,856 (26.33)	0.4161
70–75	6,271 (26.68)	4,397 (26.72)	1,874 (26.59)	
75–80	5,841 (24.85)	4,099 (24.91)	1,742 (24.72)	
80–85	3,734 (15.89)	2,641 (16.05)	1,093 (15.51)	
≥85	1,654 (7.04)	1,171 (7.12)	483 (6.85)	
Race (%)				
Black	1,741 (7.41)	1,185 (7.20)	556 (7.89)	0.1737
White	19,948 (84.87)	13,992 (85.02)	5,956 (84.51)	
Other	1,816 (7.73)	1,280 (7.78)	536 (7.60)	
Sex (%)				
Female	11,852 (50.42)	8,323 (50.57)	3,529 (50.07)	0.4884
Male	11,653 (49.58)	8,134 (49.43)	3,519 (49.93)	
Marital status (%)				
Married	12,752 (54.25)	8,917 (54.18)	3,835 (54.41)	0.7576
No	10,753 (45.75)	7,540 (45.82)	3,213 (45.59)	
Grade (%)				
I	4,164 (17.72)	2,949 (17.92)	1,215 (17.24)	0.1204
II	10,403 (44.26)	7,303 (44.38)	3,100 (43.98)	
III	8,263 (35.15)	5,717 (34.74)	2,546 (36.12)	
IV	675 (2.87)	488 (2.97)	187 (2.65)	
AJCC (%)				
I	19,896 (84.65)	13,948 (84.75)	5,948 (84.39)	0.4936
II	3,609 (15.35)	2,509 (15.25)	1,100 (15.61)	
T (%)				
T1	12,138 (51.64)	8,489 (51.58)	3,649 (51.77)	0.4955
T2	10,429 (44.37)	7,326 (44.52)	3,103 (44.03)	
T3	938 (3.99)	642 (3.90)	296 (4.20)	
***N* (%)**				
N0	20,834 (88.64)	14,590 (88.66)	6,244 (88.59)	0.9072
N1	2,671 (11.36)	1,867 (11.34)	804 (11.41)	
Surg (%)				
No	5,635 (23.97)	3,943 (23.96)	1,692 (24.01)	0.9511
Yes	17,870 (76.03)	12,514 (76.04)	5,356 (75.99)	
Radiation (%)				
No	18,471 (78.58)	12,943 (78.65)	5,528 (78.43)	0.7273
Yes	5,034 (21.42)	3,514 (21.35)	1,520 (21.57)	
Chemotherapy (%)				
No	19,554 (83.19)	13,734 (83.45)	5,820 (82.58)	0.1033
Yes	3,951 (16.81)	2,723 (16.55)	1,228 (17.42)	
Tumor size (%)				
<5 cm	20,646 (87.84)	14,459 (87.86)	6,187 (87.78)	0.9611
5–10 cm	2,579 (10.97)	1,804 (10.96)	775 (11.00)	
≥10 cm	280 (1.19)	194 (1.18)	86 (1.22)	

OS and CSS, the univariate Cox proportional hazard regression model contained 12 potential factors. A backward stepwise technique was used to enter variables with a univariable $p < 0.05$ into the multivariable model and assess their significance. The Cox proportional hazards regression technique was used to obtain hazard ratios (HRs) and confidence intervals (CIs).

A nomogram was created based on the data from the training cohort, and its ability to predict outcomes was examined in the validation cohort. R software (version 3.4.4) was used to build an effective prognostic nomogram for the training cohort based on variables that were statistically significant in the multivariate analysis. Using a scale ranging from 0 to 100, each variable's score was determined. When all variables were taken into account, each patient's overall score was calculated. Finally, each patient's OS and CSS probabilities at 1, 3, and 5 years were estimated.

Based on bootstrapped calibration curves and a C-index, the nomogram-based prediction model was verified. In order to test the final model's discrimination abilities, we used the ROC curve approach. In this investigation, a bootstrap technique with 1,000 resamples was used to create calibration curves to compare observed and projected survival. A decision curve analysis was performed to evaluate the clinical benefit of our model.

We used the survival package surv_cutpoint() function in R, of which the basic principle is based on log-rank test by using Kaplan-Meier curve to take the best cutoff value of the total risk score of the training set column line graph: 168.4566. The best cutoff value was greater than the cutoff value for the high-risk group, and less than the cutoff value for the low-risk group. To compare patient survival between groups, we used Kaplan–Meier curves and log-rank testing. We ran univariate and multivariate Cox proportional hazards regression analyses with SPSS software (version 24.0). We created the nomogram, C-indices, ROCs, calibration curves, DCA curves and Kaplan–Meier curves using R software (version 4.0.2) and relevant packages ("rms," "DynNom," "nomogramFormula," "survival," "foreign," "survivalROC," "ggDCA," "survminer"). Using the X-Tile software, we calculated the cutoff value (version 3.6.1). Statistical significance was defined as a two-sided $p < 0.05$.

Results

Basic characteristics

The selected patients were all >65 years old. In the training and validation groups, most of the patients were white (84.87%), and had a tumor in early T stage (96.01%) and N stage (88.64%) and with early histological staging (61.98%). In terms of gender and marital status, no significant difference was detected between these two groups. Most patients had undergone surgery (76.03%) and a small number of patients had received radiotherapy (21.42%) and chemotherapy (16.81%). In the external validation group, the picture was largely consistent: The majority of the patients (84.10%) were white, with tumors in the early T stage (90.08%) and N stage (92.33%), as well as early histological staging (67.87%). There was no discernible difference between the two groups in terms of gender or marital status. More than half of the patients (62.88%) underwent surgery and a few patients received radiotherapy (31.76%) and chemotherapy (15.10%) (Table 1). The distribution of pathogenic features and clinical information did not differ significantly across the training and validation sets, as shown in Table 2 (all $p > 0.05$).

Univariate and multivariate cox regression analysis

To identify predictors of OS and CSS among the 16,457 patients comprising the training cohort, univariate and multivariate analyses were performed. As can be seen in Table 3, age, race, gender, marriage, disease grade, AJCC stage, T-stage, surgery, radiotherapy, chemotherapy, and tumor size were independent risk factors affecting patient prognosis. The Cox proportional hazards regression model was utilized to investigate in depth the effects of various parameters. OS and CSS multivariate analysis revealed increased hazard ratios (HRs) for the following characteristics: older age, male gender, unmarried, higher histology grade and T stage, no surgery of the primary tumor, larger tumor sizes, and having received radiotherapy or chemotherapy ($p < 0.05$).

Prognostic nomograms for OS and CSS

The prognostic nomogram comprised all significant independent factors of the Cox proportional hazards regression in the training group. Figure 2A depicts the OS nomogram for the first, third, and fifth years, while Figure 2B depicts the CSS nomogram for the first, third, and fifth years. By combining the scores associated with each characteristic and projecting the total scores to the bottom scale, it is possible to estimate the likelihood of OS and CSS at 1, 3, and 5 years. Our model can be used to predict the outcomes of individual patients according to their characteristics.

Confirmation of the nomograms

The C-index of the OS predictive model was 0.730 (95% CI, 0.709–0.751) in the training group and 0.734 (95% CI, 0.722–0.746) in the validation group. In external validation, the C-index was 0.750 (95% CI, 0.734–0.766), indicating good discrimination. As for the CSS nomogram, the C-index for the training group was 0.755, 0.714, and 0.689 for 1, 3, and 5 years

TABLE 2 Clinicopathological characteristics of elderly lung cancer patients——the external validation.

Characteristic	Overall
	***N* = 6,231**
Age (%)	
65–70	1,654 (26.54)
70–75	1,811 (29.06)
75–80	1,444 (23.17)
80–85	854 (13.71)
≥85	468 (7.51)
Race (%)	
Black	499 (8.01)
White	5,240 (84.10)
Other	492 (7.90)
Sex (%)	
Female	3,358 (53.89)
Male	2,873 (46.11)
Marital status (%)	
Married	3,301 (52.98)
No	2,930 (47.02)
Grade (%)	
I	1,414 (22.69)
II	2,815 (45.18)
III	1,920 (30.81)
IV	82 (1.32)
AJCC (%)	
I	4,836 (77.61)
II	1,395 (22.39)
T (%)	
T1	3,538 (56.78)
T2	2,075 (33.30)
T3	618 (9.92)
***N* (%)**	
N0	5,753 (92.33)
N1	478 (7.67)
Surg (%)	
No	2,313 (37.12)
Yes	3,918 (62.88)
Radiation (%)	
No	4,252 (68.24)
Yes	1,979 (31.76)
Chemotherapy (%)	
No	5,290 (84.90)
Yes	941 (15.10)
Tumor size (%)	
<5 cm	5,667 (90.95)
5–10 cm	530 (8.51)
≥10 cm	34 (0.55)

respectively. In the validation group, the C-indexes for 1, 3, and 5 years were 0.754, 0.718, and 0.69 respectively. Patients in the external validation group had a C-index of 0.781 for 1 year only, as the longest CSS was 35 months.

For OS, the 1-, 3-, and 5-year AUCs were 0.749, 0.737 and 0.731 for the training group, 0.736, 0.739, and 0.737 for the validation group and 0.782 for the external validation group (1 year only). As to the CSS nomogram, the 1-, 3-, and 5-year AUCs were 0.767 (95% CI, 0.755–0.78), 0.733 (95% CI, 0.723–0.742), and 0.705 (95% CI, 0.696–0.714) for the training group and 0.767 (95% CI, 0.749–0.785), 0.74 (95% CI, 0.726–0.753), and 0.708 (95% CI, 0.695–0.721) for the validation group and 0.793 (95% CI, 0.769–0.817) for the external validation group (1 year only; Figure 3). These results suggested the predictive nomograms were with good discrimination performance. Furthermore, calibration curves for 1,—3-, and 5-year indicated a good consistency between the observed survival and the predicted survival in both in OS and CSS (Figure 4).

Figure 5 depicts the DCA curves for the prognostic nomogram and TNM staging scheme. DCA revealed that the prognostic nomogram had greater net advantages than the TNM staging approach, indicating greater clinical application value.

Risk classification system

According to the overall score generated by the prognostic nomogram, all cases were split into two subgroups, each representing a different prognosis. Figure 6 depicts the Kaplan-Meier survival curve that indicated the prognosis for each subgroup. Based on OS events, in the training set, the high-risk group had a 1-year OS of 69.9%, a 3-year OS of 39.2% and a 5-year OS of 39.2%. In the low-risk group, the 1-year OS was 91.4%, the 3-year OS was 74.6%, and the 5-year OS was 60.9%. In the validation set, the high-risk group had a 1-year OS of 67.7%, a 3-year OS of 34.0%, and a 5-year OS of 20.7%. The low-risk group had a 1-year OS of 90.0%, a 3-year OS of 71.5%, and a 5-year OS of 57.3%. Overall, the high-risk group had a 1-year OS of 68.8%, a 3-year OS of 37.5%, and a 5-year OS of 24.1%. The low-risk group had a 1-year OS of 90.9%, a 3-year OS of 73.4%, and a 5-year OS of 59.3%. In the external validation set, the maximum survival time in the source data was 35 months, with a minimum of 71.6% 1-year OS in the high-risk group and 93.6% 1-year OS in the low-risk group. There were statistically significant differences in survival outcomes between the two groups.

Discussion

The baseline demographic and clinical characteristics of the patients were analyzed, Then, a prognostic nomogram for the 1-, 3-, and 5-year OS and CSS of elderly patients with early lung cancer were built and validated, which could be

TABLE 3 Univariate and multivariate analyses of OS and CSS in training set.

Variable	Univariate analysis		Multivariate analysis	
	HR (95%CI)	*p*-value	HR (95%CI)	*p*-value
Age				
65–70	1		1	
70–75	1.23 (1.16–1.3)	<0.001	1.18 (1.12–1.25)	<0.001
75–80	1.58 (1.49–1.67)	<0.001	1.46 (1.38–1.54)	<0.001
80–85	2.01 (1.89–2.13)	<0.001	1.68 (1.58–1.79)	<0.001
≥85	2.84 (2.63–3.06)	<0.001	1.89 (1.75–2.05)	<0.001
Race				
Black	1		1	
White	0.99 (0.92–1.07)	0.815	1.08 (1–1.16)	0.048
Other	0.77 (0.7–0.85)	<0.001	0.85 (0.77–0.94)	0.0014
Sex				
Female	1		1	
Male	1.37 (1.32–1.42)	<0.001	1.38 (1.32–1.43)	<0.001
Marital status				
Married	1		1	
No	1.19 (1.14–1.23)	<0.001	1.19 (1.14–1.24)	<0.001
Grade				
I	1		1	
II	1.43 (1.35–1.51)	<0.001	1.4 (1.33–1.49)	<0.001
III	1.89 (1.79–2.01)	<0.001	1.6 (1.51–1.7)	<0.001
IV	2.08 (1.86–2.32)	<0.001	1.69 (1.51–1.89)	<0.001
AJCC				
I	1		1	
II	1.67 (1.6–1.76)	<0.001	1.53 (1.44–1.62)	<0.001
T				
T1	1		1	
T2	1.42 (1.37–1.48)	<0.001	1.29 (1.24–1.35)	<0.001
T3	2.33 (2.13–2.55)	<0.001	1.37 (1.23–1.52)	<0.001
Surg				
No	1		1	
Yes	0.33 (0.32–0.35)	<0.001	0.3 (0.28–0.32)	<0.001
Radiation				
No	1		1	
Yes	2.09 (2–2.18)	<0.001	0.72 (0.68–0.77)	<0.001
Chemotherapy				
No	1		1	
Yes	1.18 (1.12–1.24)	<0.001	0.83 (0.78–0.88)	<0.001
Tumor size				
<5 cm	1		1	
5–10 cm	1.7 (1.61–1.8)	<0.001	1.24 (1.16–1.31)	<0.001
≥10 cm	2.24 (1.92–2.61)	<0.001	1.75 (1.49–2.05)	<0.001

useful for prognostic evaluation, treatment strategy selection, and follow-up management. The prognostic nomogram had superior prediction accuracy for lung cancer than the present TNM staging system, according to the ROC, DCA, and error curves. Furthermore, the OS nomogram was qualified to split lung cancer patients into low and high risk categories, implying that this nomogram might be routinely used to predict lung cancer patients' prognosis.

In the present population-based cohort study, univariate and multifactorial analyses revealed that age, race, gender, marriage, disease grade, AJCC stage, T-stage, surgery, radiotherapy, chemotherapy, and tumor size were all independent prognostic

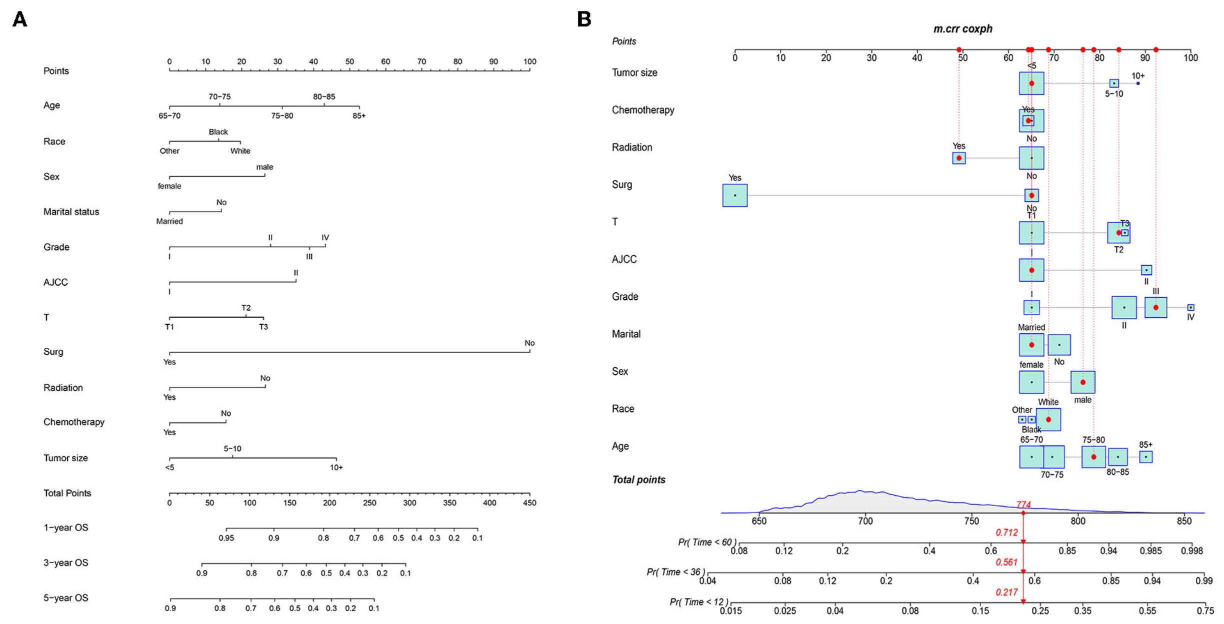

FIGURE 2
Prognostic nomograms of 1-, 3-, and 5-year OS **(A)** and CSS **(B)**.

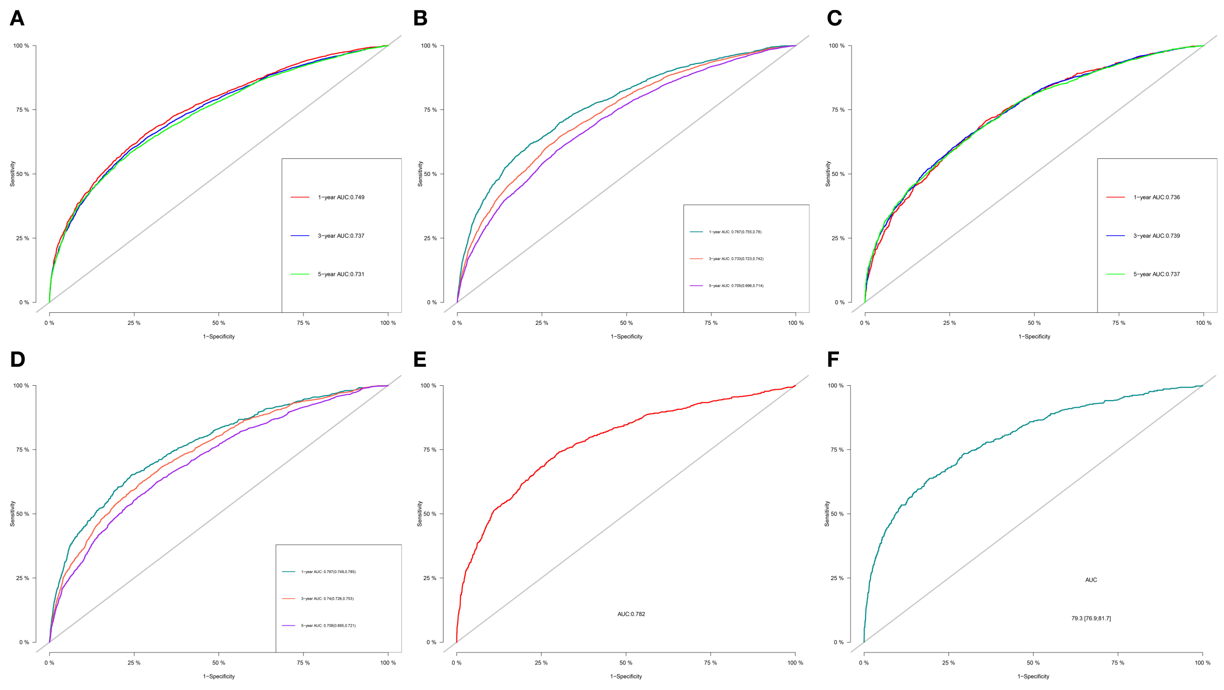

FIGURE 3
1-, 3-, and 5-year ROC curves of OS and CSS in training group **(A,B)**, validation group **(C,D)** and external validation group **(E,F)** for validating nomogram models.

predictors for older patients with early-stage lung cancer. Similar to a large number of previous studies, the univariate and multifactorial COX regression analyses in this study found higher risk rates for patients with characteristics such as advanced age, male, unmarried, late histological stage, and large T-stage. In addition, inoperative primary tumor

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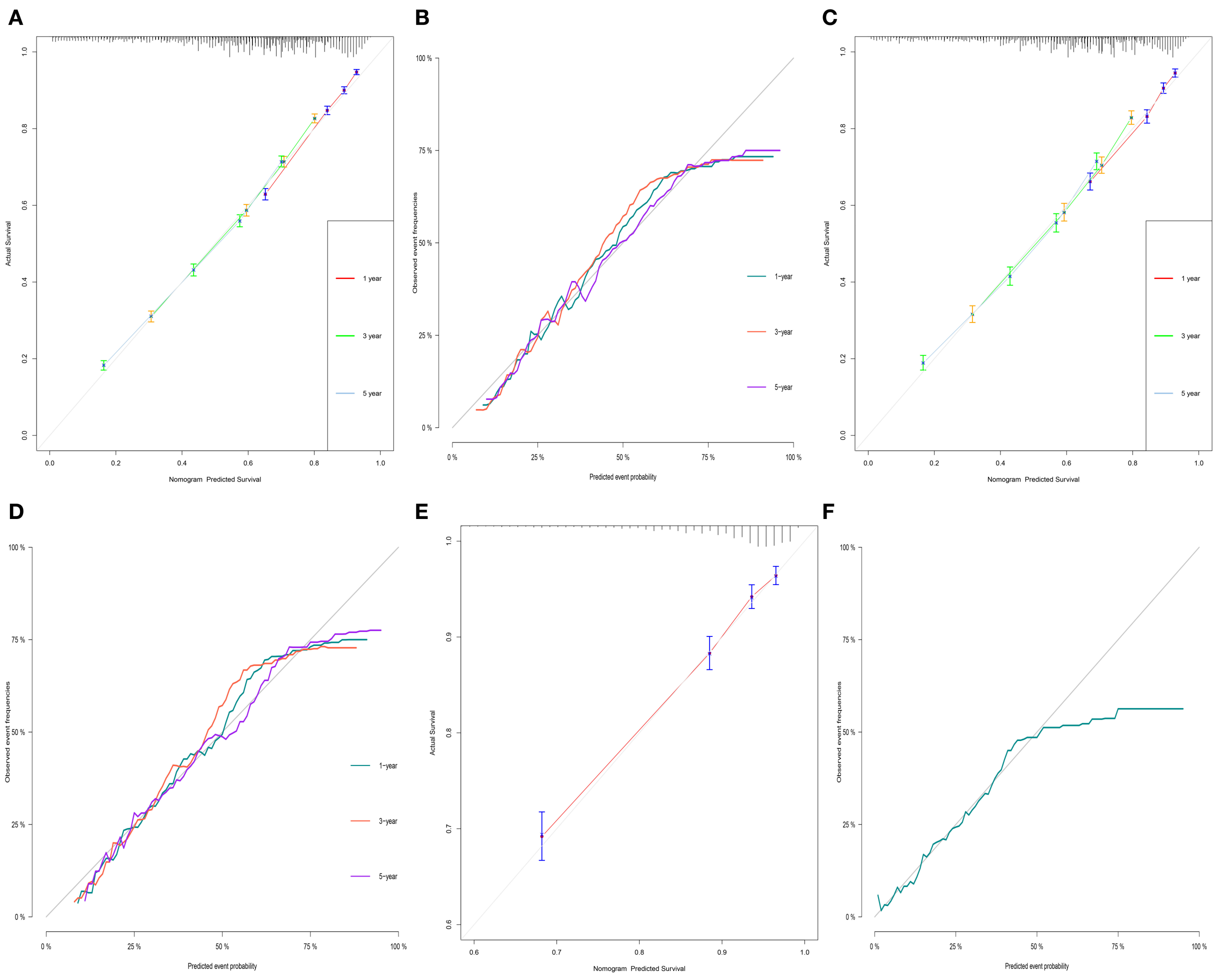

FIGURE 4
Calibration curves of OS and CSS in training group **(A,B)**, validation group **(C,D)** and external validation group **(E,F)** for validating nomogram models.

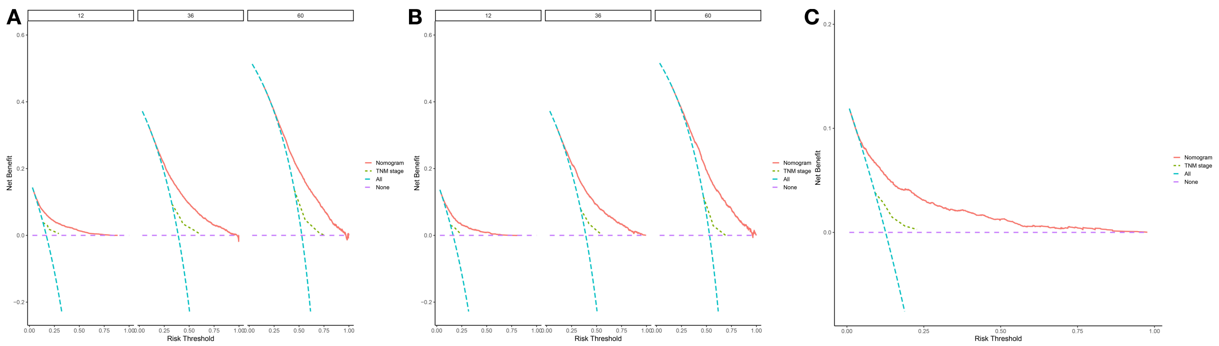

FIGURE 5
1-, 3-, and 5-year decision curve analysis of nomogram. **(A)** The DCA curves of nomogram in training group. **(B)** The DCA curves of nomogram in internal validation group. **(C)** The DCA curves of nomogram in external group. The net benefit is shown by the *y*-axis, and the threshold probability is represented by the *x*-axis. No patients have died on the purple line, while all patients have died on the blue line. The net benefit of the model exceeds all deaths or no deaths when the threshold probability is between 20 and 60%.

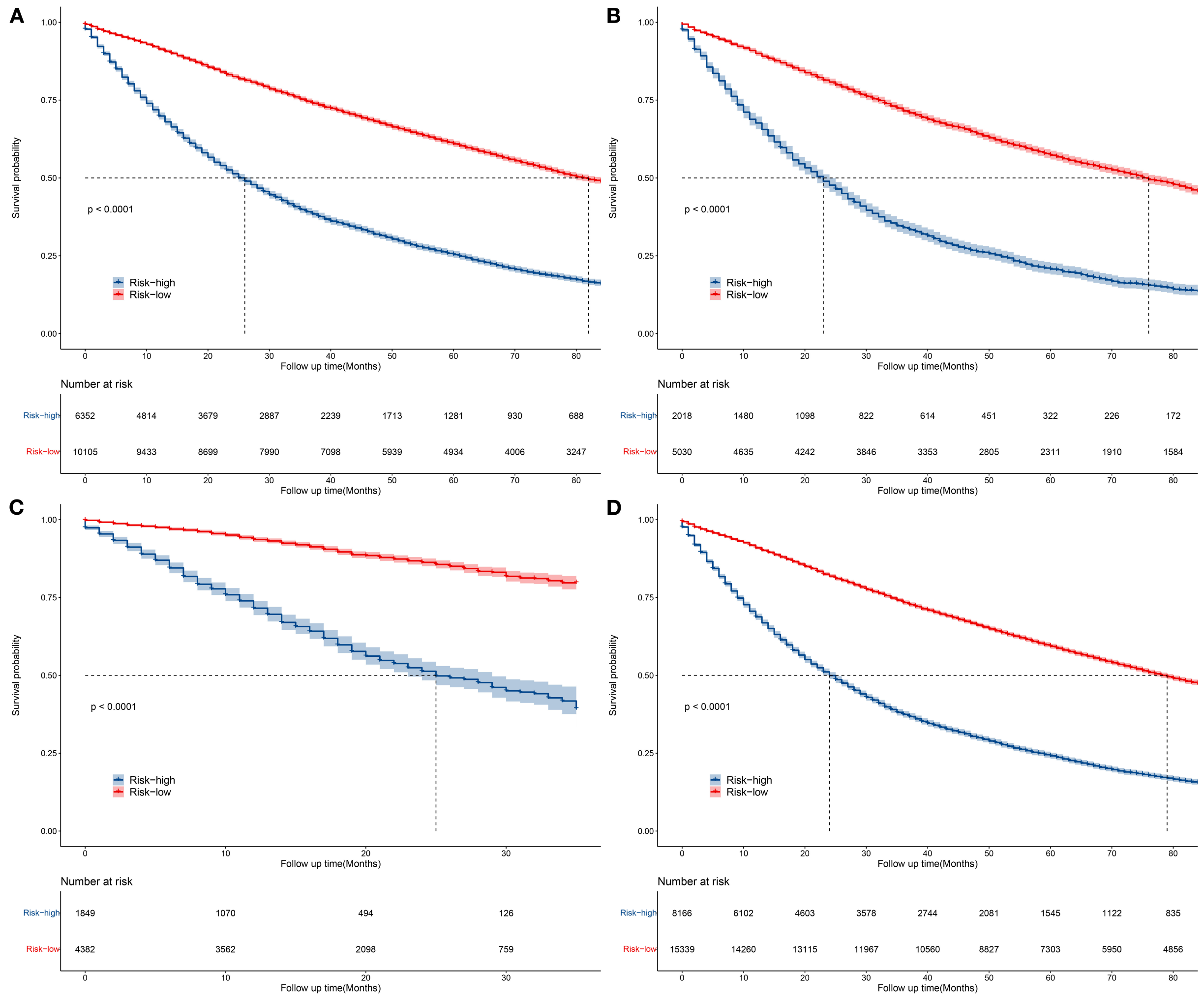

FIGURE 6
Kaplan–Meier curves of OS for patients in the low-, and high-risk groups in the training group **(A)**, validation group **(B)**, external validation group **(C)**, and general group **(D)**.

predicted a worse prognosis, suggesting that although older patients usually have a higher surgical risk secondary to their age and other underlying diseases commonly seen in the elderlies, postoperative morbidity and mortality are acceptable even in older patients (12, 13). After accurate and thorough preoperative assessment and preparation, the choice of an appropriate pneumonectomy is safe in elderly patients with lung cancer after accurate and thorough preoperative assessment and preparation, such as minimally invasive surgery (14).

Advanced age is consistently one of the risk factors affecting the long-term survival of oncology patients (15), and a variety of factors can help explain this phenomenon. The worst prognosis in older patients is associated with reduced physiological reserve, reduced effectiveness of cancer treatment, and increased risk of toxic side effects and death (16). Patients with non-small cell lung cancer (NSCLC) over 80 years of age were reported to be less likely to receive chemotherapy as initial treatment than patients aged 70–79 years (12.3% vs. 40.9%) (17). It is also important to note that unlike older patients, the development of early-stage lung cancer (lung cancer occurring before the age of 45 years) is primarily associated with genetic factors (18). Some studies have suggested that targeted genomic alterations are significantly increased in younger patients and targeted therapy is associated with improved survival (19). The present study found that advanced age negatively affected not only OS but also CSS of patients, which is relevant and consistent with the above-mentioned reasons.

Epidemiological studies have shown that men have a poorer prognosis than women in a wide range of cancer types not related to reproductive function (20), including but not limited to lung, liver and melanoma (21). A pooled analysis of five previous randomized trials showed that women with lung cancer had higher response rates and longer survival to chemotherapy compared to men with lung cancer, and that differences in OS persisted after adjustment for age, stage, performance status and histology (22). A study of 2,724 men and 1,894 women with lung cancer conducted in the USA showed that the risk of death following a diagnosis of lung cancer was significantly higher in men than in women (adjusted relative risk: 1.20, 95% CI: 1.11–1.30) (23). One of the possible explanation for this difference between men and women is smoking, as smoking rate is higher among men than women, and there are also gender differences in susceptibility to tobacco carcinogens (24). In addition, it has been suggested that an important reason for the poorer prognosis in men is that men showed increased endogenous and induced DNA damage as well as higher levels of unrepaired DNA than females (25). This study was conducted in older patients with more cumulative mutations (26), and perhaps the increased DNA damage would be more pronounced and worth further exploration.

