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Digital information for patient education

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Digital information for patient education

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Table of contents

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Editorial: Digital information for patient education

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Editorial on the Research Topic
Digital information for patient education

1. Introduction

With the development of digital technologies, numerous technologies such as online platforms, big data, live streaming, and artificial intelligence are leading the transformation of health/medical information and are bringing new models for healthcare information management (1–3). Digital information can help patients to access health knowledge remotely and benefit patient wellbeing (4, 5). For example, online health information offered by digital technologies [e.g., online health communities (OHCs) and mobile health services] create different ways of healthcare delivery, alter the management of patients' health (6, 7), and provide a boost to the quality and quantity of healthcare services (2), which is beneficial to improve patients' perceived treatment effectiveness (8).

However, research gaps exist in the literature about the relationship between digital health information and patient education and how to provide digital information to educate and benefit patients by improving their understanding. Patient understanding is significant for health information management and patient education due to the fact that only once patients understand the information online can they learn and benefit from the health knowledge-sharing processes (9). As we know, health information usually contains some medical vocabulary, and the patients have difficulty understanding them. Fortunately, digital technologies can offer personalized health information to patients in different organizational types and provision styles. In this vein, the use of digital technologies by providing new approaches for health information sharing (10) may better educate patients and enable patients to better understand their health. This Research Topic aims to explore the role of digital health information in patient education.

This Research Topic focuses on digital information for patient education and underlines original contributions on patients' better understanding the online health information and knowledge by conceptualizing and contextualizing the organization of digital information on health. In the next section, the articles in this Research Topic are introduced. Finally, we will summarize the study with a conclusion.

2. Articles in this Research Topic

This Research Topic contains nine articles that have successfully negotiated the standard *Frontiers in Public Health* peer-review process. While the nine articles are quite diverse in terms of topics, theoretical perspectives, and methodologies, they are also related to one or more of the themes identified above. We have summarized the articles and they can be classified into four themes: (1) new digital tools or methods for patient education and health, (2) social media and social networks promoting healthy information and behaviors, (3) the effect of online health community (OHC) and mobile health (mHealth) on healthy lifestyle and health conditions, and (4) physician online information sharing and patient education.

Two studies related to new digital tools or methods for patient education and health. Wang et al. conduct clinical prognosis in cervical spondylotic myelopathy by applying an established predictive nomogram which is grounded in the pre-operative Japanese Orthopedic Association score, maximal canal compromise, and maximal spinal cord compression. According to the results of the predictive nomogram, it improves the prognosis of high-risk patients by helping clinicians and patients to identify and educate high-risk patients. According to a pilot study to evaluate the efficiency of Individualized Reduction of FaLLs-Online, Van Denend et al. find that key stakeholders' feedback is vital for a meaningful process evaluation and an online delivery support program implementation is beneficial to improve the satisfaction of participants and trainers. Individualized Reduction of FaLLs-Online benefits individuals using wheelchairs or scooters with multiple sclerosis, and future iterations are encouraged to offer a program with diverse approaches to fall prevention and management.

Two articles focus on social media and social networks promoting healthy information and behaviors. Bai et al. quantitatively evaluate the quality of English YouTube video content which is an important information source for testicular torsion. Based on 66 videos collected from YouTube, the results show that general information (i.e., etiology, symptoms, and treatment) is the most common video content. While medical or education-related authors contribute a large proportion of videos on YouTube, the quality of the videos remains poor. It is worthwhile to emphasize that during the COVID-19 pandemic, misleading and false information tended to produce health risks to the viewers. In addition, great efforts are needed to improve the quality of videos about testicular torsion. Faus et al. apply a systemic review to 18 academic articles to study the different effects of healthy behavior-related campaigns. The results indicate that only a few high-quality studies evaluate the effectiveness of social campaigns that are disseminated on Twitter. Furthermore, their effectiveness and influence on public health-related behaviors are arguable due to a lack of evaluation of these campaigns, evaluation of them by ambiguous and biased indicators, and ignoring systematic follow-ups over time. Moreover, the identified limitations in this systematic review are beneficial to optimize the paradigm and improve the effectiveness of the communication strategies regardless of there being no strong evidence that Twitter is a suitable medium to rouse public health awareness about behavioral health issues.

Two articles consider the effect of online health community (OHC) and mHealth on healthy lifestyles and health conditions. Zhou et al. draw on social network theory and self-efficacy literature to explore the effect of online health community engagement on lifestyle changes. By applying structural equation modeling with 320 valid questionnaires, the results indicate that OHC engagement and health self-efficacy facilitate healthy lifestyle changes. OHC engagement also has a positive effect on informational support and emotional support which are positively related to health self-efficacy. Furthermore, the mediating effects of informational support, emotional support, and health self-efficacy are also identified. Yuting et al. track the effects of a mHealth intervention on blood pressure control in the context of a low-resource rural. Based on 148 individuals from low-resource rural settings in Hubei, China, the results show that the mHealth blood pressure monitoring intervention significantly improves systolic blood pressure and the mHealth intervention effectively controls systolic blood pressure, waist and hip circumference. In addition, the mHealth intervention was positively and significantly related to self-reported hypertension compliance, self-efficacy and quality of life.