Interestingly, this study showed a relatively poor prognosis for patients who had received radiotherapy or chemotherapy, since patient who have received radical radiotherapy or radical chemotherapy usually do not undergo further surgery, and the treatments are mutually exclusive. Patients, who opt for relatively conservative treatments including radiotherapy and chemotherapy, instead of surgery, fail to have the tumor load eradicated, which leads to a poorer prognosis. Guo et al. concluded that for elderly patients with LA-NSCLC, the curative-intent treatment (surgery or CRT) conferred better survival compared to chemotherapy alone, RT alone and BSC (27). We validated this conclusion with a larger sample size.

The most controversial finding was whether N stage was included as a factor independently affecting prognosis: in our study, N stage had no significant effect on prognosis, in contrast to the findings of Liang et al. (28) in NSCLC, who found that a greater number of ELNs is associated with more-accurate node staging and better long-term survival of resected NSCLC. However, the study did not distinguish between patient staging and age. The fact that N stage was not included In the present research as an independent risk factor for prognosis in elderly patients with early-stage lung cancer is an unconventional but novel perspective, and we believe the most important reason for this is as follow: we analyzed patients with N0 or N1 lung cancer in this study, N1 nodes include ipsilateral intrapulmonary, peribronchial, hilar lymph nodes, and direct invasion of the primary tumor, which does not influence treatment decisions requiring surgery, nor even the specific options for non-surgical therapies such as radiotherapy and targeted and immunotherapy, and so have limited impact on prognosis.

The primary tumor staging system, TNM staging, is crucial for assessing the prognosis of cancer (29). However, TNM has significant limitations: first, patients with the same TNM stage but different survival outcomes are forced into the same disease stage, introducing heterogeneity. Second, TNM staging system does include tumor, lymph nodes, or metastases as continuous variables. It is also important to note that the TNM system does not incorporate many key variables, although in general, the prognosis will be worse when the TNM stage is too high. It does not incorporate other variables associated with prognosis, such as histology, treatment status, gene mutation status, etc (30). Hence, a more comprehensive and precise prognostic model is needed. In contrast, the nomogram is a major innovation in assessing prognosis and can incorporate numerous variables that will hopefully help patients and physicians in all aspects of decision making. The prognostic nomogram demonstrated more lung cancer prediction accuracy in this study than the current TNM staging approach, according to the DCA.

The AUC values for these nomograms are 0.73–0.75, which are not very high, and we considered that it is related to the heterogeneity of tumors in elderly patients. However, the results of C-index, calibration curve and DCA, except for the AUC values, are relatively balanced indicating the good performance of the present model. The inclusion of basic patient information, clinical consensus factors known to be associated with lung cancer prognosis, and common treatments in our column nomograms allows for individualized patient assessment and the most accurate prediction of cancer patient outcomes possible. The column line graph prognostic model can greatly facilitate risk stratification and treatment planning, as well as more precise inclusion criteria for clinical trials, and also help with patient counseling and follow-up.

To visualize and integrate these independent risk factors, the present study constructed a column line graph to calculate an intuitive, quantitative, individual probability of survival for older patients with early-stage lung cancer. After internal validation, the model showed good discriminatory power and net clinical benefit to assist in treatment decision making for older patients with early-stage lung cancer. All factors listed in the column line graphs are common clinical and pathological data. The limitations of this study are as follows: First, there have been many advances in the treatment of lung cancer over the past 15 years, and there are significant differences in survival rates between now and the past due to differences in treatment, which is one of the confounding factors in our study. Second, important factors associated with lung cancer prognosis, such as smoking history, cardiopulmonary function, postoperative complications, tumor markers and genetic information, could not be retrieved from the database in this study; and the time and site of recurrence, which are closely associated with lung cancer-specific death, were also unclear. Third, other inherent limitations of this retrospective study design include selection bias and information bias. Fourth, the prognosis based on SEER estimates for the US population may not accurately reflect that of other countries.

Despite the limitations mentioned above, the column line plots obtained in this study can be easily applied clinically and do not require any complex calculations, and they provide some reference for prognostic judgments and clinical decision-making during patient consultations. More importantly, the feasibility of column line plots in predicting CSS and OS were well verified in the present study, which also provides directions for future studies.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

GY and XL: conceptualization. XL and YL: methodology, investigation, and supervision. YZ: software and formal analysis. RY and LZ: validation. ZW: resources, project administration, and funding acquisition. YZ, RY, and LZ: data curation. GY: writing—original draft preparation. XL: essay—review and editing. YZ and GY: visualization. All authors have read and agreed to the published version of the manuscript, contributed to the article, and approved the submitted version.

Conflict of interest

Authors LZ and ZW were employed by Artificial Intelligence Laboratory, Pharnexcloud Digital Technology (Chengdu).

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.946299/full#supplementary-material

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 26 September 2022
DOI 10.3389/fpubh.2022.949062

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OPEN ACCESS

EDITED BY
Gulzar H. Shah,
Georgia Southern University,
United States

REVIEWED BY
Ricardo Valentim,
Federal University of Rio Grande do Norte, Brazil
Allan Bregola,
University Hospitals Bristol NHS Foundation Trust, United Kingdom

*CORRESPONDENCE
Yuwei Wang
twyw1218@jnu.edu.cn

†These authors have contributed equally to this work and share first authorship

SPECIALTY SECTION
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

RECEIVED 20 May 2022
ACCEPTED 06 September 2022
PUBLISHED 26 September 2022

CITATION
Wang H, Sun X, Wang R, Yang Y and Wang Y (2022) The impact of media use on disparities in physical and mental health among the older people: An empirical analysis from China. *Front. Public Health* 10:949062. doi: 10.3389/fpubh.2022.949062

The impact of media use on disparities in physical and mental health among the older people: An empirical analysis from China

Han Wang[1†], Xiaojun Sun[1†], Ruyue Wang[1], Yang Yang[2] and Yuwei Wang[1*]

[1]School of Journalism and Communication, Jinan University, Guangzhou, China, [2]School of Journalism and Communication, Beijing Sport University, Beijing, China

Background: The media is playing an increasingly important role in the lives of older adults. Exploring health inequalities in older adults is essential for achieving healthy aging. However, few studies have focused on the effects of different media types on older adults' physical and mental health levels and health inequalities among older adults with varying levels of education from a health communication perspective.

Objectives: The purpose of this study was to investigate the media use, physical and mental health (Self-rated health and subjective well-being) levels of older adults in China, the relationship between different media types use (Traditional media, internet media), and physical and mental health levels and the effects of different media types use on physical and mental health disparities among older adults with varying levels of education.

Methods: The data used in this study are from the 2017 China General Social Survey. The descriptive statistical analysis was conducted on the media use and the health levels of Chinese older adults; analysis of variance and *post hoc* analysis were used to analyze the differences in health levels and frequency of media use among older people with different levels of education; bivariate correlation and regression analyses were conducted to explore the relationship between media use and health levels in older adults; multilevel regression analyses and simple slope plots explored whether the use of different media types widened or narrowed the gap in health levels among older people with varying levels of education.

Results: The results of the study show that (1) the self-rated health levels ($M = 2.986$, $SD = 1.070$) are lower in the old people group relative to subjective well-being ($M = 3.908$, $SD = 0.854$). While some older adults have mastered the internet media, most of the older population is more accustomed to using traditional media (Especially TV, 77.08% of the elderly are used to watching TV regularly). There are disparities in media use habits and health levels among older adults with different education levels ($p < 0.01$). (2) traditional media use was a significant positive predictor of physical ($B = 0.1$, $p < 0.01$) and mental health

(B = 0.165, $p < 0.01$) in the older age group. Internet media use was a significant positive predictor of physical health (B = 0.052, $p < 0.01$) in the older age group. (3) traditional and internet media use could narrow the physical and mental health disparities between older people with different education levels ($p < 0.05$).

Conclusions: There is an essential correlation between media use and the health levels of old people, and media use can effectively narrow the disparities between the physical and mental health of old people with different educational levels. Society should value the media's important role in promoting older persons' health and well-being. Government-related departments can combine the media with public health campaigns to narrow the health disparity among old people with different educational levels and promote equal healthy aging.

KEYWORDS

health disparities, elderly, media use, education level, health level

Introduction

Population aging and health issues in older age groups

The aging of the population has long been a worldwide concern, and the problem is becoming more and more severe as time goes on. According to the latest data from the World Health Organization, the number and proportion of people aged 60 and over is increasing. In 2019, the number of people aged 60 and overreached 1 billion. By 2030, this number will increase to 1.4 billion and by 2050 to 2.1 billion (1). The growth of the older population is happening at an unprecedented rate, especially in developing countries. As a developing country, China is also amidst a wave of population aging. According to China's seventh population census, the number of people aged 60 and over in China will be 260 million by 2020, accounting for 18.7% of the total population (2). At the same time, China has the fastest recorded growth rate for its old people population (3).

The accelerating aging of the population makes the health of older people a fundamental challenge for society to face. The health problems of old people are not only related to the decline in physical functions and the susceptibility to more physical illnesses (4) but also to mental health. Research has shown that the growth of the older population means an immediate increase in age-related illnesses, for example, dementia, and poor mental health outcomes, such as depression, anxiety, suicide, and severe constraints on the quality of life of older people (5). In addition, health problems in older age groups not only mean greater physical and mental suffering for older people themselves but also hurt other family members (6), directly affecting the rising cost of health care (7), increasing the burden of care on society and the cost of health care (8). Therefore, it is important to pay attention to the physical and mental health of the old people population against the backdrop of the increasingly brutal reality of the aging situation.

The relationship between media use and health in older age groups

Media use is defined as the public's daily use and exposure to media, including the frequency, duration, type, and attention of certain media (9). According to the trend of media development, the use of media can be divided into the use of traditional media (such as television, radio, newspapers, magazines, etc.) and internet media use (such as computers, networks, etc.) (10). Since media use always starts at a specific point in time and ends at a specific point in time, there are relatively clear starting and ending points and corresponding intervals (11). Therefore, media use can be measured. Retrospective self-reports have been found to have moderately high correlations with other benchmark measures in previous studies, where retrospective self-reports have been the primary measure of media use (11). It provides a prerequisite for measuring the media use behavior of old people.

Along with the continuous development of information technology in society, the influence of media on people's lives is increasing. While most older people are accustomed to using traditional media (12), the growing popularity of the internet access environment has increased the exposure of older people to the internet. According to the 47th Statistical Report on Internet Development in China released by the China Internet Network Information Center, the proportion of old internet users in China reached about 260 million as of December 2020, accounting for 18.4% of the total population (13). As a result, older people enjoy a wide range of media exposure, and both traditional and internet media have made inroads into their life. The number of older people in society has been steadily increasing (14), and so has the interest of communication scholars in the media use of this group. While much research in health communication suggests that media use can influence people's health (15), opinions on the impact of media use on older age groups' health outcomes are varied.

On the one hand, some scholars argue that media use can improve the physical health of older age groups. The use of traditional media such as television, radio, and newspapers, for example, can prevent negative changes in the health-related behavior of older people (16). Not only can internet media effectively improve the physical health of older adults by providing online medical services (17) and health information interventions (18), but internet use has also been shown to significantly increase subjective well-being and life satisfaction, as well as improve the mental health of older adults (12). A study of older adults in China found that internet use may empower them to maintain close intergenerational relationships contributing to their subjective well-being. On the other hand, many other academics have become concerned about the negative impact of media use on older people's physical and mental health. As older people age, limited mobility and geographical distance from relatives make them more likely to feel isolated (19). Because the internet can meet many needs at home, research reveals that it can lead to a loss in offline social activities, leading to less social support for older persons (20) and poor physical and mental health (21). In addition, there is a problem with media content that stereotypes the age of older people, and a study based on the impact of media on older people's mental health showed that such harmful media content could lead to a significant deterioration in older people's mental health, making them more anxious and less calm (22). In addition, there is a problem with media content that stereotypes the age of older people, and a study based on the impact of media on older people's mental health showed that such harmful media content could lead to a significant deterioration in older people's mental health, making them more anxious and less calm (22). Therefore, it is necessary to explore further the relationship between the use of different media types and the physical and mental health of the elderly population and the reasons for the inconsistency with the conclusions of previous studies. We ask questions in this study:

RQ1: What are the associations between different types of media use and older adults' physical and mental health?

From the "digital divide" to the "health divide" in older age groups

Health communication research has focused not only on the association between media use and health outcomes of older age groups but also on differences in access to and ability to use new information technologies and their further impact on health. Research has shown that older adults experience difficulties adapting to digital lifestyles (23). The digital divide among older people, also known as the silver digital divide, manifests itself in the accessibility of older people's networks and the differences in usage once they are accessed (24). Scholars have used research to reveal possible reasons for the digital divide among older people. On the one hand, age is an important factor influencing older people's media use. Research confirms significant digital divide differences across age groups (25). Lee et al.'s study points to different barriers to digital access and uses for older people at different ages (26). On the other hand, socioeconomic status is also an important factor in determining media access and use. Older age groups are unequal in terms of socioeconomic status (27), and older people with higher education and income levels are more likely to use the internet (28, 29).

This "digital divide" in media use disparities poses several problems for older people daily and even affects their physical and mental health (30). On the one hand, old people persons without access to online technology are unable to obtain timely and accurate health information through internet media and benefit from the ease of online medical services. On the other hand, the technological threshold of the internet disconnects older people from social life, further strengthening their sense of isolation and weakening their sense of social support, thus creating perceived isolation (31). In summary, the digital divide further contributes to the health divide, with differences in media use leading to inequalities in health outcomes.

While the link between differences in socioeconomic status leading to differences in media use and hence health inequalities is well established, whether media use predicts differences in health outcomes between older socioeconomic groups remains to be investigated, and whether different types of media use widen or narrow the health disparities between older socioeconomic groups? The knowledge gap hypothesis offers a possible methodological contribution to addressing this question. The "knowledge gap' hypothesis, proposed by Tichenor in the 1970s, suggested that disseminating media ' information would increase the knowledge gap between people of different socioeconomic statuses (class). People with higher education levels are more capable of acquiring new information than those with lower education levels. With the increased media information over time, people with higher education levels will get more helpful information, extending the "knowledge gap" between the two classes (32). Previous studies have used education level as a measure of socioeconomic status, with domain-specific knowledge as the dependent variable and the product term of education and different types of media use as the independent variable, to predict whether different types of media use can significantly predict the knowledge gap between different educated groups (33, 34). Health inequalities are defined as health disparities systematically related to social advantages/disadvantages such as educational attainment, wealth, and power (35). Socioeconomic status (SES) is an aggregate measure of economic and social status based on factors such as income, education, and occupation (36). It has a 'cumulative effect' on people's health status, i.e., people who are chronically advantaged (or disadvantaged) have better (or worse) levels of health (37). Therefore, in this study, we focus on the impacts of media use on the 'socioeconomic status-health level' link to explore the impacts of media use on health disparities between older people of different socioeconomic status groups. Thus, we raise research questions:

RQ2: Does the use of different media types significantly predict physical and mental health differences in older age groups with different levels of education?

RQ3: If significantly predictable, does media use widen or narrow physical and mental health disparities in older age groups with different levels of education?

Methods

Data sources

The data used in this study are from the 2017 China General Social Survey (CGSS). The CGSS is implemented by the National Survey Research Center at Renmin University of China (NSRC) and is the most nationally representative comprehensive social survey project in China. The CGSS survey uses a stratified and staged probability sampling method to choose the sample, covering residents of 31 provinces, autonomous regions, and municipalities directly under the Central Government (excluding Hong Kong Special Administrative Region, Macau Special Administrative Region, and Taiwan). The 2017 CGSS sample data included a valid sample of 12,582. It is worth noting that CGSS 2017 added a new question on residents' use of the internet compared to previously released CGSS data, which provides the basis for this study to investigate the internet media use of the old people population. Due to the differences in health care and living standards in different parts of the world, the age classification of the old people population varies. This study sets the starting age standard for older people at 60 by the provisions in the Law on the Protection of the Rights and Interests of the Old people promulgated by the Chinese government (38). This study selected data related to older people aged 60 years and above in the CGSS survey. After excluding data with missing values and outliers, a final valid sample of 3,878 was obtained.

Variables selection

Dependent variable

In this study, self-rated physical health and subjective well-being were selected as indicators to measure the health of older people, taking into account the existing literature (39). At the physical level, self-rated physical health refers to an individual's subjective personal perception of their overall health (40). It is one of the common indicators used to measure the health status of a population (41). Research has shown that there is consistency between self-rated health and objective health. Self-rated health measures are good indicators of self-assessed health status (42). Therefore, this study used this variable to observe and assess older people's physical health levels. At the psychological level, subjective well-being is an essential indicator of older people's mental health (43). At the psychological level, subjective well-being is an important indicator for measuring the mental health of old people. Subjective well-being is defined as an individual's self-evaluation of their life. Subjective well-being is related to a person's perception and cognition of their quality of life and is considered a fundamental element of positive mental health (44). Self-rated health was measured by a single item respectively. Respondents were asked to reply to the question "what do you think of your current state of physical health," and the variable in this study was coded 1–5 as "very unhealthy," "less healthy," "generally," "healthy," and "very healthy." The five-point Likert-type scale measured subjective well-being for the question: "In general, do you think your life is happy?" with responses including: "1(very unhappy)", "2(unhappy)", "3(general)", "4 (happy)", "5 (very happy)".

Independent variable

In this paper, we refer to the existing literature (45) and choose education level as an indicator of socioeconomic status. The CGSS 2017 asked for the highest education of the participants. The educational attainment variable in this study was recorded in the range of "Uneducated" (=0), "Primary school" (=1), "Middle school" (=2), "High school/Technical secondary school" (=3), "Junior college" (=4), "Bachelor's degree and above" (=5).

Media use is defined as "the extent to which an audience is exposed to a particular message or type of media content" (46). This study divided media use into traditional media use (newspapers, magazines, radio, television) and internet media use. In the CGSS, participants were asked to report their media use in the past year on a five-point scale, with responses including: "1 (never)", "2 (rarely)", "3 (sometimes)", "4 (often)", "5 (always)."

Control variables

As previous empirical studies have shown that many demographic variables (43, 47, 48) are associated with health levels, several demographic variables were set as control variables in this study. Individual characteristics control variables were as follows: (1) Gender (male coded as 1, female coded as 0). (2) Age. (3) Household registration (Agri-cultural account coded as 1, Non-agricultural account coded as 0). (4) Household income in 2016 (This variable is taken as the natural logarithm, considering that income on fertility intentions may be non-linear, with the squared term of total annual household income added to the regression).

Data analysis

Data from a total of 3,878 valid samples were used for analysis. We checked for outliers and multicollinearity before analysis and recoded variables and centered scores to fit the study design. Descriptive statistics, analysis of variance (ANOVA), bivariate correlation analysis, *post hoc* analysis, and multilevel regression analysis were used in this study. Descriptive statistics describe older individuals' education, media use, and physical and mental health. ANOVA and *post hoc* analysis were used to analyze the differences in the physical and mental health levels of older people with different levels of education. Bivariate correlation and regression analyses explored associations between media use and mental and physical health in older adults. Multilevel regression analyses with simple slope plots explored whether the use of different media types widened or narrowed the gap in health levels between older people with different levels of education. All statistical analyses were conducted using SPSS 26.0. *P*-values are two-sided, and values < 0.05 were considered statistically significant.

TABLE 1 Sociodemographic information of the participants (*N* = 3,878).

Variable	*N* (%) or Mean ± SD
Gender	
Male	1,910 (49.25)
Female	1,968 (50.75)
Age (year)	69.214±7.310
Total household income in 2016 (CNY)	
No more than 10,000 yuan	1,039 (26.8)
10,000–30,000 yuan	802 (20.7)
30,001–80,000 yuan	1,287 (33.2)
80,001–150,000 yuan	589 (15.2)
Over 150,000 yuan	161 (4.1)
Education level	
Uneducated	901 (23.23)
Primary school	1,270 (32.75)
Middle school	959 (24.73)
High school/Technical secondary school	472 (12.17)
Junior college	163(4.2)
Bachelor's degree and above	113 (2.91)
Household register	
Agriculture account	1,983 (51.13)
Non-agricultural account	1,895 (48.87)
Self-rated health	2.986 ± 1.070
Subjective well-being	3.908 ± 0.854

Results

Descriptive analysis

The demographic information of the 3,878 samples is shown in Table 1, which reveals that the self-rated health levels (M = 2.986, SD = 1.070) is lower in the old people group relative to subjective well-being (M = 3.908, SD = 0.854).

The media use of the older age group is shown in Table 2. Older people use both paper and broadcast media infrequently but have relatively high access to television, with the combined percentage of often and always choices (77.08%) being the vast majority. Most older people had never used the internet (76.79%), with only 23.21% having access.

The ANOVA results showed significant differences in traditional media use, internet media use, self-rated physical health, and subjective well-being in terms of education level ($p < 0.01$). Table 3 shows the results of the ANOVA for education level and other variables. The frequency of traditional media use (M = 3.11, SD = 0.84), internet media use (M = 3.25, SD = 1.65), self-rated physical health (M = 3.43, SD = 0.92), and subjective well-being (M = 4.05, SD = 0.73) were the highest for the older adults with the highest degree of junior college compared to the other education groups. The frequency of traditional media use (M = 1.80, SD = 0.50), internet media use (M = 1.06, SD = 0.39), self-rated physical health (M = 2.68, SD = 1.07), and subjective well-being (M = 3.73, SD = 0.95) were the lowest for the uneducated older adults compared to the other education groups.

It can be found from Table 3 that different education level samples for traditional media use, internet media use, self-rated physical health, and subjective well-being all showed significance ($p < 0.01$), which means the different education level samples for traditional media use, internet media use, physical health, and mental health are different. The *post hoc* analysis needs to be performed. The results of *post hoc* analysis are shown in Table 4. The education level shows a significant level of 0.01 ($F = 287.273$, $p < 0.01$) for the traditional media use, and the average score comparison results of the groups with significant differences was "Primary school > Uneducated; Middle school > Uneducated; High school/Technical secondary school > Uneducated; Junior college > Uneducated; Bachelor's degree and above> Uneducated; Middle school > Primary school; High school/Technical secondary school > Primary school; Junior college > Primary school; Junior college > Primary school; Bachelor's degree and above > Primary school; High school/Technical secondary school > Middle school; Junior

TABLE 2 Descriptive statistics of participants' media use ($N = 3,878$).

Items	Never n (%)	Rarely n (%)	Sometimes n (%)	Often n (%)	Always n (%)
1. Newspaper media use	2,362 (60.91)	540 (13.92)	331 (8.54)	324 (8.35)	321 (8.28)
2. Magazine media use	2,753 (70.99)	587 (15.14)	289 (7.45)	195 (5.03)	54 (1.39)
3. Broadcast media use	2,329 (60.06)	508 (13.1)	425 (10.96)	369 (9.52)	247 (6.37)
4. Television media use	169 (4.36)	236 (6.09)	484 (12.48)	1,370 (35.33)	1,619 (41.75)
5. Internet media use	2,974 (76.69)	199 (5.13)	156 (4.02)	286 (7.37)	263 (6.78)

TABLE 3 Results of variance analysis.

	Education level (Mean ± SD)						F	p
	Uneducated ($n = 901$)	Primary school ($n = 1,270$)	Middle school ($n = 959$)	High school/Technical secondary school ($n = 472$)	Junior college ($n = 163$)	Bachelor's degree and above ($n = 113$)		
Traditional media use	1.80 ± 0.50	2.13 ± 0.62	2.62 ± 0.79	2.87 ± 0.84	3.11 ± 0.84	3.07 ± 0.87	287.27	$p < 0.01$**
Internet media use	1.06 ± 0.39	1.20 ± 0.72	1.86 ± 1.39	2.49 ± 1.60	3.25 ± 1.65	2.96 ± 1.55	263.67	$p < 0.01$**
Self-rated physical health	2.68 ± 1.07	2.89 ± 1.07	3.13 ± 1.04	3.29 ± 0.99	3.43 ± 0.92	3.35 ± 1.02	38.127	$p < 0.01$**
Subjective well-being	3.73 ± 0.95	3.90 ± 0.85	3.99 ± 0.80	4.01 ± 0.77	4.07 ± 0.73	4.05 ± 0.75	13.002	$p < 0.01$**

**p < 0.01.

college > Middle school; Bachelor's degree and above > Middle school; Junior college > High school/Technical secondary school; Bachelor's degree and above > High school/Technical secondary school." The education level shows a significant level of 0.01 ($F = 263.67$, $p < 0.01$) for internet media use, and the average score comparison results of the groups with significant differences were "Primary school > Uneducated; Middle school > Uneducated; High school/Technical secondary school > Uneducated; Junior college > Uneducated; Bachelor's degree and above > Uneducated; Middle school > Primary school; High school/Technical secondary school > Primary school; Junior college > Primary school; Junior college > Primary school; Bachelor's degree and above > Primary school; High school/Technical secondary school > Middle school; Junior college > Middle school; Bachelor's degree and above > Middle school; Junior college > High school/Technical secondary school; Bachelor's degree and above > High school/Technical secondary school; Junior college > Bachelor's degree and above." The education level shows a significant level of 0.01 ($F = 38.127$, $p < 0.01$) for self-rated physical health, and the average score comparison results of the groups with significant differences were "Primary school > Uneducated; Middle school > Uneducated; High school/Technical secondary school > Uneducated; Junior college > Uneducated; Bachelor's degree and above> Uneducated; Middle school > Primary school; High school/Technical secondary school > Primary school; Junior college > Primary school; Junior college > Primary school; Bachelor's degree and above > Primary school; High school/Technical secondary school > Middle school; Junior college > Middle school; Bachelor's degree and above > Middle school." The education level shows a significant level of 0.01 ($F = 13.002$, $p < 0.001$) for subjective well-being, and the average score comparison results of the groups with significant differences were "Primary school > Uneducated; Middle school > Uneducated; High school/Technical secondary school > Uneducated; Junior college > Uneducated; Bachelor's degree and above> Uneducated; Middle school > Primary school; High school/Technical secondary school > Primary school; Junior college > Primary school; Junior college > Primary school."

Preliminary analysis

Bivariate correlation analysis (Table 5) showed that there was a significant positive correlation ($p < 0.01$) between the level of education, frequency of traditional media use, frequency

TABLE 4 Results of *post hoc* analysis.

	(I)Item	(J)Item	(I)Mean	(J)Mean	Difference value (I-J)	*p*
Traditional media use	0	1	1.799	2.127	−0.328	$p < 0.01$**
	0	2	1.799	2.623	−0.824	$p < 0.01$**
	0	3	1.799	2.867	−1.068	$p < 0.01$**
	0	4	1.799	3.109	−1.31	$p < 0.01$**
	0	5	1.799	3.071	−1.272	$p < 0.01$**
	1	2	2.127	2.623	−0.496	$p < 0.01$**
	1	3	2.127	2.867	−0.739	$p < 0.01$**
	1	4	2.127	3.109	−0.982	$p < 0.01$**
	1	5	2.127	3.071	−0.944	$p < 0.01$**
	2	3	2.623	2.867	−0.243	$p < 0.01$**
	2	4	2.623	3.109	−0.486	$p < 0.01$**
	2	5	2.623	3.071	−0.447	$p < 0.01$**
	3	4	2.867	3.109	−0.242	$p < 0.01$**
	3	5	2.867	3.071	−0.204	$p < 0.01$**
	4	5	3.109	3.071	0.038	0.652
Online media use	0	1	1.059	1.201	−0.142	0.003**
	0	2	1.059	1.86	−0.801	$p < 0.01$**
	0	3	1.059	2.485	−1.426	$p < 0.01$**
	0	4	1.059	3.245	−2.187	$p < 0.01$**
	0	5	1.059	2.956	−1.897	$p < 0.01$**
	1	2	1.201	1.86	−0.659	$p < 0.01$**
	1	3	1.201	2.485	−1.284	$p < 0.01$**
	1	4	1.201	3.245	−2.045	$p < 0.01$**
	1	5	1.201	2.956	−1.755	$p < 0.01$**
	2	3	1.86	2.485	−0.625	$p < 0.01$**
	2	4	1.86	3.245	−1.385	$p < 0.01$**
	2	5	1.86	2.956	−1.095	$p < 0.01$**
	3	4	2.485	3.245	−0.76	$p < 0.01$**
	3	5	2.485	2.956	−0.471	$p < 0.01$**
	4	5	3.245	2.956	0.29	0.029*
Self-rated physical health	0	1	2.677	2.891	−0.214	$p < 0.01$**
	0	2	2.677	3.135	−0.457	$p < 0.01$**
	0	3	2.677	3.288	−0.611	$p < 0.01$**
	0	4	2.677	3.429	−0.752	$p < 0.01$**
	0	5	2.677	3.345	−0.668	$p < 0.01$**
	1	2	2.891	3.135	−0.243	$p < 0.01$**
	1	3	2.891	3.288	−0.397	$p < 0.01$**
	1	4	2.891	3.429	−0.538	$p < 0.01$**
	1	5	2.891	3.345	−0.454	$p < 0.01$**
	2	3	3.135	3.288	−0.154	0.009**
	2	4	3.135	3.429	−0.295	0.001**
	2	5	3.135	3.345	−0.211	0.043*
	3	4	3.288	3.429	−0.141	0.137
	3	5	3.288	3.345	−0.057	0.603
	4	5	3.429	3.345	0.084	0.51

(Continued)

TABLE 4 (Continued)

	(I)Item	(J)Item	(I)Mean	(J)Mean	Difference value (I-J)	*p*
Subjective well-being	0	1	3.731	3.897	−0.165	$p < 0.01^{**}$
	0	2	3.731	3.991	−0.259	$p < 0.01^{**}$
	0	3	3.731	4.015	−0.283	$p < 0.01^{**}$
	0	4	3.731	4.067	−0.336	$p < 0.01^{**}$
	0	5	3.731	4.053	−0.322	$p < 0.01^{**}$
	1	2	3.897	3.991	−0.094	0.010**
	1	3	3.897	4.015	−0.118	0.010**
	1	4	3.897	4.067	−0.171	0.016*
	1	5	3.897	4.053	−0.156	0.061
	2	3	3.991	4.015	−0.024	0.611
	2	4	3.991	4.067	−0.077	0.285
	2	5	3.991	4.053	−0.062	0.459
	3	4	4.015	4.067	−0.053	0.494
	3	5	4.015	4.053	−0.038	0.666
	4	5	4.067	4.053	0.014	0.89

*p < 0.05; **p < 0.01, 0 = Uneducated, 1 = Primary school, 2 = Middle school, 3 = High school/Technical secondary school, 4 = Junior college, 5 = Bachelor's degree and above.

of internet media use, and self-rated physical health. Bivariate correlation analysis (Table 6) showed that there was a significant positive correlation between education level, frequency of traditional media use, frequency of internet media use, and subjective well-being ($p < 0.01$).

Further linear regression analysis was conducted based on bivariate correlation analysis (see Table 7). Model 1, with self-rated physical health as the dependent variable, explained 8.5% of the total variance in the outcome variable. Model 2, with subjective well-being as the dependent variable, explained 5.8% of the outcome variable. The linear regression results for Model 1 indicated that education level ($B = 0.036$, $P < 0.05$), frequency of traditional media use ($B = 0.1$, $P < 0.01$), and frequency of internet media use ($B = 0.052$, $P < 0.01$), were significant positive predictors of self-rated physical health in the older age group. The linear regression results of Model 2 indicated that the frequency of traditional media use ($B = 0.165$, $P < 0.01$) was a significant positive predictor of the subjective well-being of older people.

Impact of media use on physical and mental health disparities

To examine whether different types of media use widen or narrow the physical and mental health gap among older people with different levels of education. This study examined the effect of different types of media use on the 'education level-physical and mental health link through multilevel regression analysis using an interaction effects model. Thus, Table 8 shows the multilevel regression model "a" when the interaction variable is Education*Frequency of traditional media use, and the dependent variable is self-rated physical health. Table 9 shows the multilevel regression model "b" when the interaction variable is Education*Frequency of internet media use, and the dependent variable is self-rated physical health. Table 10 shows the multilevel regression model "c" when the interaction variable is Education*Frequency of traditional media use, and the dependent variable is subjective well-being. Table 11 shows the multilevel regression model "d" when the interaction variable is Education*Frequency of internet media use, and the dependent variable is subjective well-being. The multilevel regression model is performed as follows: first, the independent variables are mean-centered; second, the control variable, educational attainment, is entered into block 1; second, media use is entered into block 2; and finally, the interaction variable is entered into block 3.

The results in Table 8 show that the product term of education level and frequency of traditional media use is significant. The frequency of traditional media uses significantly predicts physical health disparities due to different levels of education.

The effect of the frequency of traditional media use on the physical health disparities due to different levels of education is further shown by plotting a simple slope diagram (see Figure 1). The increased frequency of traditional media uses further narrowed the physical health disparities between the highly educated old people group and the less educated old people group. In other words, the greater the use of traditional media, the

TABLE 5 Bivariate correlation between self-rated health and other variables.

	Self-rated health	Age	Gender (male)	Household register (Agriculture)	Total household income	Education level	Traditional media use
Age	−0.052**						
Gender (male)	0.098**	−0.007					
Household register (Agriculture)	−0.174**	−0.085**	0.017				
Total household income	0.248**	−0.036*	−0.014	−0.549**			
Education level	0.210**	−0.097**	0.202**	−0.519**	0.445**		
Traditional media use	0.200**	0.03	0.117**	−0.467**	0.401**	0.504**	
Internet media use	0.183**	−0.188**	0.056**	−0.390**	0.373**	0.485**	0.327**

*p < 0.05; **p < 0.01.

TABLE 6 Bivariate correlation between subjective well-being and other variables.

	Subjective well-being	Age	Gender (male)	Household register (Agriculture)	Total household income	Education level	Traditional media use
Age	0.075**						
Gender (male)	−0.017	−0.007					
Household register (Agriculture)	−0.127**	−0.085**	0.017				
Total household income	0.175**	−0.036*	−0.014	−0.549**			
Education level	0.116**	−0.097**	0.202**	−0.519**	0.445**		
Traditional media use	0.201**	0.03	0.117**	−0.467**	0.401**	0.504**	
Internet media use	0.073**	−0.188**	0.056**	−0.390**	0.373**	0.485**	0.327**

*p < 0.05; **p < 0.01.

TABLE 7 Linear regression analysis results.

	Model 1		Model 2	
	B	SE	B	SE
Constant	1.98**	0.207	2.427**	0.168
Age	0.161**	0.035	−0.076**	0.028
Gender (male)	−0.004	0.002	0.009**	0.002
Household register (Agriculture)	0.043	0.045	0.068	0.037
Total household income	0.038**	0.004	0.022**	0.003
Education level	0.036*	0.018	0.01	0.015
Traditional media use	0.1**	0.025	0.165**	0.02
Internet media use	0.052**	0.016	−0.002	0.013
R^2	0.085		0.058	
Adjusted R^2	0.084		0.056	
F	F (7,3706) = 49.463, p = 0.000		F (7,3706) = 32.615, p = 0.000	
Dependent variable	Self-rated health		Subjective well-being	

*p < 0.05; **p < 0.01.

smaller the physical health disparities between older adults with higher education and those with lower education ($B = -0.069$, $p < 0.01$).

The results in Table 9 show that the product term of education level and frequency of internet media use is significant. The frequency of

TABLE 8 Results of hierarchical regression analysis a.

	Block 1		Block 2		Block 3	
	B	SE	B	SE	B	SE
Constant	2.406**	0.196	2.481**	0.196	2.441**	0.196
Gender (male)	0.169**	0.035	0.159**	0.035	0.145**	0.035
Age	−0.005*	0.002	−0.005*	0.002	−0.004	0.002
Household register (Agriculture)	−0.014	0.044	0.023	0.045	0.048	0.045
Total household income	0.042**	0.004	0.04**	0.004	0.04**	0.004
Education level	0.074**	0.017	0.052**	0.017	0.065**	0.018
Traditional media use			0.105**	0.025	0.132**	0.026
Education*Traditional media use					−0.069**	0.017
R^2	0.078		0.083		0.087	
adjust R^2	0.077		0.081		0.085	
F	$F_{(5, 3,708)} = 63.047, p = 0.000$		$F_{(6, 3,707)} = 55.715, p = 0.000$		$F_{(7, 3,706)} = 50.450, p = 0.000$	
Dependent variable			Self-rated health			

*p < 0.05; **p < 0.01.

TABLE 9 Results of hierarchical regression analysis b.

	Block 1		Block 2		Block 3	
	B	SE	B	SE	B	SE
Constant	2.403**	0.196	2.312**	0.197	2.306**	0.197
Gender (male)	0.169**	0.035	0.17**	0.035	0.164**	0.035
Age	−0.005*	0.002	−0.003	0.002	−0.003	0.002
Household register (Agriculture)	−0.014	0.044	0.009	0.044	0.025	0.045
Total household income	0.042**	0.004	0.041**	0.004	0.04**	0.004
Education level	0.074**	0.017	0.055**	0.017	0.062**	0.018
Internet media use			0.056**	0.016	0.087**	0.019
Education*Internet media use				−0.031**	0.011	
R^2	0.078		0.081		0.083	
adjust R^2	0.077		0.08		0.082	
F	$F_{(5, 3,708)} = 63.047, p = 0.000$		$F_{(6, 3,707)} = 54.813, p = 0.000$		$F_{(7, 3,706)} = 48.087, p = 0.000$	
Dependent variable			Self-rated health			

*p < 0.05; **p < 0.01.

internet media use is a significant predictor of physical health disparities due to different levels of education.

The effect of internet media use frequency on the physical health disparities due to different levels of education is further shown by plotting a simple slope graph (see Figure 2). The increased frequency of internet media uses further narrowed the physical health disparities between the highly educated older adult group and the less educated older adult group. In other words, the greater the use of internet media, the smaller the physical health disparities between older adults with higher education and those with lower education ($B = -0.031$, $p < 0.01$).

The results in Table 10 show that the product term of education level and frequency of traditional media use is significant. The frequency of traditional media uses significantly predicts mental health disparities due to different levels of education.

The effect of the frequency of traditional media use on the mental health disparities due to different levels of education is further shown by plotting a simple slope graph (see Figure 3). The increased frequency of traditional media uses further narrowed the mental health disparities between the highly educated older adult group and the less educated older adult group. In other words, the greater the use of traditional media, the smaller the mental health disparities between older adults

TABLE 10 Results of hierarchical regression analysis c.

	Block 1		Block 2		Block 3	
	B	SE	B	SE	B	SE
Constant	2.715**	0.16	2.83**	0.159	2.787**	0.159
Gender (male)	−0.061*	0.028	−0.076**	0.028	−0.092**	0.028
Age	0.01**	0.002	0.009**	0.002	0.011**	0.002
Household register (Agriculture)	0.011	0.036	0.069	0.036	0.094**	0.036
Total household income	0.025**	0.003	0.022**	0.003	0.021**	0.003
Education level	0.043**	0.014	0.009	0.014	0.023	0.014
Traditional media use			0.165**	0.02	0.196**	0.021
education*Traditional media use				−0.072**	0.013	
R^2	0.041		0.058		0.083	
Adjust R^2	0.04		0.056		0.082	
F	$F_{(5, 3,708)} = 31.899, p = 0.000$		$F_{(6, 3,707)} = 38.057, p = 0.000$		$F_{(7, 3,706)} = 48.087, p = 0.000$	
Dependent variable			Subjective well-being			

*p < 0.05; **p < 0.01.

TABLE 11 Results of hierarchical regression analysis d.

	Block 1		Block 2		Block 3	
	B	SE	B	SE	B	SE
Constant	2.715**	0.16	2.708**	0.161	2.705**	0.161
Gender (male)	−0.061*	0.028	−0.061*	0.028	−0.065*	0.028
Age	0.01**	0.002	0.011**	0.002	0.011**	0.002
Household register (Agriculture)	0.011	0.036	0.013	0.036	0.022	0.037
Total household income	0.025**	0.003	0.025**	0.003	0.025**	0.003
Education level	0.043**	0.014	0.042**	0.014	0.045**	0.014
Internet media use			0.004	0.013	0.023	0.016
education*Internet media use				−0.019*	0.009	
R^2	0.041		0.041		0.042	
Adjust R^2	0.04		0.04		0.04	
F	$F_{(5, 3,708)} = 31.899, p = 0.000$		$F_{(6, 3,707)} = 26.593, p = 0.000$		$F_{(7, 3,706)} = 23.374, p = 0.000$	
Dependent variable			Subjective well-being			

*p < 0.05; **p < 0.01.

with higher education and those with lower education (B = −0.072, $p < 0.01$).

The results in Table 11 show that the product term of education level and frequency of internet media use is significant. The frequency of internet media use significantly predicts mental health disparities due to different levels of education.

The effect of internet media use frequency on mental health disparities due to different levels of education is further shown by plotting a simple slope graph (see Figure 4). The increased frequency of internet media uses further narrowed the mental health disparities between the highly educated older adult group and the less educated older adult group. In other words, the greater the use of internet media, the smaller the mental health disparities between older adults with higher education and older adults with lower education (B = −0.019, $p < 0.05$).

Discussion

Based on nationally representative data, this paper investigated the use of different media types among old people, the correlation between the use of different media types and physical and mental health, and the impact of different media type use on physical and mental health disparities among elderly groups with different educational backgrounds. Furthermore, the health disparity problem was displayed through a simple slope graph. We found an

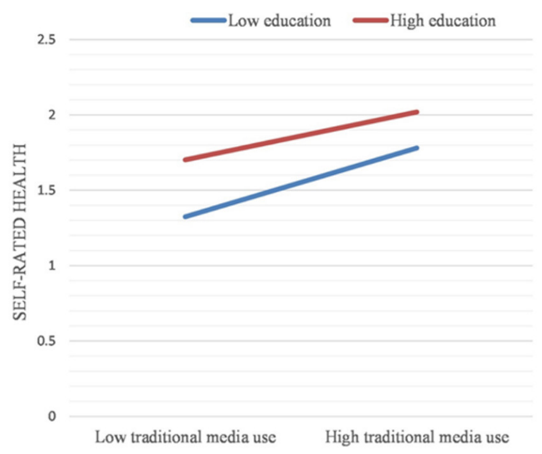

FIGURE 1
Simple slope plot for the interaction between traditional media use and education (Dependent variables: Self-rated health).

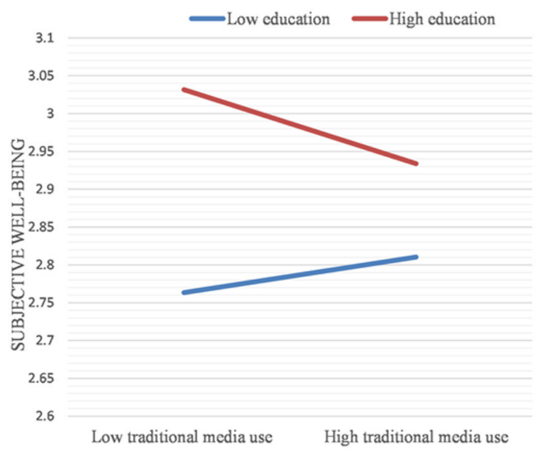

FIGURE 3
Simple slope plot for the interaction between traditional media use and education (Dependent variables: Subjective well-being).

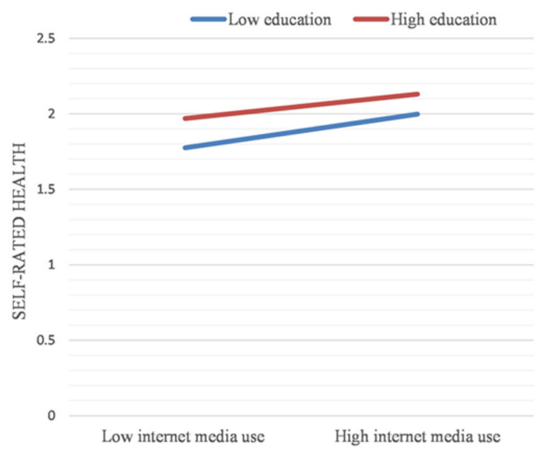

FIGURE 2
Simple slope plot for the interaction between internet media use and education (Dependent variables: Self-rated health).

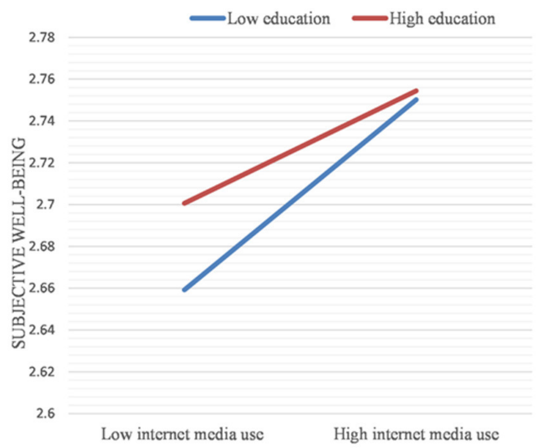

FIGURE 4
Simple slope plot for the interaction between internet media use and education (Dependent variables: Subjective well-being).

important correlation between media use and health in older adults based on the results. Specifically, traditional media use was an important indicator that significantly and positively predicted the physical and mental health of the old people, while internet media could only positively predict the physical health of the old people. In addition, traditional and internet media use could significantly predict physical and mental health disparities among old people with different educational backgrounds. Both traditional media use and internet use media have narrowed the physical and mental health disparities between elderly groups with different educational backgrounds. Finally, we used our findings and available literature to make recommendations for closing health disparities in old people and promoting health and well-being in the elderly population.

Media use and the health of older people

Firstly, we investigated media use among older adults. The media usage of the old people in Table 2 is consistent with the existing research results. Although some older people have mastered internet media, most elderly groups are more accustomed to using traditional media. However, literature of recent years has focused on the use of internet media and social media and the consequences of media use for old people (49, 50), and most of the research on traditional media use by old people is still carried out in the last century (51). The results of this study show that in the current media environment, traditional media still plays an essential role in the lifestyle of old people. Therefore, whether it is traditional or internet media, we suggest that future research needs to analyze the media use behavior of old people in the current media environment more comprehensively.

Secondly, this study found that traditional media use was a significant positive predictor of physical and mental health in the older age group, consistent with previous research findings (16). Media use behavior primarily reflects the socioeconomic status of users (52). However, due to the relative popularity of traditional media use among old people (Table 2), we speculate that this may be related to the social function of mass communication. The traditional media have proven to be very useful in effectively communicating health information (53), and public health organizations can use traditional media to produce media content around health topics (54). In China, the credibility of traditional media is higher than that of social media (55), making it easier for most older people who use traditional media (12) to trust health information in traditional media. As media content affects people's perceptions, which can influence their attitudes and behaviors (56), thus traditional media use was a significant positive predictor of physical and mental health in the older age group.

In addition, this study also found that internet media use was an important indicator of a significantly positive prediction of the physical health of old people, which is also consistent with previous research conclusions. Previous research has found a significant positive correlation between the socioeconomic status of older adults and the frequency of Internet use (57). Research on the sociodemographic correlations of ICT (information and communications technology) use among older adults showed that the average user is younger, more educated, and has a higher income than the average non-user (58–60). The analysis of variance in this study (Table 3) also reflected this to some extent. The economic productivity and physical strength of older adults decline with age (61), and the association between socioeconomic status (SES) and physical health is fairly robust (62). Therefore, the frequency of internet media usage is one of the indicators reflecting socioeconomic status (52). Compared with the old people with lower socioeconomic status, the old people with higher socioeconomic status have a higher frequency of internet media use, and their self-rated physical health level is also higher. In this study, internet media use did not significantly predict mental health in older age groups. We offer two possible explanations for this. First, conclusions about the benefits of internet media use on older adults' mental health and well-being may be premature or overstated, consistent with established conclusions. For example, the results of a meta-analysis showed that computer or internet training did not affect the well-being of older adults (63). Second, we believe that assertions that socioeconomic status significantly positively affects older adults' mental health may be premature. It is reflected in some studies' findings that there is no significant association between socioeconomic status and depression in older adults (64, 65). Therefore, although their socioeconomic status reflects the internet use behavior of the old people, the internet use frequency of the old people cannot positively and significantly predict their mental health.

The role of media use on physical and mental health disparities in older age groups

Another finding of this study was that traditional and internet media use significantly predicted the physical and mental health disparities between older people with different education levels. Traditional and internet media use narrowed the physical and mental health disparities between older people with different education levels. The ceiling effect theory offers the possibility of explaining that traditional media use can narrow health disparities in older age groups. The ceiling effect theory states that there is no end to the individual's quest for specific knowledge, and once a particular "ceiling" is reached, the knowledge increase slows down or stops. Those with higher socioeconomic status acquire knowledge faster and reach their "ceiling" sooner; those with lower economic status increase their knowledge more slowly but eventually catch up with the former over time (66). Access to media information affects people's perceptions, which can influence attitudes and behaviors (67). There may also be a "ceiling effect" on access to health knowledge for older people with different education levels. Therefore, traditional media use can ultimately positively impact narrowing the physical and mental health disparities. Internet media plays a massive role in popularizing public health information for health information. The low-barrier nature of internet media allows health professionals and laypeople alike to produce health content on online platforms and use the internet to read, comment, and share it globally with the public through the internet (68). As a result, different educational groups have access to diverse health knowledge and ideas *via* the internet, explaining why internet media can narrow the physical and mental health disparities among older people. Social media has narrowed social inequalities caused by organizational size and social status (69). This study provides further evidence of the positive impact of internet media on narrowing health disparities in older age groups.

Recommendations for narrowing the physical and mental health disparities in older age groups

This study confirmed that traditional and internet media use significantly predicted physical and mental health disparities in older age groups with different education levels, so it is necessary to make recommendations for promoting equal healthy aging.

Firstly, the mass media plays a huge role in disseminating health information to the public regarding prevention, health risk reduction, and provision of medication (70). A study with traditional media pointed out that repeated coverage of the same topic increases the likelihood that media exposure to inactive people will eventually lead to that information (71). Therefore, traditional media should repeatedly promote important health issues relevant to older people so that health information is more equally accessible to different socioeconomic groups, reducing the health disparities between older people with different education levels.

Secondly, integrating the media with public health campaigns is also very important to promote the health and well-being of older adults. The main purpose of public health campaigns is to influence the behavior of individuals by recommending changes in their habits and encouraging preventive behaviors (72). Moreover, mass media campaigns have long been a tool for promoting public health (73). Government-related departments and public health organizations can leverage social media and its low-cost operation and capacity to increase campaign reach, making it a potential communication channel for equitable, healthy aging campaigns (74). In addition, forms such as community-organizing strategies, Internet-based education, and mass media advertising (75) can all be used for reference in the health promotion of old people.

Thirdly, as discussed earlier, the digital divide further contributes to creating a health divide, so bridging the digital divide in older age groups is important in reducing the health disparities between older age groups with different education levels. "Digital feedback" refers to the teaching of older generations by younger generations in terms of digital access, use, and literacy (76), which has proven to be an important factor in helping older groups to be able to use internet media (77). Therefore, it is necessary to encourage and create a family culture of "digital feedback" so that children are aware of the benefits of digital skills for older people, which will also enable more older people to use internet media to access health information and thus narrow the "digital divide". In addition, online emotional support is an essential factor contributing to older people's mental health, especially as the COVID-19 global pandemic continues, and strict social distancing measures may negatively impact access to emotional support in older age groups which in turn may affect health levels. Therefore, this study recommends that, on the one hand, individual disparities among older people from different socioeconomic status groups need to be taken into account. Different internet media education interventions need to be developed for older people from different backgrounds (age, gender, and education level) to help them improve their digital competence. On the other hand, not only is there a need to raise awareness of the need for younger generations to educate older generations about reverse digital education, but society and the children in the family also need to help older groups access effective online emotional support through internet media to promote their mental health.

Finally, evaluating the success of a public health campaign is critical. It helps policymakers to improve strategies and close existing gaps (78). Therefore, it is also important to evaluate the effects of health-promoting campaigns on older adults. Referring to the practice of Rafael Pinto et al. (79), we recommend that government-related departments and public health organizations develop the collection and evaluation of relevant media data so that decision-makers can obtain this information clearly and accurately, to promote health literacy education, media literacy education, and healthy aging strategies for the old people.

Conclusion

Based on a nationally representative sample of the CGSS 2017, this study examined the association between the frequency of different media use and older adults' physical and mental health. This paper used an interaction effects model combined with simple slope plots to explore whether different media types of use significantly predicted physical and mental health disparities in older adults at different levels of education. The findings suggested an essential correlation between media use and fitness levels. Traditional media use was a significant positive predictor of physical and mental health in the older age group. In comparison, internet media use only was a significant positive predictor of physical health in the older age group. Traditional and internet media use narrowed the physical and mental health disparities between older age groups with different education levels. This study draws on knowledge gap-related research to demonstrate the role of media use in reducing physical and mental health disparities among older people with different education levels. The findings of this study could provide recommendations for enhancing the health and well-being of older age groups and provide a reference point for promoting equal healthy aging from a media perspective.

Implications and limitations

This study has specific theoretical and practical implications. Firstly, with the help of the research on the knowledge gap, this study examined the physical and mental health disparities in older age groups and demonstrated the role of media use in reducing the physical and mental health disparities in older age groups with different education levels, which provides a reference point for promoting equal healthy aging. Secondly, with the acceleration of the aging process, the health of older people is a significant public health issue worldwide. An empirical study on a nationally representative sample of older people in China can provide an idea for promoting older people's health and addressing older people's health inequalities, which has some social significance.

In addition, there are some limitations to this study. Firstly, the measurement of socioeconomic status is very complex, and our use of the education levels variable to measure socioeconomic status, while feasible, still has limitations. Future data analysis could use a more comprehensive measure of socioeconomic status. Secondly, this study used secondary data with limited items, so we only included older people's education levels and media use as important influences on physical and mental health. Future studies could include more other influences. In addition, chronic health conditions and disability were not accounted for in the CGSS, so we could not include them as control variables in the analysis. Future research could avoid this limitation by collecting primary data. Finally, the cross-sectional data only allow possible interpretations of the causal relationship between media use and physical and mental health disparities. Therefore, future panel studies or supplementary data are recommended to assess the causal impact of media use on physical and mental health disparities.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: http://cgss.ruc.edu.cn/English/Home.htm.

Ethics statement

The studies involving human participants were reviewed and approved by the Institutional Review Board of Social Sciences and Humanities of Jinan University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

HW and XS designed the study and analyzed the data. HW, RW, and YY were involved in manuscript writing. YW revised the manuscript. All authors have read and approved the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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TYPE Original Research
PUBLISHED 26 September 2022
DOI 10.3389/fpubh.2022.969919

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OPEN ACCESS

EDITED BY
Gulzar H. Shah,
Georgia Southern University,
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REVIEWED BY
Robert Meves,
Santa Casa of São Paulo, Brazil
Wenle Li,
Xiamen University, China

*CORRESPONDENCE
Peng Zheng
zhengpenghymu@163.com

†These authors have contributed equally to this work

SPECIALTY SECTION
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

RECEIVED 15 June 2022
ACCEPTED 26 August 2022
PUBLISHED 26 September 2022

CITATION
Yang B, Gao L, Wang X, Wei J, Xia B, Liu X and Zheng P (2022) Application of supervised machine learning algorithms to predict the risk of hidden blood loss during the perioperative period in thoracolumbar burst fracture patients complicated with neurological compromise. *Front. Public Health* 10:969919. doi: 10.3389/fpubh.2022.969919

Application of supervised machine learning algorithms to predict the risk of hidden blood loss during the perioperative period in thoracolumbar burst fracture patients complicated with neurological compromise

Bo Yang[1†], Lin Gao[2†], Xingang Wang[1], Jianmin Wei[1], Bin Xia[1], Xiangwei Liu[2] and Peng Zheng[3*]

[1]Department of Orthopedics, Baoji City Hospital of Traditional Chinese Medicine, Baoji, China, [2]Department of Spine, School of Medicine, The Honghui-Hospital, Xi'an Jiaotong University, Xi'an, China, [3]Department of Cardiology, The First Affiliated Hospital of Nanjing Medical University, Nanjing, China

Background: Machine learning (ML) is a type of artificial intelligence (AI) and has been utilized in clinical research and practice to construct high-performing prediction models. Hidden blood loss (HBL) is prevalent during the perioperative period of spinal treatment and might result in a poor prognosis. The aim of this study was to develop a ML-based model for identifying perioperative HBL-related risk factors in patients with thoracolumbar burst fracture (TBF).

Methods: In this study, single-central TBF patients were chosen. The medical information on patients, including clinical characteristics, laboratory indicators, and surgery-related parameters, was extracted. After comparing various ML model algorithms, we selected the best model with high performance. The model was validated using the internal validation set before performing recursive feature elimination (RFE) to determine the importance of HBL-related risk factors. The area under the receiver operating characteristic (AUC) curve, accuracy (ACC), sensitivity, and specificity were reported as critical model measures for evaluating predictive performance.

Results: In this study, 62 (38.5%) of the 161 TBF patients were positive for HBL. There was a significant statistical difference in age, body mass index (BMI), diabetes, hypertension, Beta (percentage of vertebral restoration), duration of operation, and other pre-operative laboratory indicators between the HBL-positive and HBL-negative groups. Nine ML-based models were built and validated, with the Random Forest model having the greatest AUC in both the training set (0.905) and internal validation set (0.864). Furthermore, following RFE, age, duration of operation, Beta, pre-operative fibrinogen (Fib), and activated partial thromboplastin time (APTT) were identified as the five main important risk factors in patients with TBF during the perioperative period.

Conclusion: In this study, we built and validated ML algorithms for an individualized prediction of HBL-related risk factors in the perioperative period of TBF. The importance of HBL-related risk factors could be determined, which contributes to clinicians' decision-making and improves perioperative management.

KEYWORDS

application, machine learning, hidden blood loss, risk factors, thoracolumbar burst fracture

Introduction

A spinal compression fracture is a type of severe spinal injury that falls under the category of traumatic spine fractures. Thoracolumbar burst fracture (TBF) accounts for roughly 25–48% of all thoracolumbar spinal fractures, as well as the highest proportion of traumatic spine fractures (1, 2). TBF commonly has a detrimental impact on patients, such as a shorter lifespan and a worse quality of life (1–3). As a result, spinal surgery is typically performed to rebuild spinal stability, relieve spinal cord compression, and restore spinal function, as well as to improve prognosis and prevent relevant complications (4). Although there is still no consensus on the need for surgical treatment for the small percentage of patients with TBF that are without neurological compromise, the majority of TBF patients have varying degrees of neurological compromise. In clinical practice, surgical interventions for TBF are usually indicated if injuries complicated with neurological compromise.

It is particularly important to note that blood loss during the intraoperative period has become a prevalent clinical concern in TBF patients (5, 6). A reduction in hemoglobin (Hb) content observed in fracture patients cannot be entirely explained by dominant blood loss during the perioperative period (6). As a result, the concept of hidden blood loss (HBL) during the perioperative period was originally presented in 2000 (7) and is progressively gaining acceptance among academics. According to this theory, HBL and dominant blood loss work together to explain why Hb levels are much lower. Numerous studies (6–8) have found a link between HBL and total blood loss (TBL) in patients undergoing joint and spine surgery. According to the findings, HBL accounted for around half of TBL. Consequently, identifying and controlling HBL risk factors during the perioperative period is critical for improving patients' prognosis and clinical administration efficacy. Although few studies have identified HBL-related risk factors under TBF (5, 6, 9), there are limited publications on determining the importance rank of HBL-related risk factors.

Machine learning (ML) belongs to a kind of artificial intelligence (AI) that is a new multidisciplinary technology based on computer science that can automatically learn and continuously improve depending on the identification of patterns and complex relationship (9–11). Its goal is fast decision-making with minimum intervention from humankind. Because of their superior prediction performance over traditional statistical tools, ML algorithms are increasingly being used in the medical field for some clinical determinations. Unfortunately, there have been few studies that use the ML algorithm to train the model and predict the high-risk factors for HBL in TBF patients. Therefore, in this study, ML-based models were constructed and validated for the importance identification of HBL-related risk factors in patients with single-level TBF.

Methods

Patient population, inclusion, and exclusion criteria

This study protocol was authorized and supervised by the Research Ethics Review Board of the Baoji City Hospital of Traditional Chinese Medicine (Baoji, China). The Approval Number was No. 2020YTH8H2. Patients (from March 2013 to March 2019) who were diagnosed with symptomatic single-level TBF in clinic were chosen. In this study, the specified inclusion criteria are involved in the following aspects: (1) patients over the age of eighteen; (2) Denis classification of TBF (T11–L2): type B with vertebral compression more than 50%, local kyphosis angle >30° (12); (3) patients' Thoracolumbar

Abbreviations: APTT, Activated partial thromboplastin time; ALB, Albumin; AUC, Area under the receiver operating characteristic; BMI, Body mass index; COPD, Chronic obstructive pulmonary disease; CV, Cross-validation; EMR, Electronic medical record; Fib, Fibrinogen; Hb, Hemoglobin; HBL, Hidden blood loss; Hct, Hematocrit; IBL, Intraoperative blood loss; KNN, k-nearest neighbors; ML, Machine learning; MLP, Multi-layer perceptron neural network; NPV, Negative prediction value; PBV, Patient's blood volume; RFE, Recursive feature elimination; PPV, Positive prediction value; SHAP, Shapley additive explanations; SVM, Support vector machine; TBF, Thoracolumbar burst fracture; TBL, Total blood loss; VBL, Visible blood loss.

Injury Classification and Severity Score (TLICS) more than 5 (13, 14); and (4) Gaines load score <6 (15). The specified exclusion criteria are involved in the following aspects: (1) patients with internal organ diseases (such as liver or kidney dysfunction); (2) patients with abnormal coagulation function; (3) patients with spinal surgical history; (4) patients with spontaneous cerebrospinal fluid leakage; and (5) patients who used hemostatic medications during the perioperative period. We categorized HBL lower than 470 mL as the HBL-negative group, and otherwise, as the HBL-positive group, as described previously (16).

Patients' data collection

The medical information of TBF surgery patients was collected in this study, which included essential information [age, gender, body mass index (BMI), smoking, and drinking], chronic diseases [hypertension, diabetes, and chronic obstructive pulmonary disease (COPD)], and history of blood transfusion and chronic steroid. Moreover, pre-operative scoring indications, including the visual analog score (VAS), Japanese Orthopedic Association (JOA) score, and 12-Item Short Form Health Survey (SF-12), were obtained. Pre-operative laboratory indicators, including hematocrit (Hct), Hb, albumin (ALB), fibrinogen (Fib), activated partial thromboplastin time (APTT), serum potassium, serum calcium, and serum sodium, were obtained. Meanwhile, we obtained surgery-related and intraoperative indicators from the electronic medical record (EMR) of the hospital. The primary indicators were operation time, levels of fused vertebrae, total time from admission to operation, and intraoperative fluid management strategy. The information on post-operative complications and scoring indications was collected, such as cerebrospinal fluid (CSF) leak, deep venous thrombosis (DVT), urinary tract infection, superficial infection, delayed wound healing, and failure of pedicle screw internal fixation, as well as VAS, SF-12, and JOA scoring.

Subsequently, we calculated percentages of vertebral restoration (Beta) to observe if fractured vertebral height had an impact on HBL. Based on X-ray parameters of patients during the pre-operative and post-operative periods, the value of Beta could be estimated using the following formula:

$$Beta = (a_4 - a_1)/a_5 \times 100\%, a_5 = (a_2 + a_3)/2$$

Here, a_1 is defined as the height of the fractured vertebra; the heights of the upper and lower anterior vertebrae that were adjacent to the fractured vertebra were presented as a_2 and a_3, respectively; a_4 is defined as the height of the post-operative vertebra; the average height of a_2 and a_3 is calculated and defined as the predicted height of the fractured vertebra (a_5). Figure 1 depicts the detected method for these parameters.

HBL evaluation

According to a previous study (17), we first calculated patients' blood volume (PBV) by the following method:

$$PBV = k1 \times height(m) + k2 \times weight(kg) + k3$$

Here, the relevant coefficients are displayed. k1 = 0.3669, k2 = 0.03219, and k3 = 0.6041 (for male); k1 = 0.3561, k2 = 0.03308, and k3 = 0.1833 (for female).

According to the method proposed by Gross previously (18), we calculated TBL by the following method:

$$TBL = PBV \times (Hct_{pre} - Hct_{post})/Hct_{ave}$$

Here, the Hct_{pre} and Hct_{post} were the Hct on pre-operative day 1 and post-operative day 3, respectively. Then, Hct_{ave} was calculated by averaging the values of Hct_{pre} and Hct_{post}.

Subsequently, we calculated patients' visible blood loss (VBL) during the perioperative period by the following method:

$$VBL = intraoperative\ blood\ loss\ (IBL) + postoperative\ drainage;$$
$$IBL = suction\ containers + soaked\ gauzes + soaked\ sponges$$

Consequently, we calculated patients' HBL during the perioperative period by the first following method. When

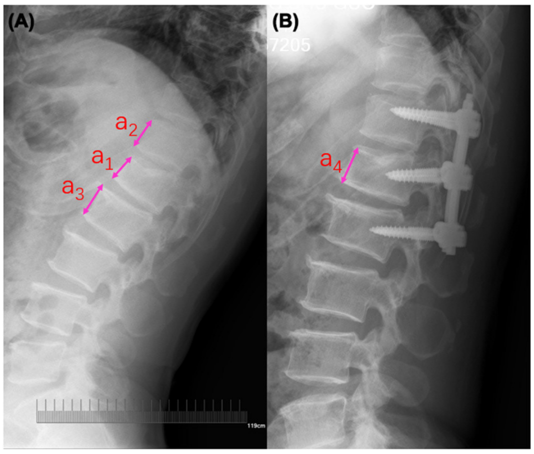

FIGURE 1
Radiographic measurement of the fractured vertebral body. **(A)** Pre-operative lateral radiograph; a_1 is defined as the height of the fractured vertebra; the heights of the upper and lower anterior vertebrae that were adjacent to the fractured vertebra were presented as a_2 and a_3, respectively. **(B)** Post-operative lateral radiograph; a_4 is defined as the height of the post-operative vertebra; the average height of a_2 and a_3 is calculated and defined as the predicted height of fractured vertebra (a_5).

patients received blood transfusions during the perioperative period, HBL was calculated by the second following method.

$$\text{The first method is}: \text{HBL} = \text{TBL} - \text{VBL}$$
$$\text{The second method is}: \text{HBL} = \text{TBL} - \text{VBL}$$
$$+ \text{autologous blood transfusion}$$
$$+ \text{allogeneic blood transfusion}$$

Model development and validation

ML algorithm-based models were built to predict HBL-related risk factors in patients with TBF during the perioperative period. The data collected from the single center was randomly divided into two cohorts (including the training set and internal validation set). In order to avoid overfitting and find the optimal hyperparameters, 15-fold cross-validation (CV) was adopted on the training set. In this study, ML-based models, including XGBoost, logistic regression, LightGBM, Random Forest (RF), support vector machine (SVM), AdaBoost, Gaussian NB (GNB), k-nearest neighbors (KNN), and multi-layer perceptron neural network (MLP), were developed for predicting HBL-related risk factors. The model with the highest prediction performance was determined as the final prediction model. In this process, we performed the Shapley Additive explanations (SHAP) values-based recursive feature elimination (RFE) algorithm to obtain crucial features. This will make the developed model feasible for application. The ML-based classifiers are implemented using the python library Sklearn69 package (19, 20). The evaluation-related indicators for the model performance, involving the area under the receiver operating characteristic curve (AUC) value, sensitivity, specificity, accuracy, and F-1 score, were reported. Figure 2 shows the flowchart of this study.

Statistical analysis

The continuous variables being normally distribution were exhibited as means ± standard deviations (SD), and otherwise, as median (interquartile spacing). The student's t-test and the Mann-Whitney U-test were carried out for the two group comparisons of continuous variables. The categorical variables were exhibited as numerical values and proportions and compared using χ^2-test or Fisher's exact test. In the present study, SPSS software (22.0 version) was used to carry out all statistical analyses. The values of $p < 0.05$ indicated a significant statistical difference.

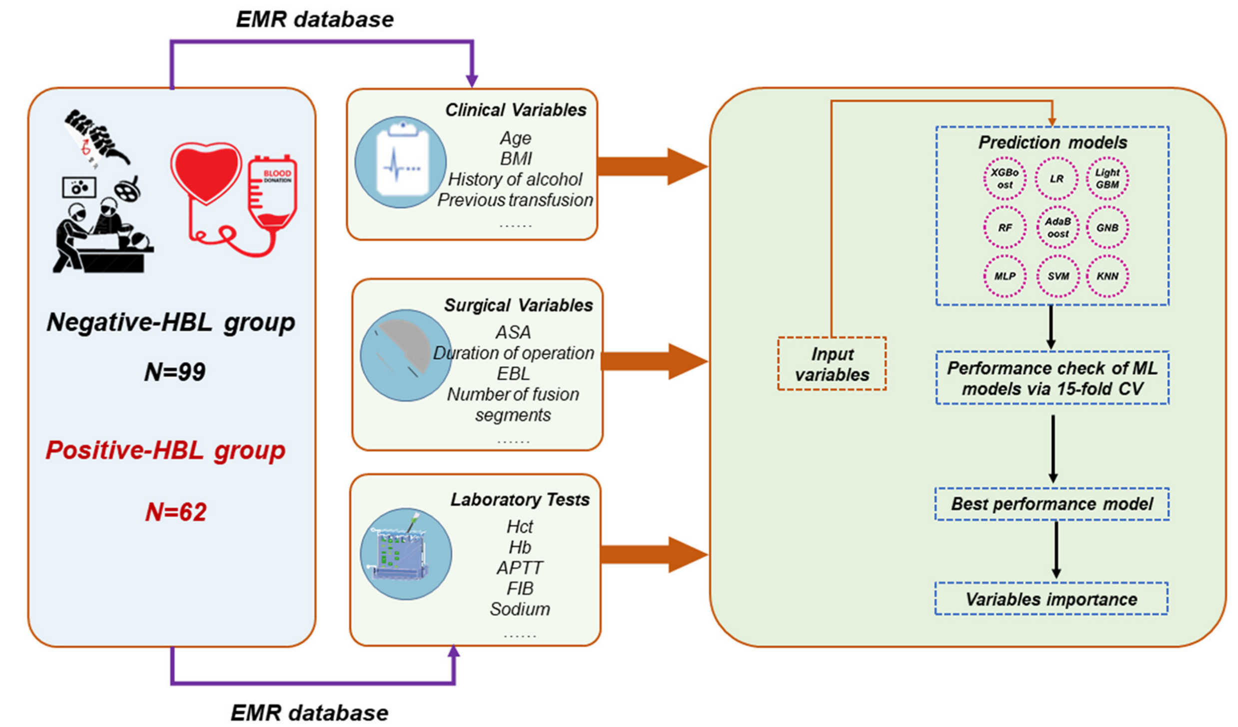

FIGURE 2
Overall flowchart. The final prediction model was determined by the maximum AUC and ACC. HBL, hidden blood loss; EMR, electronic medical record; AUC, area under the receiver operating characteristic curve; ACC, accuracy; RF, random forest; GNB, Gaussian NB; MLP, multi-layer perceptron neural network; SVM, support vector machine; KNN, k-nearest neighbors; LR, logistic regression.

TABLE 1 Comparison of variables between the two groups.

	Total	Positive-HBL group (n = 62)	Negative-HBL group (n = 99)	*P*-value
Number of patients	161	62	99	
Age (year)	41.3 (10.6)	48.9 (8.6)	36.6 (8.8)	<0.001
Sex (%)				
Female	113 (70.2)	42 (67.7)	71 (71.7)	0.592
Male	48 (29.8)	20 (32.3)	28 (28.3)	
BMI (kg/m^2)	24.8 (22.9, 28.0)	26.1 (23.1, 29.4)	24.4 (22.8, 27.2)	0.042
Current smoking (%)				
No	80 (49.7)	17 (27.4)	63 (63.6)	<0.001
Yes	81 (50.3)	45 (72.6)	36 (36.4)	
History of alcohol (%)				
No	72 (44.7)	29 (46.8)	43 (43.4)	0.678
Yes	89 (55.3)	33 (53.2)	56 (56.6)	
Hypertension (%)				
No	62 (38.5)	13 (21.0)	49 (49.5)	<0.001
Yes	99 (61.5)	49 (79.0)	50 (50.5)	
Diabetes (%)				
No	76 (47.2)	20 (32.3)	56 (56.6)	0.003
Yes	85 (52.8)	42 (67.7)	43 (43.4)	
Chronic steroid use (%)				
No	137 (85.1)	54 (87.1)	83 (83.8)	0.572
Yes	24 (14.9)	8 (12.9)	16 (16.2)	
COPD (%)				
No	157 (97.5)	61 (98.4)	96 (97.0)	0.574
Yes	4 (2.5)	1 (1.6)	3 (3.0)	
Previous transfusion (%)				
No	155 (96.2)	59 (95.2)	96 (97.0)	0.556
Yes	6 (3.8)	3 (4.8)	3 (3.0)	
Time from admission to surgery (d)	1.0 (0.0, 1.0)	1.0 (0.0, 1.0)	0.0 (0.0, 1.0)	<0.001
Duration of operation (min)	170.1 (18.1)	181.6 (13.5)	162.9 (16.8)	<0.001
Beta	30.0 (27.8, 33.0)	31.1 (28.0, 35.1)	28.9 (27.6, 30.3)	<0.001
Levels of fusion	1.0 (0.0, 1.0)	1.0 (0.0, 1.0)	0.0 (0.0, 1.0)	0.089
Intraoperative infusion of crystalloids (mL)	1,634.7 (418.1)	1,681.7 (424.4)	1,605.2 (411.4)	0.261
Intraoperative infusion of colloids (mL)	802.8 (310.1)	816.5 (317.6)	794.3 (305.0)	0.66
Autologous blood transfusion (%)				
No	128 (79.5)	48 (77.4)	80 (80.8)	0.604
Yes	33 (20.5)	14 (22.6)	19 (19.2)	
Allogeneic blood transfusion (%)				
No	128 (79.5)	50 (80.6)	78 (78.8)	0.776
Yes	33 (20.5)	12 (19.4)	21 (21.2)	
Pre-operative Hct (%)	40.8 (3.9)	41.6 (4.2)	40.3 (3.6)	0.034
Pre-operative Hb (g/L)	122.9 (15.4)	119.9 (13.1)	124.9 (16.4)	0.046
Pre-operative ALB (g/L)	39.7 (4.5)	40.0 (5.0)	39.5 (4.1)	0.459
Pre-operative APTT (s)	34.3 (3.0)	33.2 (3.2)	35.0 (2.6)	<0.001
Pre-operative Fib (mg/dL)	4.6 (0.9)	4.3 (0.8)	4.8 (0.9)	<0.001
Pre-operative serum sodium (mmol/L)	136.0 (9.0)	136.7 (10.5)	135.5 (7.8)	0.438
Pre-operative serum potassium (mmol/L)	3.8 (0.2)	3.8 (0.2)	3.8 (0.2)	0.961
Pre-operative serum calcium (mmol/L)	2.1 (0.3)	2.1 (0.1)	2.1 (0.4)	0.395

BMI, body mass index; COPD, chronic obstructive pulmonary disease; Beta. percentage of vertebral restoration; Hct, hematocrit; Hb, hemoglobin; ALB, albumin; APTT, activated partial thromboplastin time; Fib, fibrinogen.

TABLE 2 Comparison of complications between the positive-HBL group and negative-HBL group.

Parameters	Positive-HBL group ($n = 62$)	Negative-HBL group ($n = 99$)	*P*-value
Complications (%)			
CSF leak	3 (4.84%)	5 (5.05%)	0.892
DVT	4 (6.45%)	7 (7.07%)	0.294
Urinary tract infection	1 (1.61%)	0 (0.00%)	0.495
Superficial infection	4 (6.45%)	1 (1.01%)	0.023*
Delayed wound healing	2 (3.23%)	2 (2.02%)	0.729
Failure of pedicle screw internal fixation	0 (0.00%)	1 (1.01%)	0.234
Total	11 (22.58%)	16 (16.16%)	0.087

CSF, cerebrospinal fluid; DVT, deep venous thrombosis.
*$P < 0.05$.

Results

Patients' baseline characteristics

After the selection based on the set inclusion and exclusion criteria, a total of 161 patients diagnosed with TBF and treated with spinal surgery were eventually included in this study. Among these individuals, 62 (38.51%) cases were in the HBL-positive group and 99 cases were in the HBL-negative group. There were 113 (70.2%) females and 48 (29.8%) males among the 161 patients, with an average age of 41.3 ± 10.6.

The results of statistical analysis showed that there were remarked differences in age, BMI, current smoking, hypertension, diabetes, Beta, duration of operation, total time from admission to surgery, pre-operative Hct, pre-operative Hb, pre-operative APTT, and pre-operative Fib between the HBL-positive and HBL-negative groups (Table 1). There was no significant difference in overall post-operative complications between the two groups, except superficial infection (Table 2). Furthermore, there were no differences between the two groups in terms of the indicators of scoring (VAS score, JOA score, and SF-12) in the pre-operative and post-operative period, levels of fusion, and intraoperative fluid management strategy (Table 1; Figure S1).

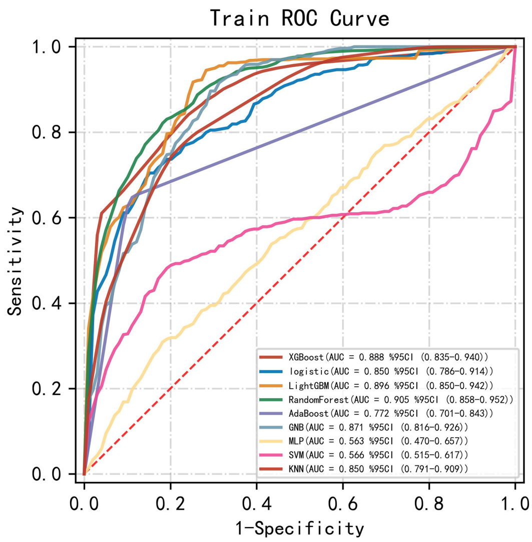

FIGURE 3
Comparisons of different machine learning models in the area under the receiver operating characteristic curve (AUC) in the training set. RF, random forest; GNB, Gaussian NB; MLP, multi-layer perceptron neural network; SVM, support vector machine; KNN, k-nearest neighbors.

Predictive performance of machine learning algorithm

Among the nine ML-based models we developed and validated in this study, the RF model algorithm for the initial prediction of HBL exhibited excellent performance, with the highest value of AUC (0.905) (Figure 3). Furthermore, the RF model's sensitivity, specificity, and accuracy in the training set were 0.839, 0.828, and 0.827, respectively (Table 3). When the models developed in the training set were performed for internal validation, the RF model still displayed the best performance (the highest AUC = 0.864), with the highest accuracy of 0.783 (Figure 4; Table 4). Accordingly, the RF algorithm was used as the ultimate model for predicting the risk of HBL in patients with TBF.

Relative importance of variables

Based on the previously mentioned indications, the ultimate prediction model was determined as the RF. Following the RFE, 15 relevant features were obtained in this study, and

TABLE 3 Model parameters in training set.

	AUC	Sensitivity	Specificity	Accuracy	PPV	NPV	F1-Score
XGBoost	0.888 (0.01)	0.830 (0.11)	0.781 (0.11)	0.759 (0.07)	NA	0.811 (0.11)	NA
Logistic	0.850 (0.03)	0.749 (0.02)	0.834 (0.04)	0.794 (0.02)	0.737 (0.05)	0.832 (0.01)	0.742 (0.03)
LightGBM	0.896 (0.08)	0.925 (0.09)	0.846 (0.08)	0.868 (0.05)	0.796 (0.08)	0.935 (0.05)	0.851 (0.07)
RF	0.905 (0.02)	0.839 (0.10)	0.828 (0.09)	0.827 (0.02)	0.777 (0.07)	0.874 (0.04)	0.799 (0.03)
AdaBoost	0.772 (0.01)	0.645 (0.02)	0.899 (0.01)	0.615 (0.00)	NA	0.615 (0.00)	NA
GNB	0.871 (0.02)	0.941 (0.01)	0.699 (0.04)	0.785 (0.02)	0.659 (0.03)	0.935 (0.01)	0.775 (0.02)
MLP	0.563 (0.12)	0.495 (0.22)	0.695 (0.16)	0.611 (0.03)	NA	0.693 (0.05)	NA
SVM	0.566 (0.38)	0.527 (0.43)	0.859 (0.13)	0.727 (0.09)	NA	0.787 (0.14)	NA
KNN	0.850 (0.02)	0.771 (0.03)	0.788 (0.03)	0.744 (0.02)	0.832 (0.03)	0.723 (0.01)	0.800 (0.03)

Data are shown as means ± standard deviations (SD).
AUC, area under the receiver operating characteristic curve; PPV, positive prediction value; NPV, negative prediction value; RF, random forest; GNB, Gaussian NB; MLP, multi-layer perceptron neural network; SVM, support vector machine; KNN, k-nearest neighbors; NA, Not applicable.

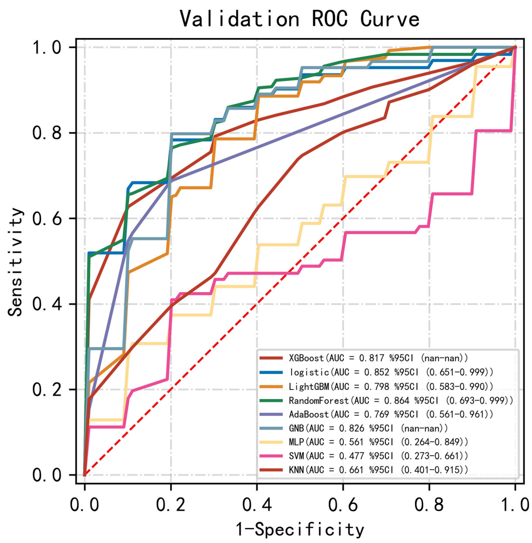

FIGURE 4
Comparisons of different machine learning models in the area under the receiver operating characteristic curve (AUC) in the validating set. RF, random forest; GNB, Gaussian NB; MLP, multi-layer perceptron neural network; SVM, support vector machine; KNN, k-nearest neighbors.

SHAP values were then utilized to assess the importance. The importance of variables in the RF model showed that age, duration of operation, Beta, pre-operative Fib, and pre-operative APTT were the top five (Figure 5).

Discussion

In this study, multiple ML-based model algorithms were developed and validated to predict HBL-related risk factors during the TBF perioperative period. We found that the RF model had the best predictive performance compared with other models. In contrast to earlier findings that primarily focused on the risk factors of HBL, our study revealed a highly intriguing finding involved in the importance of risk factors. In this study, the constructed ML model is useful for medical decision-making and clinical management throughout the perioperative period.

HBL refers to undetectable blood loss during surgery, and this part excludes directly quantified blood loss (7). Since the concept of perioperative HBL, problems with HBL-related risk factors have been increasingly noticed by spine surgeons (7). Previous study indicated that consuming a considerable amount of HBL may have serious and adverse consequences (6). Under post-operative stress, increased HBL is followed by a reduction in blood volume, which might excite the sympathetic adrenal medulla system and increase cardiac workload. Furthermore, the kidney may be more vulnerable to ischemia and thus malfunction because of inadequate blood perfusion (21). A substantial quantity of HBL can potentially increase local infection, prolong incision restoration, and delay patient discharge (22). Accordingly, in order to further identify the risk factors for patients' HBL and improve their perioperative management in clinical practice, an increasing amount of research has been designed and carried out, and some of these studies have obtained some meaningful outcomes (5, 6). Using this well-established ML model in this study, we were able to determine the importance of HBL-related risk factors and discovered that the top five risk factors were age, duration of operation, Beta, pre-operative APTT, and pre-operative Fib.

Numerous studies from the past have suggested an association between age and HBL in spine surgery patients (8, 23). Furthermore, age has emerged as the most important risk factor in comparison to other risk factors, as predicted by our ML model. In essence, we are aware that this variable is a risk factor that cannot be modified. With age increasing, bone marrow hematopoiesis and capacity to store red blood cell decline, resulting in poor compensatory ability for blood

TABLE 4 Model parameters in validating set.

	AUC	Sensitivity	Specificity	Accuracy	PPV	NPV	F1-Score
XGBoost	0.817 (0.11)	0.779 (0.20)	0.850 (0.15)	0.727 (0.09)	NA	0.778 (0.11)	NA
Logistic	0.852 (0.08)	0.902 (0.11)	0.816 (0.14)	0.765 (0.08)	0.685 (0.09)	0.826 (0.10)	0.776 (0.08)
LightGBM	0.798 (0.10)	0.852 (0.13)	0.758 (0.11)	0.758 (0.10)	0.670 (0.12)	0.855 (0.09)	0.740 (0.10)
RF	0.864 (0.09)	0.867 (0.16)	0.814 (0.16)	0.783 (0.09)	0.741 (0.15)	0.844 (0.10)	0.793 (0.14)
AdaBoost	0.769 (0.09)	0.650 (0.19)	0.889 (0.07)	0.615 (0.02)	NA	0.615 (0.02)	NA
GNB	0.826 (0.10)	0.905 (0.10)	0.776 (0.14)	0.745 (0.14)	0.652 (0.16)	0.897 (0.12)	0.750 (0.13)
MLP	0.561 (0.16)	0.557 (0.27)	0.749 (0.25)	0.553 (0.12)	NA	0.635 (0.15)	NA
SVM	0.477 (0.34)	0.538 (0.44)	0.827 (0.18)	0.659 (0.12)	NA	0.730 (0.12)	NA
KNN	0.661 (0.14)	0.640 (0.32)	0.738 (0.21)	0.640 (0.10)	0.595 (0.33)	0.652 (0.07)	0.535 (0.30)

Data are shown as means ± standard deviations (SD).
AUC, area under the receiver operating characteristic curve; PPV, positive prediction value; NPV, negative prediction value; RF, random forest; GNB, GaussianNB; MLP, multi-layer perceptron neural network; SVM, support vector machine; KNN, k-nearest neighbors; NA, Not applicable.

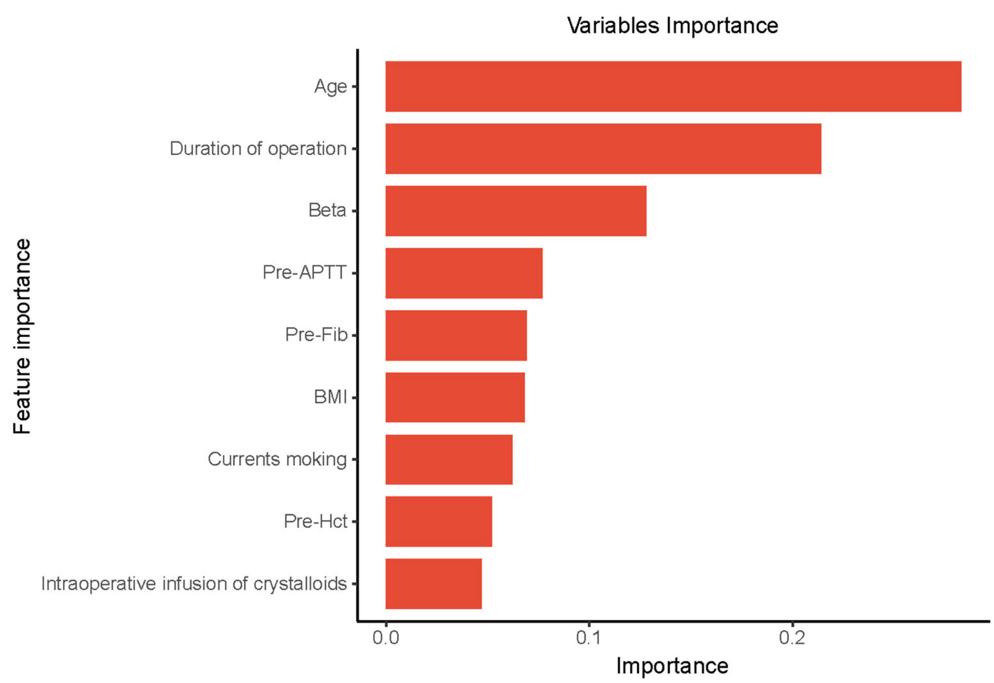

FIGURE 5
The importance of the variables in the Random Forest (RF) model is in decreasing order as follows: Age, Duration of operation, Beta, Pre-APTT, Pre-Fib, BMI, Current smoking, Pre-Hct, intraoperative infusion of crystalloids. Pre-APTT, pre-operative activated partial thromboplastin time; Pre-Fib, pre-operative fibrinogen; BMI, body mass index; Pre-Hct, pre-operative hematocrit.

loss anemia and an increase level of post-operative Hct (24). Additionally, this will further result in a higher HBL calculated by the gross formula. Meanwhile, poor compensatory capacity of the cardiovascular system is followed by the aging process, which reduces the self-regulation ability of the body under surgery-related stresses (8). Increased blood loss and decreased blood return eventually result from this failure to control and correct for blood loss. Additionally, the bleeding is vulnerable to infiltration into extravascular sites due to a decreased change in coagulation activity in older individuals (25).

Our results revealed that patients in the HBL-positive group required more time for surgery than those in the HBL-negative group. It suggested that duration of operation might be an important risk factor for HBL. At present, there are several reports on the relationship between total operational time and perioperative HBL. A retrospective study reported that patients' HBL increased in direct proportion to the length of the surgery (26). Another retrospective cohort analysis discovered a significant correlation between the quantity of HBL and the overall operating time (27). Our findings were essentially in line with those of others. Increased operation time is a highly unfavorable mechanical factor that might extend the overall period of tissue stretching. Then, local ischemia and the release of inflammatory mediators are therefore exacerbated. Eventually, enhanced inflammatory responses can compromise vascular endothelial structure and raise peripheral capillary permeability. Therefore, in order to potentially lessen the detrimental consequences caused by prolonged operation time, clinicians should pay attention to optimizing the operative plan for a shorter duration of operation.

It was reported in the literature that the percentage of fractured vertebral height restoration (Beta) had a beneficial influence on HBL and was recognized as the most influential risk factor among all medical variables (6). Interestingly, our study similarly discovered that the Beta was a crucial promotor of HBL in patients undergoing surgical treatment. Mechanistically, the more restored the fractured vertebral height is, the bigger the local "cavity" might be (6). This process is known as the "empty shell theory", and it helps explain the current study's result. Meanwhile, when the damaged vertebral height gradually returns, a bigger fracture gap will form surrounding the shattered vertebral walls. This change in the local site may result in easier blood infiltration into interstitial compartments, enhancing the HBL of patients undergoing spinal surgery.

Fib, also referred to as blood coagulation factor I, is a crucial protein that participates in the clotting cascade. In the presence of thrombin, Fib is further activated and transformed into fibrin, which governs platelet adhesion, activation, and coagulation progression (28). Several retrospective studies indicated that pre-operative Fib was a negative risk factor for patients' HBL during spine surgery (8, 29). Similarly, we obtained the same result in our investigation on the relationship between pre-operative Fib and patients' HBL. Low Fib levels may indicate a hypo-coagulable condition of the blood, which may result in blood seeping into interstitial space and an increase in HBL. Furthermore, APTT is another coagulation activity indicator, and its reduction is regarded as activation of the endogenous coagulation pathway. Most of the literature reported that pre-operative APTT was not correlated to patients' HBL during the perioperative period (8, 26). In contrast, some clinical research has identified APTT as a positive risk factor for HBL in TBF patients, and increased APTT can promote an increase in HBL, which could be explained by hemolysis (6). However, our findings suggest that pre-operative APTT content in the HBL-positive group was markedly lower. The process of clotting a cascade is a sequence of enzymatic reactions in the body that are influenced by coagulation factors and pathways. Therefore, we cautiously speculate that lower pre-operative APTT may be due to the concomitant alteration.

Several previous investigations have reported the potential detrimental effects of HBL on patient prognosis, such as post-operative infection, delayed wound healing, cardiovascular disease, renal dysfunction, and so on, and HBL is positively correlated with these poor outcomes (6, 21, 22). Therefore, the study of risk factors for HBL contributes to clinical practice and patients' prognosis. In this study, through RFE feature selection and model prediction, age, operation time, Beta, pre-operative APTT, and Fib were eventually determined as the five most important risk factors for HBL. These variables may be key reasons for a rise in HBL in patients as well as causing post-operative problems. Therefore, clinicians should pay special attention to it. However, due to the potential limitations of the included clinical indicators, other variables affecting HBL cannot be excluded, and a larger sample size and clinical data are required in the future to address this issue. Our study observed post-operative complications and scoring indicators and discovered a significant difference in post-operative superficial incision infection rate between the two groups. The rise in HBL is thought to promote blood accumulation in the third space, leading to a large fluid drainage volume and a long drainage time, which raises the risk of wound infection. However, because of the scarcity of authoritative literature, the single-center retrospective nature of our study, and the small sample size, this result should be generalized with caution. Furthermore, the model constructed in this study was only used to predict the risk factors of HBL and did not involve the prediction and prognostic evaluation indicators of HBL-related complications. In future studies, we will further explore prognostic indicators of HBL, such as length of hospital stay, wound infection, fracture healing, long-term screw-rod fracture, and other adverse events.

This study has several advantages over other studies seeking to the analysis of HBL-related risk factors during the operation of patients with TBF. First, the ML-based model developed and validated in the present study predicted the importance of HBL-related risk factors, which contributes to spine surgeons identifying and managing the HBL-related risk factors during the perioperative period as soon as possible. Second, ML-based model algorithms are reported to outperform traditional linear models in terms of predictive performance. Comfortingly, the constructed prediction model showed great performance for predicting risk factors, which may assist spine surgeons in making decisions and encourage advances in perioperative management.

However, a few limitations should be noted in this study. First, the results had a certain limitation because of the retrospective nature of the present study. Second, there was missing or incorrect data in this study. Third, the constructed model in this study lacked the external validation, particularly in other regions or countries. Finally, all enrolled patients had single-level TBF and did not have multi-level TBF. In the future study, these limitations are expected to be addressed.

Conclusion

Collectively, we developed and validated ML algorithms for individualized prediction of HBL-related risk factors in the perioperative period of TBF using pre-operative and intraoperative variables. Furthermore, the model could predict the importance of HBL-related risk factors, which might contribute to clinicians in medical decision-making and perioperative management.

Data availability statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics statement

The studies involving human participants were reviewed and approved by the Research Ethics Review Board of the Baoji City Hospital of Traditional Chinese Medical (Baoji, China). The Approval Number was No. 2020YTH8H2.

Author contributions

BY, LG, and XW collected the data, analyzed the data, and drafted the manuscript. JW, BX, and XL supervised the project and reviewed the manuscript. PZ was responsible for the whole project, designed the study, and supervised the study.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.969919/full#supplementary-material

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 11 October 2022
DOI 10.3389/fpubh.2022.1012202

Check for updates

OPEN ACCESS

EDITED BY
Gulzar H. Shah,
Georgia Southern University,
United States

REVIEWED BY
Elizabeth Ayangunna,
Georgia Southern University,
United States
Uzair Aslam Bhatti,
Hainan University, China

*CORRESPONDENCE
Jusheng Liu
jusheng.liu@163.sufe.edu.cn

SPECIALTY SECTION
This article was submitted to
Digital Public Health,
a section of the journal
Frontiers in Public Health

RECEIVED 05 August 2022
ACCEPTED 26 September 2022
PUBLISHED 11 October 2022

CITATION
Li C, Liu J, Qian G, Wang Z and Han J
(2022) Double chain system for online
and offline medical data sharing via
private and consortium blockchain: A
system design study.
Front. Public Health 10:1012202.
doi: 10.3389/fpubh.2022.1012202

Double chain system for online and offline medical data sharing via private and consortium blockchain: A system design study

Chaoran Li[1], Jusheng Liu[2]*, Guanyu Qian[3], Ziyi Wang[4] and Jingti Han[5]

[1]School of Economics and Management, Shanghai University of Sport, Shanghai, China, [2]School of Economics and Management, Shanghai University of Political Science and Law, Shanghai, China, [3]Business School, Hunan University, Changsha, China, [4]School of Humanities, Shanghai University of Finance and Economics, Shanghai, China, [5]School of Information Management and Engineering, Shanghai University of Finance and Economics, Shanghai, China

With the informatization development and digital construction in the healthcare industry, electronic medical records and Internet medicine facilitate people's medical treatment. However, the current data storage method has the risk of data loss, leakage, and tampering, and can't support extensive and secure sharing of medical data. To realize effective and secure medical data storage and sharing among offline medical institutions and Internet medicine platforms, this study used a combined private blockchain and consortium blockchain to design a medical blockchain double-chain system (MBDS). This system can store encrypted medical data in distributed storage mode and systematically integrate the medical data of patients in offline medical institutions and Internet medicine platforms, to achieve equality, credibility, and data sharing among participating nodes. The MBDS system constructed in this study incorporated Internet medicine care services into the current healthcare system and provided new solutions and practical guidance for the future development of collaborative medical care. This study helped to solve the problems of medical data interconnection and resource sharing, improve the efficiency and effect of disease diagnosis, alleviate the contradiction between doctors and patients, and facilitate personal health management. This study has substantial theoretical and practical implications for the research and application of medical data storage and sharing.

KEYWORDS

blockchain, Internet medicine, electronic health records, data sharing, data management

Introduction

With the informatization development and digital construction in the healthcare industry, the growth of medical data is showing a blowout trend. At present, many hospitals store the patients' electronic health records (EHRs) in the database to record the entire treatment process. When a doctor needs a patient's treatment and prescription records, the service system will extract the required data from the database for the doctor (1). Medical records are essential for the diagnosis and follow-up of patients. For the patient, diseases can lead to complications. In this case, the accuracy of the diagnosis is affected by the volume and accuracy of the historical health and medical information of the patient obtained by the doctor (2). By sharing the patient's health and medical data, doctors can access the patient's EHR and understand the patient's medical history and the corresponding treatment plan, to diagnose and treat the patient more accurately and comprehensively. There are various medical data sources, including clinical medical records, outpatient visits, relevant medical examination results, etc. (3). But, most hospitals don't establish cross-institution medical data sharing channels. Doctors in different hospitals are not able to access the patients' EHRs in other hospitals, resulting in information silos. Therefore, it is necessary to share patients' EHRs across hospitals in time to facilitate disease diagnosis and treatment (4). Besides, with the increasing demand for personal health management, medical institutions hope to collect health and medical information through the exchange and sharing of medical data (5). A large amount of medical data can support the development and application of recommendation systems in the medical industry (6, 7). Furthermore, the current data storage method has the risk of data loss, and tampering, and can't support extensive and secure sharing of medical data. Electronic medical data, such as prescription records, and medical records, may be tampered with or missing information, which leads to data lack of credibility (8, 9). In particular, the authenticity and fairness of medical information provided in the event of medical disputes cannot be guaranteed (10). Therefore, it is necessary to use the new electronic data storage technology to store, share and notarize data, and provide legal evidence for medical disputes and medical negligence while sharing medical data among doctors, hospitals, and other relevant stakeholders (11).

Blockchain technology, the underlying technology of Bitcoin, is characterized by transparency, anonymity, autonomy, and tamper-proof (12–14). As a technology, it is widely used in voting, supply chain, healthcare, the Internet of Things, finance, and other fields (15). In the healthcare industry, blockchain technology, as a new type of electronic data storage technology, can help hospitals, doctors, patients, and scientific researchers share and access medical data quickly and safely (16). Currently, the application and research of blockchain in the field of healthcare have received wide attention (17–20). Therefore, this research used blockchain technology to design a medical data sharing and application model between medical institutions to help solve real-life problems like medical data storage concentration, security sharing difficulties, privacy leaks, excessive dependence on authority institutions for data credibility, etc. This model helps to realize the sharing and application of decentralized, safe, efficient, and tamper-proof health and medical information, and to construct an equal and credible medical ecological environment.

The wide application of Internet technology has brought about great changes in the way people obtain disease knowledge and medical information. Online services, such as online medical consultation services, and disease information retrieval provided by Internet medical care platforms, can meet the growing health needs of the public (21, 22). Internet medical care platforms, such as online health community platforms, can solve the shortage of medical resources and uneven distribution of medical resources to a certain extent, thereby alleviating doctor-patient conflict and improving the doctor-patient relationship (23). The development of Internet medical care has generated massive online health and medical data (such as medical knowledge, online medical records, public communication records, etc.). Besides the health records from the hospitals, if a doctor can obtain a patient's health data from the online healthcare platforms, it will help the doctor to diagnose the diseases, as well as the later health management of patients. Indeed, the massive online information has high-quality and low-quality information, the low-quality information on the platform will mislead patients and affect their disease treatment. In this study, For ease of expression and understanding, we define as below: Health and medical information (HMI) refer to all information or data including health information/data and medical information/data about people's physical health and disease treatment (5, 24). Therefore, in the general application environment of Internet medicine, in addition to the use of blockchain technology to realize the storage and sharing of HMI between traditional offline hospitals, it is necessary to integrate the HMI of the traditional offline hospitals and the HMI of the Internet medicine platforms. The digital signature, endorsement, and traceability technology of blockchain can effectively avoid the generation and dissemination of low-quality information on Internet medicine platforms. In this way, we can realize the sharing and use of HMI between different offline and online medical channels. Internet medicine platforms, through the seamless connection with offline hospitals, can give full play to the role of online medical services in disease prediction,

Abbreviations: ATN, audit node; DPoS, delegated proof of stake; EHRs, electronic health records; HMI, health and medical information; KMC, key management center; MBDS, medical blockchain double chain system; PoS, proof of stake; PoW, proof of work; PoI, proof of information; PBFT, practical byzantine fault tolerance algorithm; RPN, representative node.

diagnosis, and follow-up. At the same time, we can integrate online medical services into the current health care system to improve the utilization efficiency of medical resources. However, there is a lot of information on the Internet medicine platform, and the low-quality information on the platform will mislead patients and affect their disease treatment.

In summary, this research explores how to use blockchain and Internet medicine technology to design a medical blockchain system to build an equal and credible medical ecological environment, and realize online and offline hybrid medical applications to solve the problem of medical information interconnection and resource sharing. In this paper, we define as below: offline medical treatment refers to patients going to traditional physical hospitals to seek doctors for disease diagnosis and treatment, and patients and doctors can communicate face-to-face. Online medical treatment refers to patients seeking doctors for disease diagnosis and treatment on the Internet medical platforms. Patients and doctors can only communicate through the Internet. Technically, this study systematically integrates the HMI of offline medical institutions (such as community hospitals, specialized hospitals, general hospitals, rehabilitation and healthcare hospitals, nursing homes, health examination centers, and scientific research institutions) and online Internet medical platforms by constructing a medical blockchain system. With the help of decentralization, anti-tampering, traceability, and joint participation of the blockchain, we can achieve equality, credibility, and data sharing among participating nodes in the medical ecosystem. To improve data security, reduce the computational pressure and avoid too many nodes on a blockchain, this study combined the consortium blockchain and private blockchain to build an integrated medical blockchain double chain system (MBDS) for the storage and sharing of HMI in different offline medical institutions and Internet medicine platforms. Given all this, the MBDS system can store encrypted medical data in distributed storage mode and systematically integrate the patients' medical data from different sources, to achieve equality, credibility, and data sharing among participating nodes. The MBDS system constructed in this study incorporated Internet medicine care services into the current healthcare system and provided new solutions and practical guidance for the future development of collaborative medical care. This study helped to solve the problems of medical data interconnection and resource sharing, improve the efficiency and effect of disease diagnosis, alleviate the contradiction between doctors and patients, and facilitate personal health management. This study has substantial theoretical and practical implications for the research and application of medical data storage and sharing.

The difference between this study and previous studies is as below: firstly, it used blockchain technology to integrate HMI of the online and offline channels, which contributed to building an equal and credible medical ecological environment and realizing the online and offline hybrid medical application. Secondly, the private blockchain and consortium blockchain are combined with different consensus mechanism algorithms to build a medical blockchain dual-chain system to improve the operating efficiency of the blockchain system and reduce energy consumption. Thirdly, by combining the on-chain storage of the blockchain with cloud storage, the cloud storage server is responsible for storing the encrypted original medical data, and the blocks on the blockchain are responsible for storing the hash value and data address of the encrypted data on the cloud server and information summary, the method can realize the safe and efficient storage, privacy protection and anti-tampering of the HMI with large storage capacity.

The structure of this paper is as follows: Section 2 introduces the related literature and the technology used in this study; section 3 describes our research objectives; section 4 illustrates the framework and design details of the MBDS system; section 5 illustrates the use process of the MBDS system and how to achieve online and offline hybrid medical treatment; section 6 summarizes this research and discusses the deficiencies and improvement directions of this research.

Related work

Literature review

In the healthcare industry, medical data is scattered in various medical institutions, there are no unified data storage and sharing standards in the different medical institutions, and permissions control of medical data access is backward. All these have brought great difficulties to the exchange and sharing of medical data, seriously affecting the validity and value mining of the medical data (5). How to realize the safe sharing of medical data is the focus and hot spot in the current field of medical data application. The realization of this goal mainly includes two aspects: (a) Authorized distribution and secure transmission of data; (b) Privacy protection of personal data (25). Blockchain technology provides an effective solution to the problem of the safe sharing of medical data. The application and research of blockchain in the field of healthcare have received extensive attention and great attention. Healthbank, a global innovator in digital health, is actively exploring the application of smart contracts in blockchain (17). Gem Health cooperated with the Philips Blockchain Lab to use blockchain technology to create a medical ecosystem connected to a common data infrastructure, and solve the balance between patient-centric care and operational efficiency (18). As a whole, blockchain technology can be used to store and share medical data among medical industry participants and stakeholders (such as hospitals, patients, insurance companies, etc.), which enables data users to share and apply health and medical information securely and efficiently (8, 26).

At present, the study of blockchain in the field of healthcare includes medical data protection, medical data storage and sharing, and medical data application (20, 24, 27). Mettler (28) describes the possible impact goals and potential of blockchain technology in the field of healthcare. In terms of medical data protection, Dagher et al. (24) proposed a blockchain-based framework, Ancile, which is based on the smart contract of Ethereum blockchain to strengthen access control and avoid data confusion. While protecting patients' sensitive information and privacy, medical data can be accessed safely, conveniently, and efficiently by patients, data providers, and third parties. Albalwy et al. (29) described ConsentChain, as a block-based system, which can allow patients to grant or withdraw medical data access. In terms of data storage and sharing, Azaria et al. (27) built a medical information sharing platform (MedRec) based on the Ethereum blockchain, which combined medical blockchain and big data. Liu et al. (15) proposed a blockchain-based privacy-preserving electronic medical record data sharing system, BPDS, which stores the original medical record information in a cloud storage server. Zhang et al. (8) designed a consortium medical blockchain system based on the PBFT algorithm to store and share medical data. In addition, some data-sharing systems based on blockchain technology are constantly being proposed and studied (13, 30). Regarding medical data application, Miyachi and Mackey (20) proposed a modular hybrid privacy-preserving framework leveraging off-chain and on-chain blockchain system design applied to three different reference models that illustrate how blockchain can enhance healthcare information management. Yue et al. (31) proposed a blockchain-based App (Healthcare Data Gateway). The system not only enables patients to easily and securely own, control, and share their data, but also allows untrusted third parties to access and process medical data while ensuring patients' privacy.

In summary, in the healthcare industry, blockchain technology, as a new data storage technology, can realize the sharing and access of health data while providing data notarization. By using blockchain technology, we can realize the sharing and application of decentralized, safe, efficient, and immutable health data among various institutions.

Preliminaries

Blockchain

The blockchain is a distributed database that contains an ordered list of records linked together through a chain of blocks, which it is jointly participated in and maintained by multiple independent nodes (32, 33). Compared with the traditional distributed database maintained by a central server, blockchain is a decentralized distributed database in which the data stored on the blockchain is jointly maintained by all nodes in the blockchain network, each of the nodes holds a complete set of data. To ensure the safety and reliability, the consensus mechanism in the blockchain network is crucial, which determines who recording the transaction data and how to check the validity of new blocks (2, 30, 34).

Blockchain can be classified into three categories: public blockchain, consortium blockchain, and private blockchain. (a) The public blockchain refers to everyone involved who can review transactions and participate in the consensus-building process. For example, Bitcoin and Ethereum are both public blockchains. (b) Consortium blockchain, only nodes (authorized organizations) in the system can access and manage the blockchain. Usually, there is a commercial cooperation relationship between nodes. The data in the consortium blockchain can be public, private, or partially decentralized. (c) Private blockchain, nodes will be restricted. Not every node can participate in this kind of blockchain. The written permission of a blockchain is only in the hands of a certain person or organization, and there is strict permission management for data access. For example, the internal use of blockchain for document management within an enterprise is the use of private blockchain. No matter what type of blockchain it is, it has its advantages and applicable application scenarios. Sometimes we need a public blockchain because it is convenient and there are many individuals involved, but sometimes we may need a consortium blockchain or a private blockchain to control read and write permissions, depending on what kind of services we need to provide and what kind of scenario we are applying to Niranjanamurthy et al. (35).

Combined with the research work in this paper, this study will introduce two types of blockchains, private blockchain, and consortium blockchain, to store and manage the patient's HMI, which will help solve the problems of medical information interconnection and resource sharing, also contribute to improving the doctors' disease diagnosis efficiency and treatment effect for patients. In the medical blockchain system constructed in this study, each hospital has a private blockchain to store the HMI of its patients. The hospitals, health authorities, third-party regulatory agencies, medical insurance companies or organizations, etc. negotiate and establish consortium blockchain, which is used to realize cross-organization HMI sharing.

Consensus mechanism

The consensus mechanism is the core technology for blockchain because it determines whether the new block is validated and who keeps the record. Therefore, it impacts the security and reliability of the whole blockchain system (2, 34). The consensus algorithm in the blockchain system is a confirmation mechanism for the blockchain system to detect the legitimacy of data and add blocks to the blockchain (8). There are many consensus algorithms in practical applications, such as Proof of Work (PoW) used in Bitcoin, Proof of Stake

(PoS), Delegated Proof of Stake (DPoS) (15), Practical Byzantine Fault Tolerance (PBFT) (8, 36), as well as Proof of Information (PoI) (37).

DPoS is the consensus algorithm used by the BitShares project (15). All participating nodes in the blockchain have voting rights. One hundred and one equity representative nodes that are selected through a fair and democratic voting method are in turn responsible for creating and verifying blocks in turn. In the subsequent algorithm execution process, all nodes can re-vote freely based on the performance of the equity representatives, and dynamically manage the selected 101 equity representatives to ensure the reliability and stability of the selected equity representative nodes in the blockchain system (16). Compared with PoW and PoS, DPoS is a faster, more effective, more decentralized, more flexible, and more energy-saving consensus mechanism. In addition, this algorithm can effectively reduce the number of participating accounting nodes and achieve rapid consensus verification (34). PBFT is a consensus algorithm introduced in 1999 by Barbara Liskov and Miguel Castro (36). PBFT was designed to work efficiently in asynchronous (no upper bound on when the response to the request will be received) systems. It is optimized for low overhead time. PBFT tries to provide a practical Byzantine state machine replication that can work even when malicious nodes are operating in the system. Nodes in a PBFT-enabled distributed system are sequentially ordered with one node being the primary (or the leader node) and others referred to as secondary (or the backup nodes). It is noted that any eligible node in the system can become the primary by transitioning from secondary to primary (typically, in the case of a primary node failure). The goal is that all honest nodes help in reaching a consensus regarding the state of the system using the majority rule. A practical Byzantine Fault Tolerant system can function on the condition that the maximum number of malicious nodes must not be $\geq$1-third of all the nodes in the system. As the number of nodes increases, the system becomes more secure (8).

In this study, we constructed a medical blockchain double-chain system by simultaneously using both consortium blockchain and private blockchain. DPoS is used as the consensus algorithm in the consortium blockchain established by hospitals, health authorities, third-party regulatory organizations, insurance companies, and other relevant institutions or organizations. DPoS algorithm has the advantages of lower energy consumption, more decentralization, and faster confirmation speed. For a consortium blockchain in this study, the participating nodes are relatively stable and the change is less, thus, DPoS can give full play to the role of each equity representative node, and realize fast transactions in the face of a large number of transactions. Furthermore, this research improves the election method of equity representative nodes in the DPoS algorithm by considering nodes' offline business performance and credit, which can better urge each node to play the role of miners and validators.

Regarding the private blockchain established within each hospital mainly for doctors and patients to store the generated HMI, we use PBFT as the consensus algorithm. Because different hospitals have huge differences in the number of doctors and the number of patients are constantly changing, the DPoS algorithm requires that the number of participating nodes in the blockchain system is always maintained at more than 101, so the DPoS algorithm cannot meet the requirements of the hospital's internal private blockchain. This paper studied the use of the PBFT algorithm as the consensus algorithm of the hospital private chain. The minimum number of participating nodes required by this algorithm is 4, which can well-meet the requirements of large and flexible participation nodes in the private blockchain of each hospital.

Proxy re-encryption

Proxy re-encryption (PRE) is a conversion mechanism that can be used between ciphers. It was originally proposed by Balze et al. (38). This technique solves the problem of transferring encrypted records between nodes without sharing symmetric keys by using a proxy. The proxy is responsible for reconstructing an encrypted message in such a way that other users can use their private key to decrypt the received encrypted documents to obtain the plaintext, even if the documents were not originally encrypted with their associated public key (39). This system allows secure sharing between parties without fully decrypting the document during the transfer process (24). The purpose of using proxy re-encryption is to solve the inconvenience of sharing data, reduce the burden on users, and enhance data reliability and security. In the process of proxy re-encrypting, each participator cannot individually retrieve any plaintext messages alone.

The specific working process involves three roles: data owner, data user, and proxy. We take an example to introduce how it works. When the data owner (Alice) wants to share the encrypted document with the data user (Bob), Alice generates a proxy re-encryption key for Bob and transmits the proxy re-encryption key to a third-party semi-trusted proxy through a secure channel. The semi-trusted proxy uses the proxy re-encryption key to re-encrypt the encrypted document according to the proxy re-encryption algorithm and send the re-encrypted document to Bob. After Bob obtains the re-encrypted document, he can use his private key to decrypt the re-encrypted document and obtain the plaintext after decryption. The specific workflow is as follows:

(1) KeyGen: generating public and private keys. Alice and Bob request the Key Management Center (KMC) to generate their public and private key pairs, and KMC generates Alice and Bob's public and private key pairs (PK_A,SK_A) and (PK_B,SK_B), and return them to Alice and

Bob, respectively. PK is the public key, and SK is the private key.

(2) Encryption (Enc): Encrypting plaintext. Alice encrypts the plaintext M with her public key PK_A, $C_{PK_A} = Enc(PK_A, M)$, where M is the document that Alice wants to transmit to Bob.

(3) Transfer (Trans): Transferring encrypted document. Alice sends the encrypted document C_{PK_A} to the semi-trusted proxy. At the same time, Alice uses Bob's public key PK_B and her private key SK_A to generate a re-encryption key $RK_{A\rightarrow B}$, and sends the re-encryption $RK_{A\rightarrow B}$ to the semi-trusted proxy.

(4) Re-Ecrpytion (ReEnc): Proxy re-encrypting the encrypted document. Using the re-encryption algorithm $ReEnc(C_{PK_A}, RK_{A\rightarrow B})$: given the encrypted document C_{PK_A} corresponding to the public key PK_A, the proxy uses the re-encryption key $RK_{A\rightarrow B}$ provided by Alice to convert the encrypted document C_{PK_A} into the re-encrypted document C_{PK_B} by using this re-encryption algorithm.

(5) Trans: Transferring the re-encrypted document. The proxy sends the re-encrypted document C_{PK_B} to Bob.

(6) Decryption (Dec): Decrypting the re-encrypted document. Bob can use the private key SK_B corresponding to the public key $PK_B$to decrypt the re-encrypted document C_{PK_B}, $M = Dec(SK_B, C_{PK_B})$, then to obtain the original plaintext M.

The above process reduces the workload and resource consumption of Alice as the data owner. Alice only needs to generate a re-encryption key for Bob, and the transmission, transformation, and storage of the document are all processed by the semi-trusted proxy. The proxy re-encryption mechanism provides convenience for users to share data, which can not only reduce the burden of users but also enhance the reliability and security of data (40). The process and advantages are conducive to the storage and transmission of HMI of medical institutions and patients, then to achieving secure and efficient transmission of medical data.

Public encryption with key search

Public encryption with key search (PEKS) was proposed by Boneh et al. (41), which aims to search over the encrypted data in asymmetric settings. Usually, a keyword w is extracted from a message M. While storing the data, the keyword will be encrypted with the user's public key and stored in the server. By using the private key corresponding to the user's public key to generate a trapdoor, the visitor can search for the encrypted keyword C_W. The PEKS algorithm mainly includes the following four parts:

(1) KeyGen(λ): Key generation algorithm. The user i inputs a security parameter λ to obtain the public and private key pair (PK_i,SK_i), where PK_i is the public key and SK_i is the private key.

(2) Enc(PK_i,w): Keyword encryption algorithm. Given the keyword w of a document, the user i encrypts the keyword with his public key PK_i, and outputs the encrypted keyword C_W.

(3) Trapdoor(SK_i,w'): Trapdoor generation algorithm. Input the private key of the user i and the target keyword w', and output the trapdoor $T_{w'}$corresponding to the target keyword w'.

(4) Test($T_{w'}$,C_W): Test algorithm. Input the trapdoor $T_{w'}$ and the ciphertext C_W, when the trapdoor and the ciphertext correspond to the same keyword, that is, $T_{w'} = C_W$, output "True," otherwise output "False".

The MBDS system constructed in this study will encrypt the keywords extracted from the patient's HMI, then it will store the encrypted keywords, the patient's public key, and the encrypted patient's HMI in the blockchain system. When a user needs a patient's medical data for a certain disease, a proxy can retrieve the record corresponding to the keyword through the PEKS algorithm and obtain the storage addresses. Then, by using PRE technology, the patient instructs the proxy and delegates the proxy to transmit the encrypted HMI of the corresponding storage addresses to the data users who need to access the patient's HMI. The PEKS algorithm retrieves the encrypted ciphertext of the keywords stored on the blockchain, which can realize the data retrieval function under the premise of protecting the privacy of the patient, avoiding the transmission and decryption of a large amount of useless information, and realizing the improvement of the efficiency of data retrieval and reading and saving energy.

Research objective

As we know, it is necessary to ensure that the benefits of the designed blockchain-based information management system features can be applied to a variety of health-related data, while also maintaining the privacy and security of healthcare data governance. These design objectives are very necessary and crucial in breaking down data silos to ensure the maximal utility of healthcare data for all relevant stakeholders in the medical industry (20, 42). Therefore, in this study, we aimed to conceptualize, design, and implement a blockchain-based information management system framework to store and manage HMI. The use of blockchain technology can safely and transparently store and manage HMI. The MBDS system constructed in this study aimed to realize the shared application of multi-source HMI between offline medical institutions and Internet medicine platforms. This study adopted the idea of a hybrid chain to combine the private blockchain for each hospital and the consortium blockchain between different related organizations in the medical industry, and used proxy re-encryption (PRE) and public encryption with keyword search (PEKS) technology to construct a medical blockchain double-chain system (MBDS). In this system, private blockchain and consortium blockchain were used to store and manage the patient's HMI, which helps improve the diagnosis. Each hospital operates a private blockchain that stores the patient's HMI in the hospital. The hospitals and related stakeholders, such as health authorities, research institutions, online health community platforms, and insurance companies, negotiated to manage a consortium blockchain, which keeps records of the secure indexes for the healthcare data.

Thus, referring to the existing research (2, 20, 43), the constructed MBDS system needs to achieve the following design objectives:

(1) Data security. HMI involves the patients' privacy, and the disclosure of information without the patient's consent will hurt the patients' lives. In addition, HMI concerns the health of the users, and an error and omission of information may affect the diagnosis and treatment of the patient's disease. Therefore, the designed MBDS system must ensure the security of stored data, including data confidentiality and integrity. Firstly, the HMI is encrypted and signed by asymmetric encryption technology to prevent data errors and omissions to happen; secondly, HMI is hashed and stored in the next block to prevent data errors through a hash algorithm; thirdly, the user's public key is used to replace the user's real identity; lastly, data auditing and access control are used to monitor all data access activities to ensure the confidentiality and integrity of data. Moreover, as an independent third-party organization, the nodes of health authorities in each blockchain need to play a supervisory role to ensure that the data on the chain will not be tampered with, and at the same time serve as a participating node to store all the data on the blockchain to avoid data loss. In addition, the MBDS system uses a combination of the hospital's internal private blockchain and the consortium blockchain among hospitals to improve data security. The above actions help to achieve data security storage.

(2) Data sharing and access control. The traditional way of healthcare information storage makes it difficult to integrate and connect the data of different medical institutions, which hinders the sharing of medical data. The MBDS system can integrate the HMI into the Internet medicine platforms and offline medical institutions to realize the cross-institution and cross-channel sharing of the patients' HMI. The doctors can obtain the most comprehensive medical information about patients. Thereby, the MBDS can improve the efficiency and effectiveness of the patient's disease diagnosis. As the owner of the HMI, the patients need to have full control over the data. The patients can determine whether other people can access their own HMI based on their situation and the application of others. The person with authorization can access the patient's data stored in the MBDS system. In addition, the patients can set the validity period for others' access authority and revoke others' access authority at any time.

(3) Privacy-preservation. While storing data securely, the data storage must be anonymized. All user identity information is stored using the user's identity code, that is, the user's public key, to avoid any information about the user's real identity in the stored data. Furthermore, the HMI and its extracted keyword stored in the block and cloud storage server should be encrypted, so no readable information can be obtained in the undecrypted state.

(4) Secure search. The MBDS system only allows doctors or institutions authorized by the patient to query the patient's HMI, and unauthorized units or individuals cannot access the data. The system uses PEKS to encrypt the keyword data stored in the blockchain. In the process of accessing the data, the visitor needs to use PEKS to retrieve the data that matches the search keyword trapdoor. This method can prevent other nodes in the distributed database from knowing the medical data keywords related to the patient's public key, which better protects the patient's privacy, and at the same time reduces the burden caused by unnecessary data access.

(5) The operability and scalability of the system. Convenient operability is a primary and important requirement of the medical blockchain, which must consider the convenient use of patients with different backgrounds. Regarding scalability, the system needs to have the ability to provide function extensions according to the requirements of participating institutions. It can not only store medical data of medical institutions but also store data of related institutions or enterprises in the medical industry. For example, to support the business and work of medical insurance companies and scientific research institutions, it is particularly necessary to integrate the user's healthcare and exercise information collected from mobile health devices. Comprehensive and all-sided medical data can be widely used in the health and medical industry to solve the problems of medical service quality supervision and control, as well as the timeliness and accuracy of medical insurance claims.

(6) Support the construction of an equal and credible medical ecological environment. All participating nodes in the system are equal and reliable. Based on ensuring the operability and scalability of the system, with the large-scale practical application of the system, all participating institutions in the medical industry are equal and credible, thus, it contributes to the formation of an equal and credible medical ecological environment in the society.

MBDS system design

System architecture

This study combined private blockchain and consortium blockchain to design a medical blockchain double-chain system (MBDS). By applying this system to the medical industry for large-scale use, an equal and credible medical ecological environment can be built. The MBDS system systematically integrates the medical resources and online doctor-patient information from offline medical institutions and Internet medicine platforms and integrates Internet medical care into the current healthcare system, which aims to realize the sharing and use of medical information between offline medical institutions and Internet medicine platforms. The constructed system includes plenty of private blockchains used in each hospital and a consortium blockchain between various institutions such as hospitals and insurance companies, to improve data security on the blockchain, reduce computational pressure and avoid the situation of too many nodes on a blockchain. Thereinto, the private blockchains store medical data generated when patients visit hospitals, and each hospital builds its private blockchain system. The only one consortium blockchain stores the transaction data between the institutions and the information summary of the HMI stored in the private blockchains (such as patient ID, encrypted patient's HMI, HMI hash value, HMI belonged blockchain ID, block ID, transaction order ID, etc.), which is used for cross-hospital data retrieval. This double-chain system can achieve lower computational pressure, faster transactions, lower operating costs, and better privacy protection.

The framework of the MBDS system is shown in Figure 1. The system can be divided into three layers, namely the data generation layer, data storage layer, and data sharing layer. The functions of each layer are as follows:

(1) Data generation layer. In this layer, the patient sees a doctor in an offline or online hospital, and the patient's HMI is generated by the offline doctor or online doctor. Then, the doctor encrypts the patient's HMI and sends it to the patient for verification and confirmation. As the owner of the data, the patient has complete control over the data, and can control the access rights of the data to determine who can access it, but does not have the right to write or modify the data.

(2) Data storage layer. The function of this layer is to store the HMI and address the index generated during the patient's visit. The module includes three parts:

- Cloud storage. The medical data sources are various and numerous. Considering the high cost and storage capacity limitations of storing large amounts of data directly on the blockchain, the raw medical data will be encrypted and stored in the cloud storage under the blockchain. At the same time, the data generation timestamp, transaction type, transaction content, doctor ID, patient ID, encrypted HMI keywords, encrypted HMI storage address, and HMI hash value is stored in the transaction slip in the block body on the blockchain. Access control is determined by access permissions, and different nodes have different access control permissions.
- Private blockchain for hospitals. The private blockchain is established within the hospital, the participants are doctors and patients of the hospital and health authorities. The MBDS system uses a private blockchain to store the returned information after the cloud storage server under the blockchain stores the medical data. Each time a piece of information is returned, a transaction slip is established and stored in the block body. In the MBDS system, the right to use the patient's HMI is completely controlled by the patient, who can authorize data users to access relevant data or revoke authorization on time. Patients can pre-define access permissions in the smart contracts to improve convenience while ensuring secure data sharing. In addition, each access request and access activity must be recorded in the blockchain for future audits or investigations. For offline hospitals, each hospital corresponds to a private blockchain. On the contrary, the Internet medicine platform takes the platform as the object. A platform builds a private blockchain for storing and sharing patients' online HMI.
- Consortium blockchain for institutions. The participants of consortium blockchain include hospitals, Internet medicine platforms, health authorities, insurance companies, scientific research institutions, and medicine companies. The hospitals extract information summaries (such as block ID, transaction slip ID, patient ID, encrypted HMI keyword, and HMI hash value) from the data stored on their private blockchains and store them in the consortium blockchain for other nodes to retrieve and share information.

(3) Data sharing layer. The participants in this layer include offline hospitals, Internet medicine platforms, doctors, patients, health authorities, insurance companies, scientific research institutions, medicine companies, etc. At this layer, data users (such as doctors and insurance companies) can apply for access to patients' HMI, and systematically analyze the patient's full-cycle medical data to provide patients with accurate disease diagnosis and treatment or timely insurance claims. For researchers, scientific research can be carried out based on the collected patient data. In short, authorized data users can retrieve the data stored in transaction slips on the blockchain and access data stored in a cloud storage server under the blockchain.

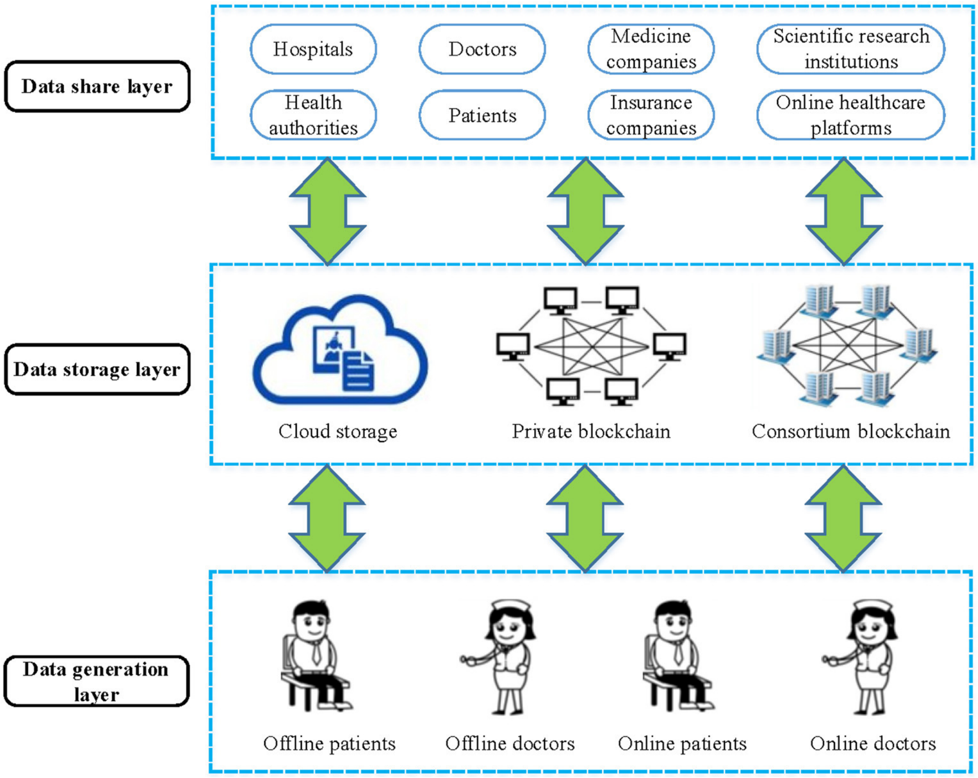

FIGURE 1
The architecture of the MBDS system.

Double-chain system

User role

The MBDS system constructed in this study consists of five roles, namely, data owner, data user, authority center, proxy, and miner. In the hospital's private blockchain, the participating nodes are mainly composed of a hospital, doctors, patients, and health authorities. In the consortium blockchain, the participating nodes are mainly composed of hospitals, Internet medicine platforms, health authorities, insurance companies, scientific research institutions, medicine companies, and other relevant organizations. Each node plays at least one role. In addition, the nodes like authority centers, proxies, and miners need to store full copies of the data on the blockchain, while other roles can store partial copies of the data based on business needs.

(1) Data owner. Data owners have their HMI and control over the data. Besides the data owners can share the data with other individuals or organizations but do not have the right to write and modify the data. A data owner can use the public key to encrypt and sign the original HMI and its keywords to store in the cloud storage server bundled with the blockchain, then he will store the hash value of stored HMI, storage address, encrypted HMI keywords, and access control policy on the blockchain for others to retrieve while preventing malicious tampering of data and protecting the privacy of patients. The data owners control the transmission and access rights of their HMI. In the process of data sharing, the data owner needs to rely on the proxy to re-encrypt the shared data and share the encrypted HMI with others.

(2) Data user. Data users can read and write shared files according to access control policies. Data users who are authorized by the data owner can obtain the re-encrypted HMI from the proxy by sending an authentication request, and then decrypting the received ciphertext with their private keys to obtain the plaintext of the HMI. Specifically, when data users need to update a file, they are the writer, and when they look up a file, they are the reader.

(3) Authority center. There are some nodes, which play an important role in the blockchain node network due to their business scale and institutional nature. The authority centers represent some of the participating nodes in the blockchain. In the MBDS system, the authority centers within the private blockchain are hospital and health authorities; the authority centers within the consortium blockchain are a certain number of representative institutions or organizations who are selected from various participating institutions, such as hospitals, Internet medicine platforms, health authorities,

insurance companies, and scientific research institutions. The authority centers need to have a good infrastructure and the ability to invest resources to maintain and upgrade the hardware facilities in the blockchain system. Therefore, the authority centers need to store a full set of data copies on the blockchain.

(4) Proxy. The proxy employs PRE technology to realize data transmission and sharing for data users, and at the same time assists data users in PEKS retrieval of data on the blockchain. Due to the technical and resource advantages of the authority centers, the proxies generally come from authority centers.

(5) Miner. Miners are responsible for verifying file writing and reading transactions. It is determined by the consensus mechanism in the blockchain which node is responsible.

Client category of MBDS system

Different users in the MBDS system have different functional requirements for the system. In practical applications, the MBDS system provides three types of clients for different user roles: complete client, lightweight client, and online client. (a) Complete client: it stores copies of all data. Users who use this client are generally authority centers and proxies, and provide external services such as data query and download to other users through interfaces. (b) Lightweight client: it does not save all data, but only saves data blocks related to itself. When it needs to access other data or data verification, it needs to query other nodes or authority centers. (c) Online client: it browses in web mode, and provides users with simple operation and access services without saving data copies. Five types of users can choose to use different clients or a combination of them according to their own needs. For example, patients, as data owners, will use lightweight clients to save their data locally, which makes it faster and more convenient to load data when accessing them. At the same time, they will also use online clients to view HMI anytime, anywhere. As an authoritative center and data user, the hospital will choose to use a complete client to save a copy of all the data. After obtaining the authorization of the data owner, the hospital can quickly access relevant documents and provide data query and verification services for other nodes. Health authorities, as the authority centers, will also use complete clients to save a full set of data copies of the blockchain.

Node network of MBDS system

Figure 2 shows the nodes network diagram of the hospitals' private blockchain and consortium blockchain in the MBDS system. The network of the MBDS system is divided into two layers.

(1) The bottom layer is the private blockchain (PBC). It stores the HMI generated within the hospital or on the Internet medicine platform. The original HMI data is generated when the patient visits are stored in the cloud storage server bundled with the blockchain, while the blockchain itself stores the information returned by the cloud storage server. The returned information includes data generation timestamp, transaction type, transaction content, doctor ID, patient ID, encrypted

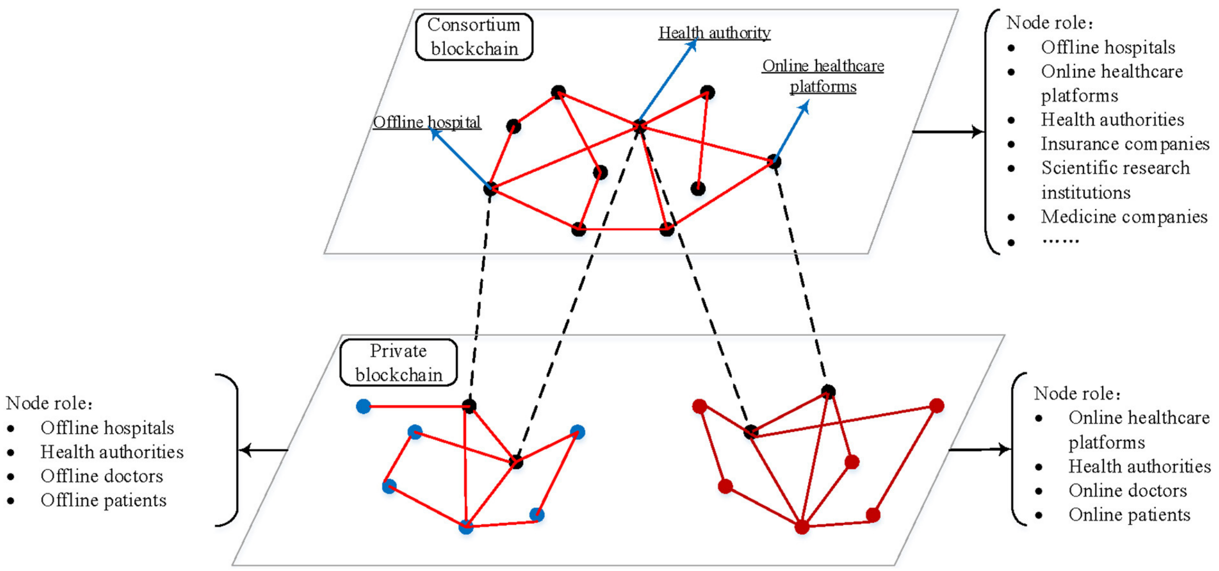

FIGURE 2
The node network of the MBDS system.

HMI keyword, encrypted HMI storage address, HMI hash value, etc. Executing the preset smart contracts on the private chain can realize the transaction activities between doctors and patients in the hospital. Participants are hospitals or Internet medicine platforms, doctors, patients, and health authorities at all administrative levels.

(2) The upper layer is the consortium blockchain. It stores the information summary of the data that are stored on the underlying hospital private blockchain (e.g., patient ID, encrypted HMI keyword, HMI hash value, HMI stored blockchain ID, Block ID, transaction slip ID, etc.), to facilitate the retrieval of required data by participating node institutions on the consortium blockchain. Executing the preset smart contracts on the alliance chain can realize the transaction activities between participating institutions. Participants are offline hospitals, Internet medicine platforms, health authorities at all administrative levels, medical insurance companies, scientific research institutions, medicine companies, etc.

Figure 2 shows that the private blockchain is divided into two types: the private blockchain of offline hospitals and the private blockchain of the Internet medicine platform. A private blockchain of the offline hospital is only for one hospital, which is used to store and share the HMI of the patient in the offline hospital. The participants are the offline hospital, offline doctors, patients, and health authorities. Besides, a private chain of the Internet medicine platform is only for a platform (e.g., haodf.com), which is used to store and share patients' online HMI generated at this platform. The participants are Internet medicine platforms, online doctors, patients, and health authorities. In both kinds of a private blockchain, the hospital (or Internet medicine platform) and the health authorities at all administrative levels serve as the authority centers and proxies and use a complete client to store a full set of data copies of the located blockchain. Participating doctors can choose to use either a complete client or a lightweight client, and patients can use a lightweight client or an online client. The consortium blockchain between institutions includes numerous hospitals and Internet medicine platforms. This consortium blockchain is connected to the private blockchain that each hospital located through each hospital node and health authority node. In the consortium blockchain, multiple participating institutions are selected as authority centers and proxies, and a complete client is used to store a full set of data copies of the consortium blockchain. In the MBDS system, two types of nodes, the hospital (Internet medicine platform) and the health authorities, play a bridge role in linking the private blockchain to the consortium blockchain. Through these two types of nodes, the communication between the bottom private blockchain and the upper consortium blockchain can be realized. Further, the intercommunication between blockchains realizes the cross-chain combined application of the blockchain.

In particular, in the private blockchain of many different hospitals, there are nodes of the national health authorities and the provincial and municipal health authorities of the region to which the hospitals belong. The health authorities are the common node in the private blockchain of different hospitals, which have the full set of data copies of the hospitals' private blockchains. Thus, other institutions on the consortium blockchain with the authorization of the data owner can access the patient's medical data in other institutions through the health authorities.

By combining multiple hospitals' private blockchains and institutional consortium blockchains, a cross-chain system is established to realize distributed storage and efficient sharing of medical data, while avoiding the disadvantages of large data load, low efficiency, and high energy consumption caused by too many participating nodes on a single blockchain. At the same time, on the premise of ensuring that data stored on the private blockchain can be accessed by other institutions, each hospital's private blockchain can manage its data more efficiently and actively.

Table 1 described the notations used in this study.

Data structure and storage

The data storage medium of the MBDS system consists of three parts: cloud storage server, block, and transaction slip. The original HMI is encrypted and stored in the cloud storage server bundled with the blockchain. At the same time, the returned information, such as doctor ID, patient ID, encrypted HMI keyword, encrypted HMI storage address, HMI hash value, etc., will be stored in the transaction slips in the block body on the blockchain. Blockchain is composed of blocks that record the previous block ID and hash value, and the body part of each block stores several transactions slip using the Merkle tree structure. These transaction slips are the medium for storing the blockchain data, which are used to store the information records returned from the cloud storage server.

In the MBDS system, the functions of the private blockchain and consortium blockchain are different, and the information stored on the blockchain is different. Therefore, the data storage structure of the blocks in the two types of blockchains is also different. Figure 3 shows the data storage structure of a block in the bottom private blockchain of the hospital. The block header contains the current block ID, the ID and hash of the previous block, the timestamp of creating the block, the user ID of the creator of the current block, and the root hash value of the Merkle tree. The block body contains the digital signature, transaction number, and transaction slip. Among them, the digital signature in the block body is to ensure that the content of the block is not tampered with and to ensure that the block creator cannot deny it after generating a malicious block. Transaction slips are stored in a Merkle tree structure, and each

TABLE 1 Notation and description.

Notations	Description	Notations	Description
W	The set of keywords.	$T_{w'}$	The trapdoor of the searched keyword.
w	Keyword.	(PK_i, SK_i)	The public and private key pair of node i.
p	Patient.	$address$	The address storing HMI.
d	Doctor.	ID_h	Hospital's private blockchain ID.
h	Hospital.	ID_b	Block ID.
e	Internet medicine platform.	ID_t	Transaction slip ID.
t	Timestamp.	$H()$	Hash algorithm.
$Type$	The transaction type.	$SIG()$	Digital signature.
$Text$	The Transaction content.		

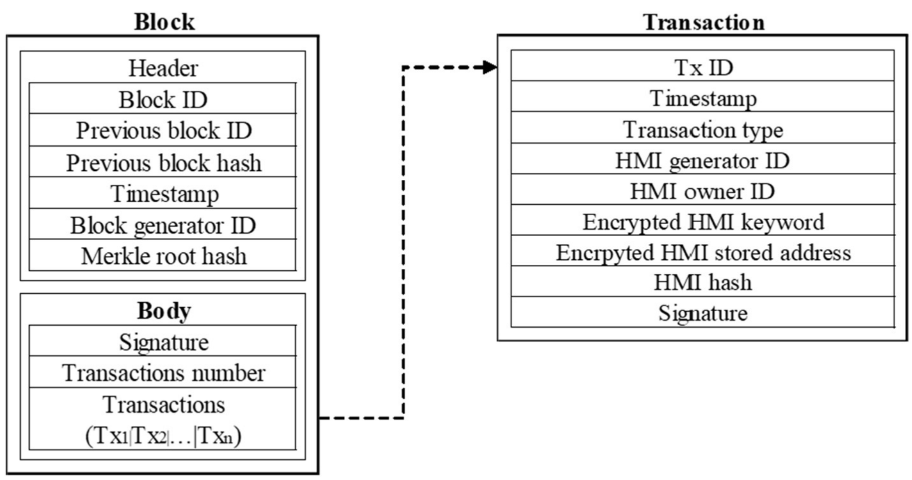

FIGURE 3
Structure of a block in the hospital's private blockchain.

transaction slip is stored in a leaf node. When the cloud storage server stores the HMI, it will add the data generation timestamp, transaction type, doctor ID, patient ID, and HMI hash value into the data. After storing the data, this information will be returned to the blockchain and stored in the transaction slip. Therefore, in the design of the transaction slip storage structure, the storage data includes transaction slip ID, data generation timestamp, transaction type, transaction content, doctor ID, patient ID, encrypted HMI keyword, encrypted HMI storage address, HMI hash value, and digital signature. The digital signature is to ensure that the transaction content is not tampered with and to ensure that the creator cannot deny it after generating a malicious transaction slip.

It is noted that in the MBDS system, a transaction slip has an ID, which ID only points to the HMI stored at the HMI storage address in the transaction slip. Separating the original HMI from the stored data on the blockchain, can reduce the data capacity on the blockchain, facilitate synchronization and backup, and improve the operational efficiency of the blockchain. Blocks and transaction slips are physically stored in the database, and logically stored in the form of a blockchain, to realize the unmodifiable, traceable, and efficient sharing of data.

Figure 4 shows the data storage structure of a block in the upper consortium blockchain between institutions. The block is used to store the information summary of the data stored in the private blockchain of the hospital, to facilitate the retrieval of the required data by each institutional node on the consortium blockchain. The hospital node in the consortium blockchain will regularly submit the information summary of their private blockchain to the consortium blockchain and store it in the block. The header of the block in the consortium blockchain is the same as that in the private blockchain. The difference is that the transaction slip in the block of the consortium blockchain contains a transaction slip ID, transaction slip generation timestamp, 10 items, and a digital signature. Among them, the item is used to store the information summary of the HMI stored on the private blockchain submitted by the hospital. The item contains the patient ID, encrypted HMI

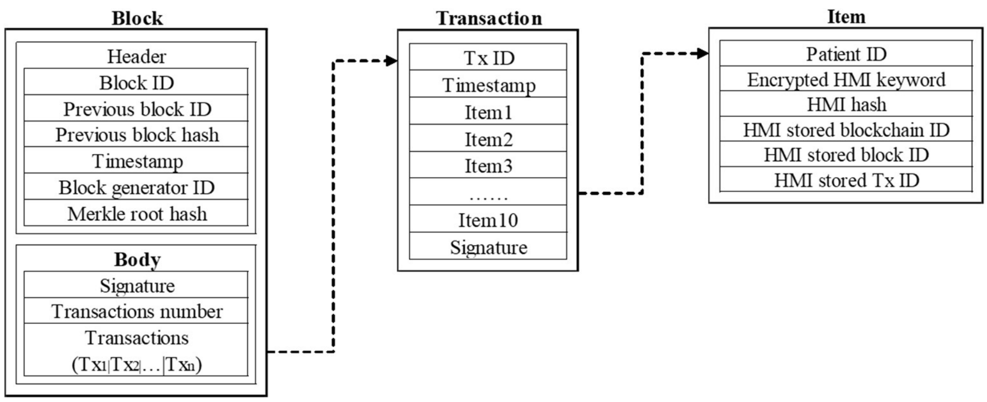

FIGURE 4
Structure of a block in the consortium blockchain.

keyword, HMI hash value, HMI stored blockchain ID, block ID, and transaction slip ID. When a hospital needs to know the electronic medical records of a patient in other hospitals, by obtaining authorization from the patient, as well as the patient ID and the trapdoor $T_{w'}$ of the searched keywords, the hospital can retrieve the required information in the consortium blockchain, and find the storage information, such as blockchain ID, block ID, and transaction slip ID, then the health authorities, as the proxy, will obtain the patient's HMI and share with the prior hospital.

Consensus mechanism

Due to the different participating groups and functions, the consortium blockchain and private blockchain in the MBDS system adopt different consensus mechanisms. The consortium blockchain uses the DPoS algorithm as the consensus algorithm, and the hospital private chain uses the PBFT algorithm as the consensus algorithm. Each node in the institutional alliance chain is relatively stable with few changes. Using the DPoS consensus mechanism can give full play to the role of each representative node. The DPoS consensus mechanism has many advantages, but when starting to use the DPoS consensus mechanism, the initial method of selecting the representative node is through the election of node voting. This method may have problems when applied to the medical blockchain, namely: the initially selected representative node may not have enough influence and the ability to provide the full range of services such as full copy data storage and query. Therefore, the MBDS system has improved the initial selection method of the representative node of DPoS. According to the current rating of medical institutions in China, the deployment scale of information centers, and enterprise strength, participating institutions are scored from multiple dimensions to obtain credit scores. Then, we select the top 101 institutions with high credit scores who are willing to be representatives as the representative node (RPN) and select the top 102–121 as the audit node (ATN) (15). RPN is responsible for creating blocks in turn to save the data submitted to the blockchain by each node, and ATN, in turn, verifies the authenticity and validity of each created block.

The ranking of institutions is based on credit scores, which indicates the comprehensive strength of the institutions. The credit score is bound to the institution's identity ID. Providing services for the operation of the blockchain and data sharing can increase own credit score. Actions that disrupt the stable operation of the blockchain, such as RPN creating an invalid or incorrect block, or ATN verification errors, will deduct the institution's credit score. When the credit score is lower than the set threshold, the institution will be kicked out of the RPN group and replaced by ATN in turn. Nodes in the ATN group will be replaced by nodes with high subsequent credit scores. By introducing the credit score system to assess the performance of RPN and ATN, it can fully mobilize the initiative of participating institutions to participate in the evaluation, and provide a reference for the evaluation of the ability of representative institutions. In addition, in the process of nodes jointly maintaining the operation of the blockchain, the credit score system evaluates the performance of each node in a quantitative way, which improves the rationality of group decision-making.

The private blockchain of the hospital in the MBDS system adopts the PBFT algorithm as the consensus mechanism. This algorithm requires the minimum number of participating nodes to be 4, which effectively solves the shortcomings of the DPoS algorithm in that the number of participating nodes in the blockchain system is always more than 101. It can meet the requirements of large and flexible nodes in the hospital's private blockchain (8). In addition, compared with POW and

POS algorithms, PBFT does not need to spend computing power to solve mathematical problems, saving energy and higher efficiency.

Process of MBDS system

Medical data sharing is an important step to realizing an intelligent medical system and improving medical service quality (31), which can also help patients become active participants (44, 45), improve the quality of medical services (46), provide patients and doctors with better recommendations and diagnosis and treatment recommendations (47). In this paper, MBDS systems which are designed based on blockchain technology can help hospitals, patients, and service providers quickly and securely authenticate permissions and achieve efficient data access and sharing. Based on blockchain technology, patient medical data can be obtained quickly and accurately, and better medical services can be provided to patients, which is conducive to building an equal and credible medical ecological environment. When a patient visits a doctor, medical data in the MBDS system goes through four steps from generation to sharing and spans the data generation layer, data storage layer, and data share layer, as shown in Figure 5.

System initialization

In the initial operation of the MBDS system, the participants (hospitals, Internet medicine platforms, doctors, health authorities, medical insurance companies, etc.) need to authenticate to the Key Management Center (KMC) and request the generation of public and private key pair (PK_i, SK_i). A participating node can only apply for one public and private key pair. The real identity of the node is bound to the public and private key pair, and the KMC encrypts and protects the identity information of the node. In this system, the public key PK_i of a user is used as the user's identity ID. When a patient visits a doctor for the first time, the patient p will go to the hospital h and complete the identity verification with the assistance of the hospital h and at the same time authenticate to the KMC to obtain his public and private key pair (PK_p, SK_p). This public and private key pair will be the patient's unique identity ID information in the MBDS system, which can be used by the patient later when visiting other hospitals or Internet medicine platforms.

HMI data generation and release

The patient p visits the doctor d in the hospital h, doctor d will write the electronic medical records after medical examinations and treatment. All the information is aggregated to form the patient's HMI. The doctor extracts keywords w

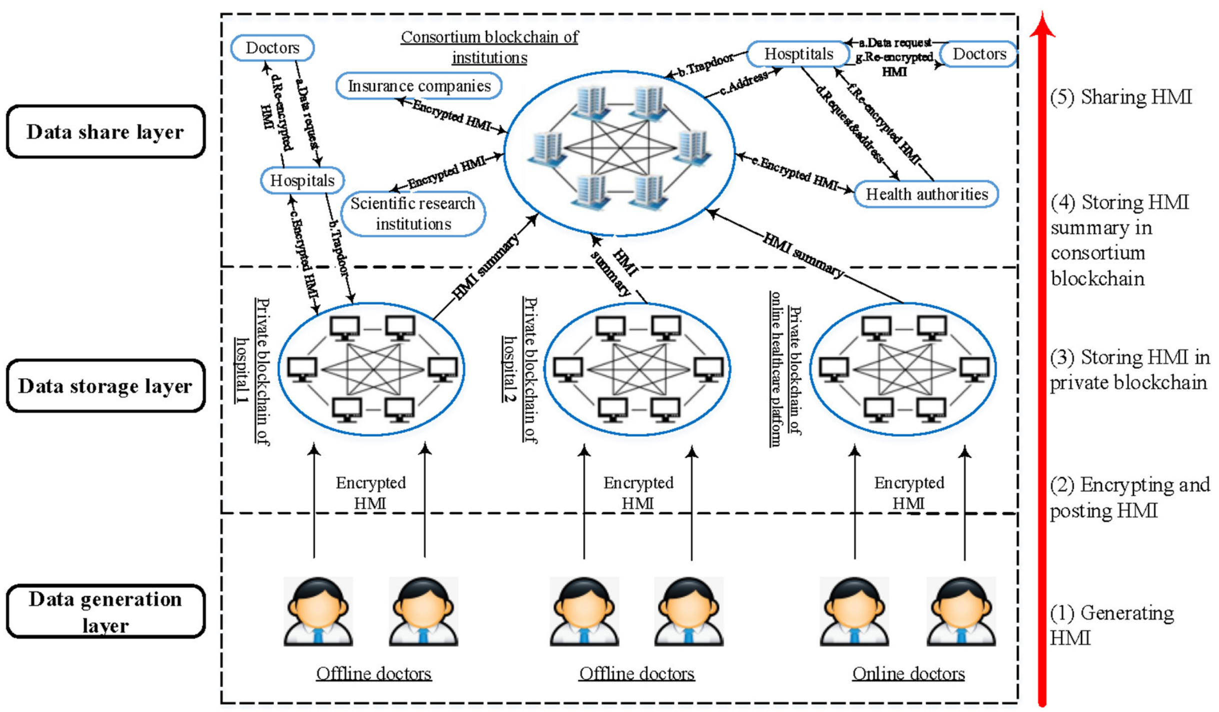

FIGURE 5
The protocol in the MBDS system.

TABLE 2 Pseudocode of encryting data.

Algorithm 1	**Encrypting data**
Input:	HMI M, keywords w, patient's public key PK_p, doctor's public key PK_d, doctor's private key SK_d, timestamp t, transaction type $Type$, transaction content $Text$.
Output:	Ciphertext C_M, C_w, digital signature Sig.
1:	$C_M = Enc(PK_p, M)$;
2:	$C_w = Enc(PK_p, w)$;
3:	$Sig = SIG(SK_d, t\|Type\|Text\|PK_d\|PK_p\|H(M)\|C_M\|C_w)$;
4:	**Return** C_M, C_w, Sig.

according to HMI to describe the patient's disease or symptoms. It is noted that the keywords need to comply with unified standards (such as the FHIR standard, a standard used to specify data formats and elements for the exchange of electronic medical records, to promote interoperation between healthcare systems). After generating the HMI M and the keywords w, firstly, the doctor d calculates the hash value $H(M)$ and then uses the patient's public key PK_p to encrypt the HMI and keywords to get the ciphertext C_M and C_W. After that, the doctor uses his private key SK_d to digitally sign the uploaded data. Finally, doctor d uploads the encrypted data and digital signature to the private blockchain ID_h of the belonged hospital h. The specific process is shown as Algorithm 1 in Table 2. The cloud storage server bundled with the blockchain stores the data and the blockchain executes the preset smart contract and notifies the patient p to confirm it after verification.

Data storage

After the doctor generated and uploaded the HMI to the private blockchain, the patient will receive a notification from the client. The patient first verifies the doctor's signature and uses the private key SK_p to decrypt the received ciphertext to obtain the plaintext M and w. The specific process is shown as Algorithm 2 in Table 3. After reviewing the HMI and related information, the patient will use the private key SK_p to encrypt and sign the data, the process is similar to Algorithm 1. During this process, the patient does not have permission to write or modify the data. So far, the data verification process of the patient has been completed. The private blockchain system stores the information confirmed by the patient according to the preset data structure, and returns the timestamp, transaction type, transaction content, doctor ID, patient ID, encrypted HMI keywords ($Enc(SK_p, w)$), encrypted HMI storage address ($Enc(SK_p, address)$) and HMI hash value. The returned information is stored in the transaction slip automatically, and at the same time, the patient digitally signs

TABLE 3 Pseudocode of decrypting data.

Algorithm 2	**Decrypting data**
Input:	Ciphertext C_M, C_w, patient's private key SK_p.
Output:	HMI M, keywords w.
1:	$M = Dec(SK_p, C_M)$;
2:	$w = Dec(SK_p, C_w)$;
3:	**Return** M, w.

TABLE 4 Pseudocode of sharing data.

Algorithm 3	**Sharing data**
Input:	Patient's public key PK_p, patient's private key SK_p, searched keywords w', doctor's public key PK_d, doctor's private key SK_d.
Output:	HMI M.
1:	Patient p generates the trapdoor of searched keywords w' and sends to doctor d: $T_{w'} = Trapdoor(SK_p, w')$;
2:	Doctor d sends PK_p and $T_{w'}$ to the proxy; then, the proxy checks whether there are records in the blockchain that the encrypted HMI keywords corresponding to PK_p match the trapdoor $T_{w'}$, if any, the proxy will obtain the encrypted HMI storage addresses stored in the transaction slips;
3:	Patient p decrypts the encrypted HMI storage addresses, then encrypts the addresses using the proxy's public key, and at the same time generates the re-encryption key $RK_{p\to d}$ for the proxy;
4:	The proxy accesses the encrypted HMI according to the received HMI storage addresses and re-encrypts the encrypted HMI to obtain re-encrypted HMI $C_{M\leftarrow PK_d} = ReEnc(C_M, RK_{p\to d})$;
5:	Doctor d decrypts the re-encrypted HMI sent by the proxy to obtain the plaintext: $M_i = Dec(SK_d, C_{M\leftarrow PK_d})$;
6:	Combine the multiple decrypted HMI to get integrated medical records: $M = Combine(M_1, M_2, \ldots, M_n)$;
7:	**Return** M.

the transaction slip. When 128 transaction slips are accumulated in the private blockchain or 10 min later, the primary node determined by the PBFT consensus mechanism will create a block to store the accumulated transaction slips. The data storage structure of a block in the hospital's private blockchain is shown in Figure 3.

Each hospital extracts the information summary from the data stored in each own private blockchain and submits it to the consortium chain for storage. When 10 new blocks are created on the private blockchain or 10 min later, the hospital on the private blockchain will extract the data summary from the stored transaction slips and upload them to the consortium blockchain. The data storage structure is shown in Figure 4. A block stores several transactions slip, a transaction slip contains 10 items, and an item stores the information summary of a transaction slip on the private chain (patient ID, encrypted HMI keywords, HMI hash value, HMI stored blockchain ID, block ID, and transaction slip ID). When the number of transaction slips accumulated in the consortium blockchain reaches 128 or 10 min later, the RPN determined by the DPoS consensus mechanism will create a block on the consortium blockchain, and ATN will be responsible for verifying the block.

Data sharing

The patient has full control over the access rights of his HMI, the patient can control data transmission and sharing by controlling the access rights. To ensure secure sharing of HMI and improve data access efficiency, patients can preset access permissions in the smart contract of blockchain, such as access permissions, access actions (such as read, write or copy), duration, etc. Once the access conditions are met, the smart contract will automatically trigger and perform corresponding operations to ensure the validity and fairness of data sharing. For nodes that are not in the set of nodes with preset access permissions, an application needs to be submitted to the patient, and the applicant can obtain the data access permission after the patient's confirmation.

When a patient p goes to a hospital h, a doctor d in this hospital thinks that it is necessary to know the patient's historical medical records, then the doctor can apply for access authorization from the patient and review the patient's relevant medical records. In the MBDS system, we can divide the data retrieval and share it into three scenarios. The first scenario is that the patient only visits the doctor in one hospital and has never been to other hospitals; the second is that the patient has treatment experience in multiple hospitals; the third is that the patient has treatment experience in many offline hospitals and Internet medicine platforms. There are some differences in data sharing among the three scenarios, Algorithm 3 in Table 4 shows the core steps in sharing HMI in the MBDS system.

In addition, as for the possible security vulnerabilities of the MBDS system, the MBDS system has established a security vulnerability identification mechanism. In terms of infrastructure components and facilities, the key points who provide infrastructure components and facilities must provide security protection for facilities and offline databases. In terms of identity theft, the system monitors the access times and IP addresses of the different types of users. If there is abnormal access, the node is temporarily disabled until the user identification is confirmed.

The process of a patient using the MBDS system

By integrally managing and distributing storing the healthcare information in the different offline hospitals and Internet medicine platforms, the MBDS system designed in this study aims to resolve the information silos and information fragmentation problems caused by the traditional centralized way of storing and sharing healthcare information, to integrate the online medical services provided on Internet medicine platforms into the current official healthcare system. In this way, we can achieve efficient and complete medical data sharing between various online and offline hospitals, and finally, provide a feasible solution to build an equal and credible medical ecological environment in the whole society. In an equal and credible medical ecological environment, all parties involved in the medical industry are equal and mutually trusted, the status between doctors and patients is equal, and information is transparently shared. Information silos, crises of confidence, and moral hazards will all be addressed to a certain extent.

In the established, equal, and credible medical ecological environment, through the MBDS system, the integration of offline medical care and online medical care can promote the seamless connection of online and offline medical treatment services, which helps to achieve the goal of hybrid medical treatment in both online and offline channels. In this way, both online and offline doctors can grasp the patient's disease information and historical electronic medical records, so there is no need to conduct secondary medical examinations and repetitive doctor-patient conversations. In addition, by referring to a patient's complete electronic medical records, doctors can conduct a unified analysis of the physical symptoms and treatment plans of patients in different periods and find potential or easily overlooked causes of disease, to facilitate a more careful and comprehensive diagnosis and treatment for patients.

To better understand, this section takes the complete process of a patient's online and offline medical treatment as an example to illustrate how to implement online and offline hybrid medical applications based on the MBDS system in an equal and credible medical ecological environment.

- Step 1, visit doctors on Internet medicine platforms. When a patient feels unwell, he will look up relevant information on the Internet medicine platforms (such as haodf.com), and infer the diseases he may have based on their symptoms. The patient will find appropriate an online doctor on the Internet medicine platform to seek online medical services. The patient can communicate with the doctor through text messages, voice messages, or phone calls. The doctor can make a preliminary diagnosis of the disease that the patient may have based on the patient's descriptions. If the doctor thinks that the patient's symptoms are normal or will heal and improve naturally, there is no need to worry about it too much. Afterward, the online doctor will generate HMI for the patient and submit the record to the private blockchain of the using Internet medicine platform. Then the patient will check and confirm the generated HMI. The encrypted HMI is stored in the private blockchain of the Internet medicine platform and the bundled cloud storage server. Hereto, the doctor and patient complete the online medical consultation service.

- Step 2, visit doctors in offline hospitals. If the above patient is not satisfied with the diagnosis result of the online doctor, or the doctor thinks that the patient needs to go to an offline hospital for necessary medical examinations and diagnosis, then after the first step, the patient will go to the offline hospital to find an appropriate doctor to seek offline medical service. The doctor in the offline hospitals has a preliminary understanding of the patients, and then obtains the patient's historical electronic medical record on Internet medicine platforms in the MBDS system after obtaining the patient's authorization. Then, the offline doctor will arrange medical examinations and treatment based on the medical records generated by online doctors and his medical knowledge and experience. Afterward, the offline doctor will generate HMI for the patient and submit it to the blockchain, the patient will check and confirm the generated HMI. The encrypted HMI is stored in the private blockchain of the offline hospital and the bundled cloud storage server. Hereto, the doctor and patient complete the offline medical service.
- Step 3, visit a different offline doctor or go to another offline hospital. If the above patient is not satisfied with the doctor he visited in the second step, he can choose to seek medical service from a different doctor or expert in the same hospital, or go to another hospital for treatment. When a patient goes to another doctor or hospital, the subsequent doctor can access the patient's historical electronic medical records through the data sharing operation in the MBDS system for further diagnosis and treatment. Information such as diagnosis results and treatment plans are also stored in the private chain of the belonging hospital. Hereto, the doctor and patient complete the online medical referral service.
- Step 4, online follow-up service on Internet medicine platforms. When the patient completes the diagnosis and treatment of the doctors in step 2 or Step 3, he can go to the Internet medicine platforms and seek online follow-up services from previously visited offline doctors. Online doctors can access the patient's historical electronic medical records and inquire about his recent physical condition, follow up on the patient's physical recovery and disease treatment, realizing closed-loop control. Online doctors will generate HMI for the patient based on the information during follow-up service and submit the HMI to the private blockchain. Hereto, doctors and patients complete the online follow-up service.

Through the above four steps, the MBDS system can realize patients' treatment between online hospitals and offline hospitals, and can also realize the referral between different offline hospitals or different online hospitals, providing technical support for the realization of online and offline hybrid medical care. Through the MBDS system, the medical resources and HMI of offline medical institutions (such as community hospitals, specialist hospitals, general hospitals, rehabilitation hospitals, scientific research institutions, etc.) and Internet medicine platforms can be systematically integrated to achieve efficient data sharing and incorporate the online medical service into the current healthcare system, to realize online and offline hybrid medical care. The designed system and proposed solution can solve the problems of medical information interconnection and resource sharing, improve the utilization efficiency of medical resources (including doctors and medical equipment), improve the efficiency and effectiveness of disease diagnosis, ease doctor-patient conflict, and improve the doctor-patient relationship.

Conclusions

This study used blockchain technology to store encrypted health and medical information in distributed storage mode and systematically integrated the health and medical information of patients in offline medical institutions and Internet medicine platforms, to achieve equality, credibility, and data sharing among participating nodes. To improve the data security on the blockchain, reduce the computational pressure and avoid the situation of too many nodes in the blockchain, this study built the private blockchains used for the hospitals and a consortium blockchain used between institutions, respectively, then combined the consortium blockchain and private blockchain to design the MBDS system. In terms of data storage, the system used the combination of blockchain and cloud storage to store medical data, which can meet the large-capacity demand of medical data while ensuring the safe storage of data. Besides, PEKS technology was used to achieve data retrieval on the premise of protecting patient privacy. In terms of data sharing, the MBDS system adopted PRE technology to facilitate data sharing and enhance data reliability and security while reducing the users' burden. By using the MBDS system, patients can achieve a seamless connection between Internet medicine platforms and offline hospitals, realize the efficient sharing of medical information, integrate online medical services into the current official healthcare system, and promote online and offline hybrid medical care. The realization of this will improve the utilization efficiency of medical resources, solve the problems of "difficult in seeing a doctor" and "inconvenient in seeing a doctor," and finally realize the purpose of alleviating doctor-patient contradiction and improving the doctor-patient relationship.

Currently, the medical industry is still trying various ways for storing and sharing health data. However, the existing medical data sharing system cannot achieve universal cross-regional and cross-institutional data sharing and application, and patients have no control over their medical record data. Most importantly, the current data-sharing system only realizes the sharing application of medical data, which cannot guarantee the accuracy of data and cannot provide endorsement for data. Therefore, the credibility and effectiveness of patient medical data in the process of cross-organization use are greatly reduced. The medical industry in the whole society cannot form a credible medical ecological environment. In contrast, the MBDS system designed in this study is based on the features of blockchain technology such as tamper-proof, traceability, decentralization, and joint participation, which realized the safe storage of medical data. Based on digital signatures, the doctor's endorsement of the patient's medical data ensures the accuracy and credibility of the data. In general, the system can achieve the goals of medical data security storage, tamper-proof, traceability, data sharing, and permission control, user privacy protection, information security retrieval, etc., which improves the shortcomings of the existing medical data sharing system and can better help build an equal and reliable medical ecological environment.

This study has some theoretical and practical implications. In terms of theoretical implications, firstly, this study put forward for the first time the concept of using medical blockchain to build an equal and credible medical ecological environment, which provided a new idea for the future development of the medical and health field. Secondly, from the perspective of cross-chain and double-chain, this research combined private chains and alliance chains to build a medical blockchain double-chain system. And at the same time, the designed system adopted different consensus algorithms in different types of blockchain. This study provided a new way for data storage and sharing in the medical industry, and provided a new idea for the design of a medical blockchain system. In terms of practical implications, the MBDS system constructed in this study and the proposed online and offline hybrid medical treatment mechanism incorporated online medical services into the current healthcare system and provided new solutions and practical guidance for the future development of collaborative medical care.

This study has several limitations, in the future, we will do further research in the following scope. Firstly, in terms of data retrieval, the use of PEKS technology can only realize the encrypted search of a single keyword, and the system through multiple searches to achieve multiple keyword retrieval. In the future, conjunctive keyword searchable encryption technology can be considered to reduce the number of searching times and improve retrieval efficiency. Secondly, in terms of data storage, the MBDS system used a combination of blockchain and cloud storage servers to store large-capacity data, but the storage of original data relies on cloud storage servers. Therefore, the choice of cloud storage providers needs to be extra cautious, and it is necessary to introduce multiple suppliers. The distributed storage of data will be distributed on multiple cloud storage servers to ensure data security.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

CL, JL, ZW, and JH: conceptualization. CL: methodology. CL and ZW: formal analysis. CL, JL, and GQ: writing- original draft. CL, JL, GQ, ZW, and JH: writing-review and editing. CL and JH: funding acquisition. GQ: literature. All authors contributed to the article and approved the submitted version. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding

This work was supported by the Major Program of the National Fund of Philosophy and Social Science of China (grant no. 18ZDA088), supported by research project of Shanghai University of Sport (grant no. 2022XJ024), and support by Shanghai Universities Young Teacher Training Funding Program.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 13 October 2022
DOI 10.3389/fpubh.2022.952415

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OPEN ACCESS

EDITED BY
Gulzar H. Shah,
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Amir Faisal,
Sumatra Institute of Technology, Indonesia
Simon Grima,
University of Malta, Malta

*CORRESPONDENCE
Al Asyary
al.asyary@ui.ac.id

SPECIALTY SECTION
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

RECEIVED 25 May 2022
ACCEPTED 20 September 2022
PUBLISHED 13 October 2022

CITATION
Herawati MH, Idaiani S, Maryati, Fitriana, Lucitawati, Veruswati M, Hoekstra K and Asyary A (2022) Health information system concept in health services in the national health insurance (JKN) era in Indonesia: An environment and one health approach. *Front. Public Health* 10:952415. doi: 10.3389/fpubh.2022.952415

Health information system concept in health services in the national health insurance (JKN) era in Indonesia: An environment and one health approach

Maria Holly Herawati[1], Sri Idaiani[1], Maryati[2], Fitriana[1], Lucitawati[1], Meita Veruswati[3], Karina Hoekstra[4] and Al Asyary[5]*

[1]National Research and Innovation Agency, Jakarta, Indonesia, [2]Health Sciences College of Abdi Nusantara, Jakarta, Indonesia, [3]Faculty of Health Science, Universitas Muhammadiyah Prof. Dr. HAMKA (UHAMKA), Jakarta, Indonesia, [4]Institut für Informationsmanagement Bremen (IFIB), University of Bremen, Bremen, Germany, [5]Department Environmental Health, Faculty of Public Health, Universitas Indonesia, Depok, Indonesia

The health information system is a component of the healthcare system. The health information system in health services in Indonesia has experienced many problems in getting support for policy making, the implementation of the industrial revolution 4.0, and national health insurance (JKN). To answer the above problems, it is necessary to make a concept of health information systems in health services that based on environment and one health perspectives. This research was part of the thematic research of the 2019 JKN National Health Facilities Survey (Rifaskes) in Indonesia. The systems approach and cross-sectional research were carried out by collecting quantitative data. A structural equation model with Lisrel 88 software was used to model the health information system. The health information system produced a concept that included the following structured input components: governance, human resources, infrastructure, types of information system (IS) (program, JKN, management), and financing; process components: funding, technical guidance, and verification and validation; and output components: open access, standards and quality, utilization, bridging, and security. The concept for strengthening the health information system prioritizes improving the output components (standards, utilization, bridging, open access, and security) in the process components (funding, verification, technical guidance) while the input components (financing, human resources, governance, IS programs, infrastructure, IS JKN, IS management).

KEYWORDS

health information system (HIS), health service, national health insurance, public health, one health approach

Introduction

Indonesia implements sustainable development in the health sector based on the principle of non-discrimination. Sustainable development begins with strengthening the system, which in this case is the health information system. The health information sys-tem can only be the basis for decision-making if the data is accurate, open, and interoperable, which was called one data in 2018 (1–6). The health information system in Indonesia faces several problems: Indonesia is currently still implementing the industrial era 4.0, while the world is already in the industrial era 6.0; information systems have not yet been merged or are not interoperable, both in the implementation of routine information systems and in implementing JKN; and time is not spent prioritizing developing technology, developing open standards, and managing security and privacy in health information systems (7–14).

In this case, the Ministry of Health is like a health organization, where this organization has service efforts in the form of hospitals, health centers, and clinics. The Ministry of Health also has administrative management at each level, from the central administration all the way to the smallest sub-district. Health service efforts with these administrations aim to make health services more accessible for communities in order to promote a healthy society (14, 15). To achieve its goals, the healthcare organization requires costs, technology, and planning as part of the identification of critical success factors. Improving the quality, accessibility, and sustainability of health services as well as increasing the availability and quality of health data or information and changes in the world in various sectors have an impact on health services in general and health information systems in particular (16).

In this article we propose an environment and one health framework for developing a high-level prospective concept of the implementation of health information systems in healthcare organizations. Based on the existing framework, we identified several critical dimensions that exist in the health information system, namely, management, financing, human resources, infrastructure, and the types of existing information systems (management information systems, program information systems, and JKN information systems) as an effort to achieve national health goals at the sub-district, district, provincial and national levels. This captures two important characteristics in the healthcare delivery process: the level of mediation and the level of internal and external collaboration.

Materials and methods

Ethical approval

This paper was developed based on the results of research on health information systems with Ethics Permit LB.02.01/2/KE.186/2019 (10).

Research period and location

The study was conducted in 2019 (July–December) in 7 provinces (Aceh, West Kalimantan, Central Sulawesi, South Sulawesi, NTB, West Java, and West Papua) in 103 districts with 420 healthcare units (400 health centers and 20 hospitals) (10). The selected study's location is regarded to Indonesia's representative multi-stage clustered sampling technique.

Research question

What is a mathematical concept for implementing the health information system in the implementation of JKN in Indonesia?

Data collection

This paper was part of the thematic research on health information systems in Health Facility Research 2019 and used the cross-sectional method. Quantitative data collectors used questionnaires that have been tested in their work. These tested instruments were checking its validity and reliability result before it was done to collect the information in healthcare facilities. Respondents were service officers of both hospitals and health centers who handled management data, program data, and JKN data. The questionnaire's structure followed that of the system research, which included input, process, and output categories. Inputs consisted of internal (HR, governance/leadership, infrastructure, financing, types of health services, management information systems, program information systems, and JKN information systems) and external (Border Remote Areas and Islands (DTPK) fiscal capacity) topics. Processes covered funding, technical guidance, and verification. And outputs consisted of quality standards, data utilization, bridging/interoperability, open access, and security. The researchers used a generic health facility research data collection team that had been retrained for the purposes of this thematic data collection. Researchers supervised the collections twice to maintain the quality of the research.

Data analysis

The analysis required structural equation modeling using the Lisrell method (16). The first step of our modeling was to normalize all variables, and after all variables were normal, then a good initial estimate was made of the latent component of the input with several forming variables (management, human resources, infrastructure, funding, management information systems, and program information systems, information on JKN, types of health services, health service facilities according to DTPK status, fiscal capacity status), the latent component

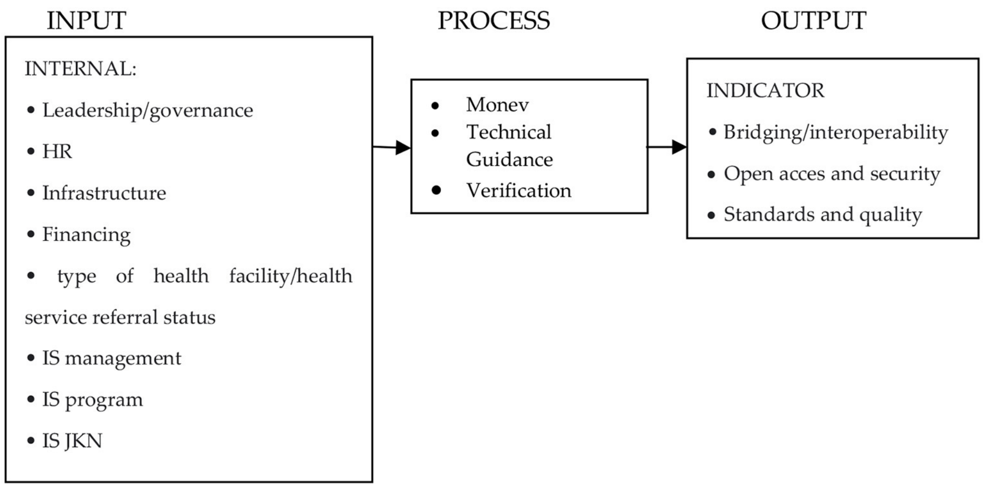

FIGURE 1
General form of structural equation modeling of the health information system in health services in the implementation of JKN in Indonesia.

of the process with several forming variables, and the latent component of the output with several forming variables. The input latent was an exogenous variable (X), and the process latent was an endogenous variable. For the next modeling, the process latent was an exogenous variable for the latent output, which was the final endogenous variable (Y).

Results

The research revealed several very useful findings, which were largely missing in existing literature. Several variables formed the input component: leadership/governance, human resources, infrastructure, funding, management information systems, program information systems and JKN information systems, types of health services, health service facilities according to DTPK status, fiscal capacity status. Thus, the variables of monitoring and evaluation, technical guidance, and verification and evaluation form the components of the process. Furthermore, the standard and quality variables, data utilization, bridging and interoperability, open access and security, formed the output components (Figure 1).

Input modeling

Information system modeling is essentially input modeling with several steps, namely, making an initial estimate and making a final estimate. The final estimation results of indicators that met the requirements of good validity were governance, human resources, infrastructure, funds, IS management, IS Program, and IS JKN [absolute value of Standardized Factor Loading (SFL) > 0.50]. However, several indicators had an SFL < 0.50 (DTPK, Fiscal, and Type of Health Facility) and were thus be excluded from the measurement model (Figure 2).

Process modeling

The process modeling shows the initial estimation and final estimation of the indicators that comprised the process components that met the requirements for entering the measurement model. The three indicators that comprised the process component can be seen in the (Figure 3).

Output modeling

Output modeling produces initial estimates of 5 constituent variables.

The Path Diagram shows that the SFL of Standard, Utilization, Bridging, Open Access, Security ≥ 0.50. The five indicators are valid indicators for the output variable. The next modeling forms a full model using the inputs, processes, and outputs and considers SFL, composite reliability, and validity. The (Table 1) and (Figure 4) below show the full fit model.

Structural model analysis

The (Figure 5) below illustrates the structural model and the results of the analysis. The (Table 2) below presents t values and coefficients.

From the Table 2 above, it can be interpreted that the results of the modeling analysis indicate that the health information

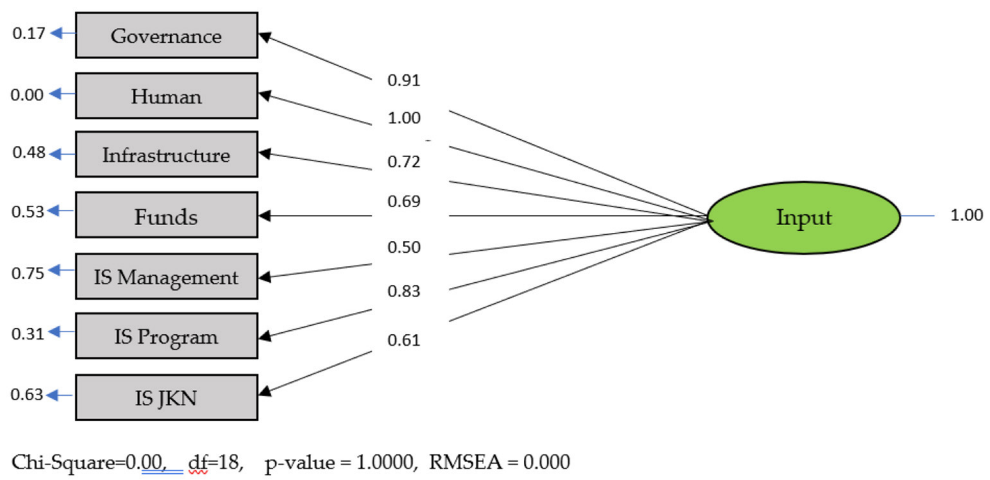

FIGURE 2
Standard input model solution.

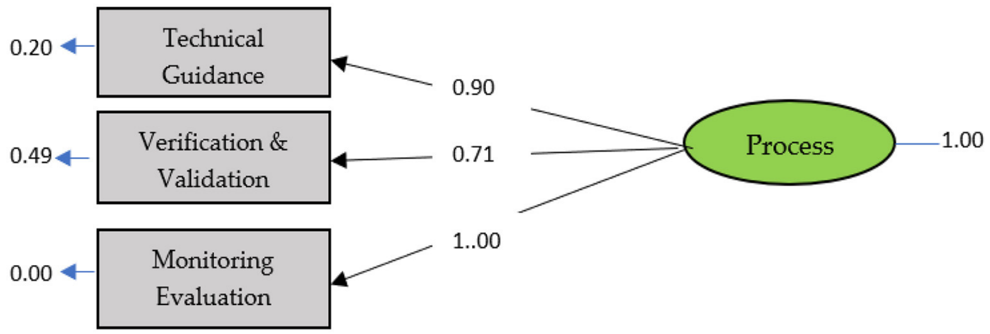

FIGURE 3
Standard process model solution.

system would be ready to be implemented with improvements in the outputs, then inputs, and then the processes. This means that the health information system already exists, but the output needs improvement in monitoring and evaluation and verification and validation, while the recommended output is improvement in output starting from open access, utilization, standards, bridging, and security. The input components to the process need to be improved in HR, Health Information System Governance, IS program, Infrastructure, Funds, IS JKN, and IS management.

Discussion

The results showed that the indicators of leadership/governance, HR, infrastructure, financing, IS management, IS Program, and IS JKN comprise the input components of the health information system in this modeling. Regulations that relate to the results of this study are the 2012 National Health System (SKN, 2012) article 2 paragraph 1, which states that health information is part of health management. Furthermore, Article 3 states that in the management subsystem includes health information and regulation. In the implementation of the JKN health information system at the public health center, the health information system was constrained by the lack of internet and human resources (17). To control the implementation of information systems in an organizational system, human resources and technology are important (18–20). Likewise, an organization must prepare human resources to adapt to face problems in the implementation of the system, especially information systems (21). Improving the health information system requires 3 components: the performance of the information system, which in this paper is included as infrastructure; the support

TABLE 1 Results of measurement model analysis.

Indicator variables	Standardized factor loading (SFL)	Composite reliability (CR) Variance extra (VE)	Conclusion
INPUT		CR = 0,91; VE = 0,59	Good validity
Governant	0,91		Good validity
Human resources	1,00		Good validity
Infrastructure	0,72		Good validity
Fund	0,69		Good validity
Management IS	0,50		Good validity
Program IS	0,83		Good validity
JKN IS	0,61		Good validity
Process		CR = 0,91; VE = 0,77	Good reliability
Technical guidance	0,90		Good validity
Verification & validation	0,71		Good validity
Monitoring evaluation	1,00		Good validity
OUTPUT		CR = 0,99; VE = 0,94	Good reliability
Standard	0,99		Good validity
Utilization	0,98		Good validity
Bridging	0,97		Good validity
OpenAccess	1,00		Good validity
Security	0,90		Good validity

CR, Composite Reliability; VE, Variance Extracted. CR 0.70 and VE 0.50 Good Reliability.

organization, which is termed in this paper as governance; and feedback from the health facilities as end-user. All three are necessary for a process to maintain quality (22).

In implementing the health information system at the health office, there were problems with human resources, supporting facilities, and commitment from the activity leaders who had not been trained to understand good data and information management (23, 24). As an analogy for this result from previous study on implementing the health information system at the Minahasa District health office, the manager of the health information system said that the most frequent obstacles were puskesmas reporting late, carrying out manual reporting, having no guidelines, lacking human resources in the field of health information systems (HIS), and lacking training, funds, facilities, and infrastructure (electricity, computers and internet) (25).

Further modeling finds that several indicators that make up the process components are technical guidance, monitoring, and evaluation as well as verification and validation. In some cases of recording and reporting systems, if there is no monitoring by village supervisors and program holders, it will usually be late. Because it is late, the head of the puskesmas often does not have time to check and dispose of it. Thus, it is signed and reported to the health office (11, 25). The results of other studies also stated that there was a need for agreement on the use of terminology standards so that the integration of various data sources can be done electronically (26).

The results of modeling the output components revealed the vital indicators of standards, utilization, bridging, open access, and security. The final modelers with the highest influence are HR, governance, program, infrastructure, funds, IS JKN, and management. In the process component, it is necessary to successively improve the health information system in monitoring and evaluation, technical guidance, verification and evaluation. Meanwhile, the output components are open access, standards, PE, the use of bridging, and security. Several studies have found that health information systems need bridging or interoperability. Too many health centers using health information systems require users to enter the same health data repeatedly, especially about the patient's social identity and clinical data, which makes the work inefficient (27). There needs to be a web-service-based bridging system development concept developed from the results of the prototype design of this health service information center that can meet user requests, such as users getting information on doctor's schedules, hospitalization, total blood stock nationally, pharmacies, reporting in the event of a disease outbreak, and reporting health agencies that have poor service (28). With the implementation of an information system with the web, the input of the health information system will be well documented in the system (18). Another study stated that the existing health information system has

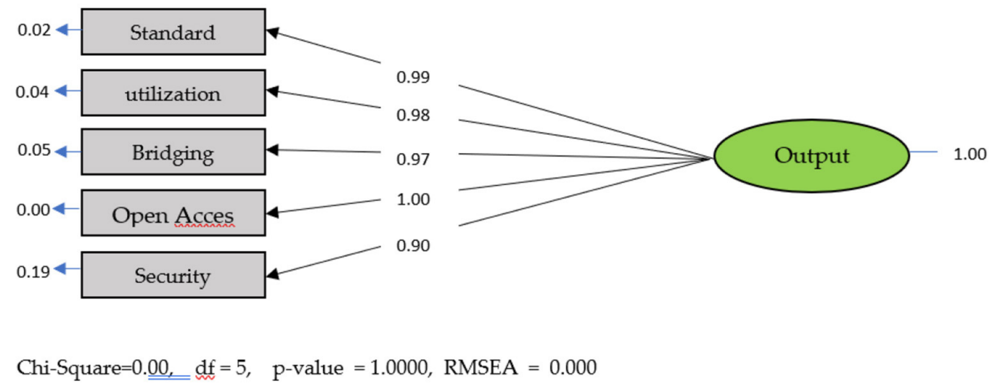

FIGURE 4
Standard output model solution.

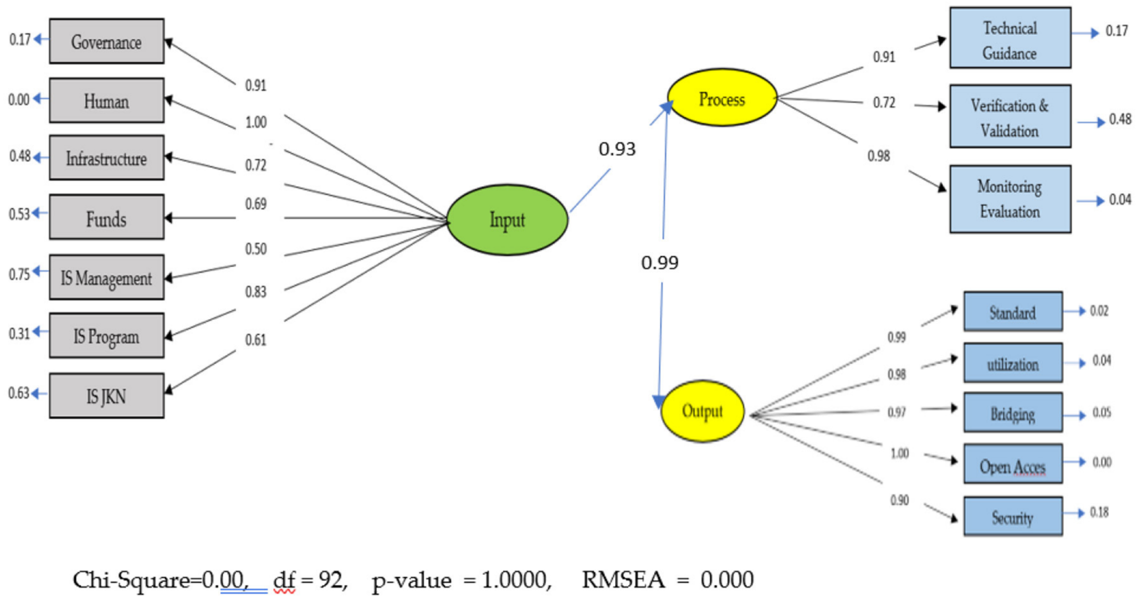

FIGURE 5
Complete model standard solution.

not run well because the recording and reporting process is still done manually, there is a lack of data security and a lack of data integration, and the information produced is not in accordance with the needs for decision-making (29). The design of the HIS at WEB-based mobile health centers overcomes the inability to provide the required information quickly, accurately, and on time manually through the information system (30).

The health information system is a means to support health services provided to the community. An effective health information system provides information support for the decision-making process at all levels, even at puskesmas or small hospitals. Not only data, but also complete, precise, accurate, and fast information can be presented with a well-organized and well-implemented health information system (16, 31). The health information system must have secure conditions (32). The results of several research projects suggest that the implementation of health information system integration will be carried out with policy support (33). Technology, which is part of the infrastructure in the input in this study, will facilitate the steps needed to achieve the output (33). In the health information system, data standardization is needed (34). Some studies argue that routine data is vital in making decisions as a basis for policy determination (34, 35). Another article mentions the role of doctors have in implementing health information systems (HR) in health services by improving the

TABLE 2 Results of structural model analysis.

Path	t-value	Coefficient	Conclusion
Input → Process	21.84	0.93	Significant positive
Process → Output	41.23	0.99	Significant positive

quality of health information systems as an effort to improve health services (36). Health information technology is indeed not the only effort to complete an information system, but it needs other components such as timely, complete, and accurate data as well as support from organizations such as feedback on reports and so on (37). This all will certainly affect the quality of information system data (38).

Conclusion

The health services concept in the JKN era for strengthening the health information system that based on environment and one health approach is formulated by each components including standardized and utilized input, process, and output. These can include factors such as bridging, open access, and security. In process, the recommend strengthening components, especially funding, verification, technical guidance. It is also important to strengthen input components: funding, human resources, governance, information system programs, infrastructure, JKN information systems, and information system management.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The study was approved by the Institutional Ethics Committee of Indonesian Ministry of Health (LB.02.01/2/KE.186/2019). Written informed consent was obtained from the participants.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding

This research was funded by the National Institute for Health Research and Development, Indonesian Ministry of Health. The publication was also funded by the Hibah PUTI UI 2022 (NKB-455/UN2.RST/HKP.05.00/2022). The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Acknowledgments

Our gratitude to all data collecting personnels in this study.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer ID declared a shared affiliation with the author(s) AA to the handling editor at the time of review.

Publisher's note

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TYPE Original Research
PUBLISHED 17 October 2022
DOI 10.3389/fpubh.2022.907141

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OPEN ACCESS

EDITED BY
Gulzar H. Shah,
Georgia Southern University,
United States

REVIEWED BY
Alexandru Corlateanu,
Nicolae Testemiţanu State University of Medicine and Pharmacy, Moldova
Ricardo Valentim,
Federal University of Rio Grande do Norte, Brazil

*CORRESPONDENCE
Runtong Zhang
rtzhang@bjtu.edu.cn

SPECIALTY SECTION
This article was submitted to Digital Public Health, a section of the journal Frontiers in Public Health

RECEIVED 29 March 2022
ACCEPTED 26 September 2022
PUBLISHED 17 October 2022

CITATION
Zhang X and Zhang R (2022) Factors influencing patients' opt-in intention of exchanging health information. *Front. Public Health* 10:907141.
doi: 10.3389/fpubh.2022.907141

Factors influencing patients' opt-in intention of exchanging health information

Xijing Zhang and Runtong Zhang*

Department of Information Management, School of Economics and Management, Beijing Jiaotong University, Beijing, China

Introduction: Health information exchange (HIE) exhibits tremendous benefits in improving the quality of healthcare and reducing healthcare costs. However, it also poses challenges related to data security, data privacy, patient engagement, etc.

Objective: This study aimed to explore the factors affecting patients' opt-in intention to HIE by using an empirical study based on the theory of planned behavior.

Methods: A Web-based survey was conducted involving 501 valid participants in China (69% validity rate).

Results: Information sensitivity and perceived HIE transparency affected the patients' opt-in intention to HIE through the mediation of perceived behavior control and trust in HIE. Information sensitivity negatively influenced perceived behavior control (−0.551, $P < 0.001$) and trust in HIE (−0.489, $P < 0.001$). Perceived transparency of HIE positively influenced perceived behavior control (0.396, $P < 0.001$) and trust in HIE (0.471, $P < 0.001$). Moreover, patients' opt-in intention to HIE can be positively affected by perceived HIE transparency (0.195, $P < 0.001$) and trust in HIE (0.294, $P < 0.001$). In addition, the moderating effect of health status was positive and significant between trust in HIE and opt-in intention to HIE but not between the perceived behavior control and opt-in intention to HIE.

Conclusion: This study contributes to the theory of planned behavior and enriches the literature on HIE efforts. HIE administrators should design personalized health services on the basis of these different health statuses to successfully achieve patients' opt-in intention to HIE.

KEYWORDS
opt-in intention, health information exchange, the theory of planned behavior, health status, transparency

Introduction

Health information exchange (HIE) is the sharing of electronic health information among different medical professionals and medical institutions with the help of health information technology (1). When patients directly switch from one medical institution to another, timely sharing of key patient information can prevent readmission, improve diagnosis rate, reduce repeated examinations, and avoid medication mistakes (2–5). However, some obstacles hinder the development of HIE. For example, researchers can retrieve electronic databases to reuse the data; therefore, seeking informed consent from patients when obtaining data is unrealistic for each platform (6). As important stakeholders of HIE projects, patients can influence data collection and information sharing (7). Opt-in intention to HIE is the extent to which a patient is willing to rely on HIE as a useful and reliable technology to be used by healthcare entities for information dissemination (8).

The theory of planned behaviors (TPB) is a social psychological theory explaining the relationship between attitude and behavior. As one of the important theories to predict and explain human behavior, TPB is widely used in healthcare, management, education, psychology, information science, economics, and other fields (9–11). Based on TPB, perceived behavior control, attitude, and subjective norms are three factors affecting opt-in intention (12). However, in the healthcare industry, Deng et al. (13) and Heart et al. (14) found that subjective norms will not significantly affect the patients' intention to use health information and communication technology. The subjective norms depend on normative beliefs. This normative belief has two meanings given as follows: one is the degree to which individuals perceive that their significant people expect them to perform certain behaviors; another is the extent to which individuals conform to these views. In line with these meanings, social pressure is difficult to understand directly by obeying or disobeying the wishes of others (15). Therefore, subjective norms do not have a good effect in reflecting the influence of social pressure on individual behavior. Moreover, attitude is a broad concept and cannot be described using some single words. Studies using a single measurement to decide attitudes, such as interesting–boring, useful–useless, upset level, and regrets, are available (12, 16). Many scholars use trust to represent attitude when studying the patients' opt-in intention to HIE (8, 17). Thus, we reset the TPB model by removing subjective norms and further expand the factor attitude to trust.

Thus, according to TPB, perceived behavior control and attitude (i.e., trust) are the two factors affecting opt-in intention. Perceived behavior control is widely applied to behavior research models, referring to the degree to which individuals feel that they can control or master a particular behavior (18). Trust is defined as trusting beliefs, which are the cognitive beliefs shaped by the trustor (19). Meanwhile, information sensitivity refers to the degree to which individuals pay attention to the information in a particular environment (20) and is closely linked to privacy concerns. Information sensitivity and privacy concerns are major barriers to patients' acceptance of information sharing. Moreover, transparency refers to the right to know what type of health information is shared, with whom, when, and for what purposes (17) and represents how patients can understand the type of information shared, frequency, senders, recipients, and purpose of exchange. The transparency of privacy policy dimensions is a sound rationale for consumers to trust in HIE competence (17). Thus, information sensitivity and HIE transparency may be factors affecting perceived behavior control and trust in HIE.

This study is conducted to investigate how individual consumers develop their opt-in intention to HIE by utilizing the TPB and advances in this research area. An important knowledge gap is also addressed by applying this model to assess the factors affecting patients' opt-in intention to HIE. Previous studies have found physicians' influence of HIE (21, 22), but limited empirical studies have examined the effect of health status on individuals' intentions to disclose their personal information in the field of HIE [e.g., Esmaeilzadeh's study (23) and Yaraghi's study (24)]. Moreover, no prior work has explored the moderating effect of health status on the relationship between perceived behavior control and patients' opt-in intention to HIE and between trust in HIE and patients' opt-in intention to HIE. Thus, how the health status strengthens or suppresses the effects of perceived behavior control and trust in HIE on opt-in intention to HIE is a valuable research field (22). Especially, research on HIE in China is still in its infancy because foreign research results cannot be directly applied in this country (25, 26).

Hypotheses

The research model describes how patients' opt-in intention to HIE is influenced. The independent variables are information sensitivity and perceived transparency of HIE, the mediators are perceived behavior control and trust in HIE, the dependent variable is opt-in intention to HIE, and the moderate variable is health status.

Whether consumers are willing to disclose personal information is related to the sensitivity of such information (27). Patients may intend to hide health information from healthcare providers if their needs for protecting information sensitivity are not met. This behavior occurs because the low sensitivity of the information required by the website will reduce users' anxiety about personal information being leaked or shared, thereby making them feel that they have high control over personal information (28).

The content of privacy statements is founded as a significant factor to predict consumer trust in many industries (29–31). If health records are exchanged confidentially, patients will increase trust toward HIE (32). Consumers' responses to privacy issues depend on the type of health information that is exchanged electronically with other healthcare providers (33). A trustful attitude toward an HIE system is a result of a solid match between the HIE mechanisms and security or privacy requirements (34). The greater the sensitivity involved in medical information, the more serious people's privacy concerns will be when releasing it, which will reduce their trust toward behaviors (35). This discussion results in the following hypotheses:

H1: Information sensitivity has a negative impact on perceived behavior control.
H2: Information sensitivity has a negative impact on trust in HIE.

If the privacy policy is transparent, patients can recognize the suppliers, information type, and the switching mechanism (12). Consequently, patients will have a comprehensive understanding of main functions of the HIE and related sharing procedures and safety mechanisms. Then, patients will perceive that the electronic exchange of information among healthcare providers is a convenient and cost-effective sharing method (36). Accordingly, people will feel that they can control the process of HIE, and the perceived behavior control can be improved.

If individuals realize that some technology is logically reliable, they will become more likely to rely on it emotionally (30). Clearly defining and promoting privacy policies are efficient and practical methods for patients to realize that information is shared electronically between medical institutions and individuals in a complete and unblemished way. This recognition may increase the trust in HIE capabilities and encourage patients to believe that the HIE technology is a true expert system in the field of information sharing. In other words, patients believe that HIE is trustworthy because it has the necessary technical basis and effective communication mechanism, which can effectively share health information between providers. Thus, we propose the following hypotheses:

H3: Transparency of HIE has a positive impact on perceived behavior control.
H4: Transparency of HIE has a positive impact on trust in HIE.

According to the TPB, perceived behavior control and attitude (i.e., trust) in HIE are the two main factors affecting opt-in intention to HIE (12). Users believe that if they have enough information (e.g., website privacy settings and legal requirements) to ensure that the information they publish is safe, then they will be willing to share their personal medical information. Simultaneously, if they think they have the skills and tools to deal with the consequences of releasing the information, they will be happy to allow information exchange among medical instructions.

Mital et al. (37) argued that trust promotes individuals' willingness to share information. Given that patients often cannot adopt HIE directly, they can develop attitudes, beliefs, and emotions that participate in the concept of shared efforts. Therefore, the use of perceptual measures should be evaluated, rather than the actual selection of the behavior. The patients' sense of security and strong comfort in relying on the HIE network can increase the intention to opt-in the HIE system. The sense of trust becomes their tool to help them decide to support medical institutions in using HIE to improve the quality of care and reduce the cost of care. Accordingly, perceived behavior control and trust in HIE can encourage patients to share their medical records with related entities. Thus, we hypothesize as follows:

H5: Perceived behavior control has a positive impact on opt-in intention to HIE.
H6: Trust in HIE has a positive impact on opt-in intention to HIE.

Individuals will have different views on information disclosure under different health conditions (38). The extent to which perceived behavior has control on opt-in decisions may vary depending on the current health status of people. People who are always plagued by illness are more anxious about HIE behavior held by healthcare providers than healthy people because they have more privacy concerns and feel less control over their private health information (39). However, patients with poorer health status are more likely to choose HIE for better therapeutic effects, regardless of the level of perceived behavior control (39). Given the physical or mental weaknesses, they believe their control over HIE is limited, but they may allow medical institutions to exchange their electronic information in the hope of helping suppliers access their complete and updated medical records. Thus, health status enhances the relationship between perceived behavior control and opt-in intention to HIE.

The psychological characteristics of patients are anxiety, depression, and pessimism (40). Patients with worse health status have better information needs than other patients and will rely more on HIE to improve health statuses and relieve mental stress. Accordingly, patients with poorer health status have a stronger sense of and dependence on the HIE than others for the purpose of obtaining social support and care whether they trust in HIE or not. Health status can especially strengthen the effect of trust in HIE on patients' intention to HIE. On the contrary, people with healthy status have less demands for the HIE system. Whether they trust in HIE or not and perceive that they can control the process of HIE or not, they will not have strong intention to use it, indicating that the relationship between perceived behavior control and opt-in intention to HIE and between trust in HIE and opt-in intention to HIE can be weakened when health status is well. Thus, we hypothesize as follows:

H5m: Health status positively moderates the relationship between perceived behavior control and opt-in intention to HIE.
H6m: Health status positively moderates the relationship between trust in HIE and opt-in intention to HIE.

Materials and methods

Measurement development

The constructs included in the model were measured in accordance with the literature. The variables in the research model were measured using a five-point Likert response format, ranging from strongly disagree to strongly agree (as shown in Supplementary material), which was validated by previous works. Items measuring opt-in intention to HIE were modified from the studies by Venkatesh et al. (41) and Angst et al. (42). A total of five items reflecting perceived health information sensitivity and three items reflecting health status were adapted from the scales by Bansal and Gefen (35). We adapted the method mentioned in studies by Chua et al. (43) to measure the transparency of HIE. Trust in the HIE was measured by modifying the methods in the studies conducted by Wu et al. (30). Perceived behavior control was measured by modifying the methods in the studies by Hsieh (25).

Analysis tool selection

Structural equation modeling (SEM) is useful in analyzing the causal relationships between research models and for exploratory research and theory development. This study adopted the partial least squares (PLS)-SEM method to analyze the research model and used SmartPLS version 3.0 to estimate path models with latent variables and their relationships.

Data collection and respondents

The formal investigation was conducted in March 2020 in a Web-based platform. The study was approved by the Ethical Committee of the School of Economics and Management, Beijing Jiaotong University. At the beginning of the online survey, the HIE technology was described in detail to the respondents to ensure that they fully understood the background and purpose of the research as most respondents were not aware of HIE (44). We specified an additional qualification that they must know HIE by defining screening questions to check whether their experience in the HIE project satisfied our criteria. They were asked to describe whether and why they were familiar with HIEs before answering the main survey questions. The completion time was also checked; if the completion time was obviously lower than the average time, the survey would be invalid. In total, 728 individuals attempted the survey, and 69% (501/728) of them were aware of HIE by visiting a healthcare provider participating in an HIE project or attending HIE project before. Others were not aware of HIE or were aware of HIE because of other reasons, such as reading newspapers, through Internet searching, families, and friends.

TABLE 1 Sample demographics ($N = 501$).

Demographic characteristics	Participants, *n* (%)
Age (years)	
<20	8 (1.6)
20–29	127 (25.35)
30–39	222 (44.31)
40–49	112 (22.36)
50–59	31 (6.19)
60 and above	1 (0.02)
Gender	
Male	239 (47.7)
Female	262 (52.3)
Resident status	
Urban	341 (68.06)
Rural	160 (31.94)
Education	
Junior middle school or below	3 (0.60)
High school	65 (12.97)
Junior college	158 (31.54)
Bachelor's degree	225 (46.31)
Master's degree	43 (8.58)
Doctor's degree	7 (1.40)

Table 1 shows the demographics of the sample. The demographic characteristics of the participants showed that the age of respondents ranged from 18 to 65 years. Approximately 70% of respondents were 20–39 years old, and only 2% were 60 years and older. Approximately 45% of the participants had education of below high school, and some had college degrees. Close to 46% had bachelor's degrees, and the remaining had graduate degrees (master's degree or doctorate). The largest number of participants (68%) lived in urban areas. More female (52.3%) than male (47.7%) participants were involved. A previous study has also reported that HIE users are likely to be young, female, and educated (17). Therefore, the sample met our requirements.

Results

Hypothesis testing

We first calculated the outer loading for all construct by using SmartPLS software 3.0, and all values were > 0.700. The Cronbach alpha of each construct was greater than the cutoff value of 0.700 (45), which indicated good reliability of scales. The convergent validity of scales was acceptable because the composite reliability (CR) and average variance extracted (AVE) of constructs exceeded the cutoff values of 0.700 and 0.500, respectively. All the diagonal values were >0.7 and exceeded the correlations between any pair of constructs; thus, the discriminant validity was acceptable.

We added gender, age, living area, and education level as control variables. Cohen f^2 was used to assess the effects of the control variables (46). In the regression relationship, all the variables had good explanations because all the multivariate coefficients of determination (R^2) were higher than 0.67. We contended that all control variables had insignificant effects on the research model (i.e., insignificant: <0.020; small: ≥0.020 and <0.150; medium: ≥0.150 and <0.350; and large: ≥0.350).

According to Figure 1 and Table 2, all hypotheses were supported (i.e., H1, H2, H3, H4, H5, H6, and H6m), except H5m. The possible reasons for the insignificant relationship are stated in the next section, and we estimated the medicating effect by bootstrapping. Table 3 shows the effect size of each construct in the research model. The results indicate that information sensitivity and perceived transparency of HIE had medium influences on the perceived behavior control and trust in HIE, and the influences of perceived behavior control and trust in HIE on opt-in intention to HIE were weak with small effect sizes.

We conducted additional analysis by bootstrapping to confirm the mediating effect, as shown in Table 4. The indirect relationship between information sensitivity and opt-in intention to HIE was significant ($p < 0.01$ and exclusive 0 among confidence intervals), indicating that the mediating effects of perceived behavior control and trust in HIE between information sensitivity and opt-in intention to HIE existed. Similarly, the mediating effects of perceived behavior control and trust in HIE between perceived transparency of HIE and opt-in intention existed because the p-value of path was <0.001 and exclusively 0 among confidence intervals. Furthermore, the direct and total effects were all significant, showing that the partial mediating effects existed between information sensitivity and opt-in intention and between perceived transparency of HIE and opt-in intention.

Moderating effect

The moderating effect of health status on the paths of trust in HIE to opt-in intention to HIE was significant ($\beta = 0.138$, $p = 0.006$), whereas the moderating effect of health status on the paths of perceived behavior control to opt-in intention to HIE was insignificant ($\beta = 0.075$, $p = 0.016$). We performed simple slope analysis to further explore the moderating effect of trust in HIE on opt-in intention.

The results in Figure 2 revealed that a significant difference existed in the relationship between trust in HIE and opt-in intention between healthy and unhealthy individuals. This difference implies that individuals who perceive their health status to be worse have a higher level of influence on the relationship between trust in HIE and opt-in intention to HIE than those who perceive themselves as healthy. Thus, unhealthy status has a stronger moderating effect on the relationship between trust in HIE and opt-in intention to HIE than healthy status. Therefore, the results indicate that the linkage of trust in HIE with opt-in intention is positively moderated by the health status.

Discussion

This study explores the factors affecting opt-in intention to HIE based on the TPB control, and it is one of the first attempts to study the moderating effect of health status on patients' opt-in intention to HIE. Moreover, this study applied the famous TPB widely used in people's behavior intention to HIE context. First, we drew upon the TPB to explain how patients' opt-in intention is affected in the context of HIE. We clarified that the patients' opt-in intention to HIE can be affected by information sensitivity and perceived HIE transparency through the mediation of perceived behavior control and trust in HIE. Information sensitivity and perceived HIE transparency directly impact the perceived behavior control and trust in HIE and indirectly affect the patients' opt-in intention to HIE because all the paths were significant as per hypothesis testing. The path coefficient from trust in HIE (0.294) was significant and higher than that from perceived behavior control (0.195) to opt-in intention to HIE. Therefore, trust in HIE is an important variable in the context of HIE rollout. HIE policymakers should take actions to increase reliability and transparency of sensitive information for fostering patients' trust. For example, hospitals can publicize privacy protection policies to patients in a timely manner, explaining how information is collected and how it is used and stored in an easy-to-understand manner so that patients know that their personal privacy is closely protected. At the same time, the amount and type of required information can be reasonably set, and some highly sensitive information filling requirements can be set as optional so as to avoid forcing patients to provide sensitive personal information, thus cultivating patients' trust in the platform and reducing their concerns about information privacy sharing.

Second, information sensitivity had negative and significant influences on perceived behavior control (−0.551) and trust

TABLE 2 Hypothesis testing.

Hypothesis	Path coefficient	*T*-test	*P*-value
H1: Information sensitivity has a negative impact on perceived behavior control.	−0.551	12.788	<0.001
H2: Information sensitivity has a negative impact on trust in HIE.	−0.489	12.516	<0.001
H3: Perceived transparency of HIE has a positive impact on perceived behavior control.	0.396	9.160	<0.001
H4: Perceived transparency of HIE has a positive impact on trust in HIE.	0.471	12.049	<0.001
H5: Perceived behavior control has a positive impact on opt-in intention to HIE.	0.195	4.711	<0.001
H6: Trust in HIE has a positive impact on opt-in intention to HIE.	0.294	5.582	<0.001

TABLE 3 Partial least squares effect size analysis.

Variables	R^2		ΔR^2	Cohen f^2	Effect size
	In	Out			
Opt-in intention to HIE					
Perceived behavior control	0.900	0.894	0.006	0.06	Small
Trust in HIE	0.900	0.888	0.012	0.12	Small
Perceived behavior control					
Information sensitivity	0.869	0.832	0.037	0.282	Medium
Perceived transparency of HIE	0.869	0.850	0.019	0.145	Medium
Trust in HIE					
Information sensitivity	0.893	0.863	0.030	0.280	Medium
Perceived transparency of HIE	0.893	0.865	0.028	0.262	Medium

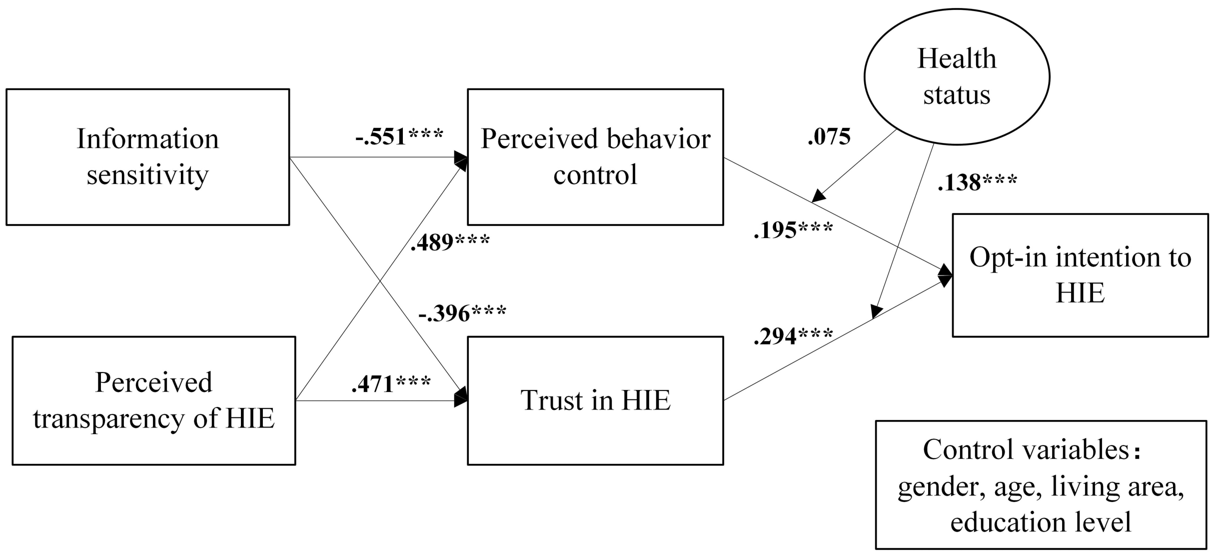

FIGURE 1
Research model with path coefficients. ***P <0.001.

in HIE (−0.396). The perceived transparency of HIE also significantly affected the perceived behavior control (0.489) and trust in HIE (0.471). Thus, healthcare entities should implement strategies to demonstrate HIE policies for the purpose of generating knowledge of operation in HIE, resolving uncertainty in the process of data sharing, and advancing awareness of HIE. For example, practitioners and government officials can promote the main objectives and policies of HIE by holding

TABLE 4 Path coefficients by the bootstrapping method ($n = 5000$, 95% CI).

Effects	Path coefficient (SD)	*P*-value	Confidence interval
Direct effects			
Information sensitivity -> perceived behavior control	−0.551 (0.043)	<0.001	0.459–0.635
Information sensitivity -> trust in HIE	−0.489 (0.039)	<0.001	0.413–0.567
Perceived behavior control -> opt-in intention to HIE	0.124 (0.041)	<0.001	0.044–0.203
Perceived transparency of HIE -> perceived behavior control	0.396 (0.044)	<0.001	0.313–0.488
Perceived transparency of HIE-> trust in HIE	0.471 (0.039)	<0.001	0.392–0.548
Trust in HIE -> opt-in intention to HIE	0.187 (0.049)	<0.001	0.087–0.279
Indirect effects			
Information sensitivity -> opt-in intention to HIE	−0.160 (0.032)	<0.001	0.101–0.223
Perceived transparency of HIE -> opt-in intention to HIE	0.138 (0.028)	<0.001	0.086–0.192
Total effects			
Information sensitivity -> opt-in intention to HIE	−0.341 (0.055)	<0.001	0.234–0.451
Perceived transparency of HIE -> opt-in intention to HIE	0.355 (0.047)	<0.001	0.256–0.444

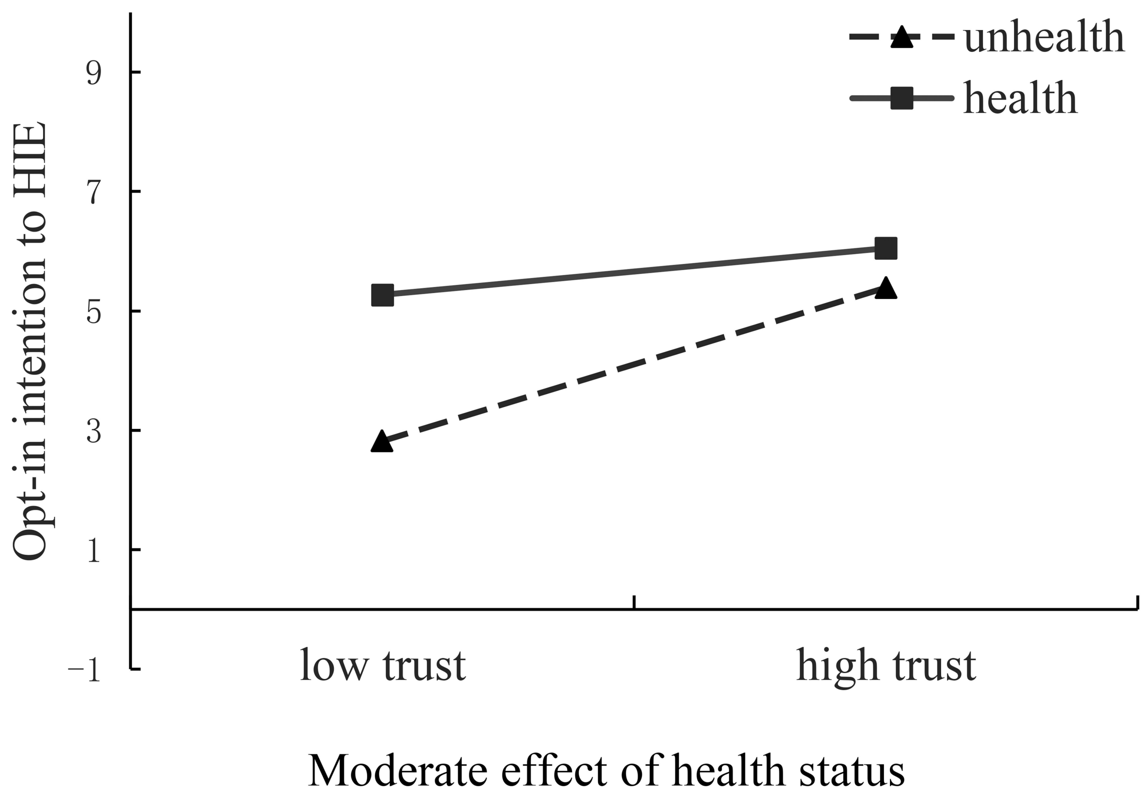

FIGURE 2
Interaction graphs.

national education programs, which are accessible to a wide range of people. The Internet, such as forums of health, is an effective place to broadcast HIE efforts and increase the general public awareness on HIE mechanisms. Moreover, during the outbreak of the new coronavirus, the short board of HIE development was also shown. Given the lack of policy and regulatory guidance, data exchange and sharing were difficult during the COVID-19 pandemic because of concerns about data security and patient privacy. With some supports by economic laws (47, 48), a great deal of assurance can be achieved for the rapid data collection during possible future outbreaks of infectious diseases.

Third, the findings on the moderating effect indicate that the health status may change the beliefs of consumers about the extent to which their health information will be released. When patients are in an unhealthy status, the influence of trust in HIE on opt-in intention to HIE will be enhanced. Given the unexpected results regarding the moderating role of health status between the perceived behavior control and opt-in intention to HIE, further studies can deeply investigate the effect of health status, which may be more complex than we discussed. The HIE administrators must design personalized health services based on these different health demands and especially focus on a non-stigmatizing service design. Accordingly, patients' opt-in intention to HIE will be enhanced.

The limitations of the study must be considered. First, we only focused on the moderating effect of health status on patients' opt-in intention to HIE. Other factors can be added for further investigation, for example, patients' social network. Second, we only considered subjects who are in China. China has a large population and unbalanced healthcare development in different areas. There may be different aspects between China and other countries. Therefore, the generality of the results should be further explored in other countries. Third, this study only collected data through one cross-sectional survey; thus, we cannot capture patients' dynamic changes of attitudes toward all variables. Last, although our sample met the characteristics of typical HIE users, the number of respondents was relatively small considering the feature of Chinese census data.

Conclusion

The patients' opt-in intention to HIE is crucial for the wide use of HIE. This study clarified that patients' opt-in intention to HIE could be affected by information sensitivity and perceived transparency of HIE through the mediation of perceived behavior control and trust in HIE. The perceived behavior control and trust in HIE were positively and significantly affected by information sensitivity and perceived HIE transparency, respectively. In terms of the moderating effect, health status was confirmed to enhance the relationship between patients' trust in HIE and opt-in intention to HIE. These findings are as follows: (1) Educating consumers about HIE mechanisms and sharing procedures to appeal to their awareness of sensitive information policies and mechanisms of HIE are important because of the difficulties in each confirmation of HIE; (2) researchers, physicians, and policymakers should design personalized health services based on these different health statuses for acquiring patients' opt-in intention to HIE; and (3) enhancing research collaboration and information sharing is necessary to improve the timeliness and effectiveness of clinical trials and enhance the research response capacity to public health emergencies.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Ethical Committee of the School of Economics and Management, Beijing Jiaotong University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

XZ and RZ contributed to this study, conceived and designed the study, developed the research model, designed the questionnaire, and drafted the manuscript. XZ mainly conducted data collection and analysis. RZ modified the manuscript. Both authors approved the final version of the manuscript for submission.

Funding

This work was supported by a major project of the National Social Science Foundation of China (Grant Number 18ZDA086), a project of the National Natural Science Foundation of China (Grant Number 62173025), and a key project of the Beijing Social Science Foundation Research Base (Grant Number 18JDGLA017). Meanwhile, this work was supported by Beijing Logistics Informatics Research Base.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.907141/full#supplementary-material

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