Another three studies concentrate on physician online information sharing and patient education. Guo et al. adopt the attention perspective to investigate the effect of physician online information sharing on patient education and consider the moderating effects of offline expertise and online reputation. On the basis of 61,566 physician-month observations from an online health platform in China, the results indicate that physician online information sharing positively impacts potential patient education while there is an inverted U-shape relationship between physician online information sharing and realized patient education. Furthermore, a physician's offline expertise impairs the positive effect of physician online information sharing on potential patient education and flattens the curvilinear relationship between physician online information sharing and realized patient education. Finally, a physician's online reputation reinforces the positive effect of physician online information sharing and potential patient education. The study makes contributions to the literature on attention theory and information sharing for patient education and has important implications for patients, physicians, and platform managers. Ma et al. investigate the effect of physician-free and paid knowledge sharing on patient engagement including patient visits and patient consultations from the perspective of signaling theory. Based on the obtained sample of 168,377 physicians from one of the largest OHCs in China, the results reveal that both physician-free and paid knowledge sharing are beneficial to patient visits and patient consultations. In addition, physicians' registration duration in OHCs positively moderates the relationships between physician knowledge sharing (i.e., free knowledge sharing and paid knowledge sharing) and patient engagement (e.g., patient visits and patient consultations). This study contributes to the literature on signaling theory in the OHCs context by revealing the effect mechanism of physicians' educational knowledge-sharing on patients' engagement and provides important implications for practitioners in OHCs. Zhang et al. explore the impact of practical benefits, psychological rewards, and perceived connectedness with OHCs on physicians' continuous knowledge-sharing behaviors from the perspective of motivation theory and consider the contingent effect of physicians' online seniority status. The empirical results indicate that the relationships between practical benefits, psychological rewards and physicians' continuous knowledge-sharing behaviors are positive while the relationship between perceived connectedness and physicians' continuous knowledge-sharing behaviors is negative. Meanwhile, physicians' online seniority status enhances the positive relationship between practical benefits and physicians' continuous knowledge-sharing behaviors but weakens the positive effect of psychological rewards and physicians' continuous knowledge-sharing behaviors. Moreover, physicians' online seniority status alleviates the negative effect of perceived connectedness and physicians' continuous knowledge-sharing behaviors. This study also makes contributions to understand the motivational mechanisms on physicians' continuous knowledge-sharing behaviors in OHCs and has significant implications for managers and decision-makers in OHCs.

3. Conclusion

Research on digital information in healthcare is rare in terms of how to provide digital information to educate and benefit patients. This Research Topic includes nine articles that address the gap in the literature by conceptualizing and contextualizing the organization of digital information on health to facilitate patients' education and a better understanding of online health knowledge. It also offers practical implications for patients, physicians, and healthcare providers to improve patient education. In addition, digital information for patient education is a hot topic in the field of E-health and there also existed some limitations (e.g., OHC engagement influences lifestyle changes through dynamic processes), which offers opportunities for future studies.

Author contributions

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

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Conflict of interest

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Quality Assessment of YouTube Videos as an Information Source for Testicular Torsion

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Background: Testicular torsion is an acute scrotal disease requiring urgent management, and the COVID-19 pandemic has been demonstrated to lead to poor outcomes for this disease. Presently, many people tend to seek health information *via* YouTube. This study aims to quantitatively assess the quality of English YouTube video content as an information source of testicular torsion.

Methods: In this cross-sectional study, a search was performed with the search term "testicular torsion" on YouTube, and the first 100 videos listed by relevance were selected for our analysis. Duplicate, non-English, videos without audio and surgical videos were excluded. Video features (duration, number of days online, views, likes, comments), source of the video, and author's country were collected. Each video included in the study was assessed using DISCERN and Journal of the American Medical Association (JAMA) Benchmark Criteria. A correlation analysis was performed considering video features, video source, DISCERN scores and JAMA scores.

Results: A total of 66 videos were included and analyzed. The most common video content was general information, including etiology, symptoms, and treatment. The majority of videos were from education and training websites (30%), physicians (23%), and independent users (21%). The mean DISCERN and JAMA scores were 36.56 and 2.68, respectively. According to DISCERN, the quality of video uploaded by physicians was relatively high ($P < 0.001$), and the quality of video uploaded by independent users was relatively low ($P < 0.001$). The JAMA score had no relevance to the video source ($P = 0.813$). The correlation between the video features, DISCERN and JAMA scores was controversial by different assessment methods.

Conclusions: Despite most of the videos on YouTube being uploaded by medical or education-related authors, the overall quality was poor. The misleading, inaccurate and incomplete information may pose a health risk to the viewers, especially during the COVID-19 pandemic. Much effort needs to be undertaken to improve the quality of health-related videos regarding testicular torsion.

Keywords: testicular torsion, internet, quality, DISCERN, YouTube

INTRODUCTION

Testicular torsion involves twisting the spermatic cord and its contents along with the longitudinal access with resultant ischemia (1). It accounts for ~10–15% of acute scrotal disease in children, with an incidence rate of 1/4,000 in males younger than 25 years (2). The torsion of the spermatic cord can reach 180 to more than 720 degrees, resulting in different levels of ischemia and even necrosis in testicular tissue. The viability of testis decreases 6 h after the onset of symptoms (3). It has been reported that the orchiectomy rate was 42% in boys undergoing surgery for testicular torsion, and ~56.6% of boys receiving salvage orchiopexy had testicular atrophy (4, 5). As the prognosis of testicular torsion is closely related to the degree and duration of torsion, and the symptoms need to be differentiated from orchitis and epididymitis, it is vital that patients be promptly identified and receive correct management. European Association of Urology (EAU) guidelines recommend early manual detorsion or direct surgical exploration in all suspected patients with testicular torsion (6).

Due to the urgency and harmful outcomes, testicular torsion is challenging for patients or guardians to access early and proper treatment. Testicular atrophy or orchiectomy caused by testicular torsion is not unusual and may affect testicular function and fertility (7, 8). Some studies found that wait time for manual detorsion or surgery positively correlated with orchiectomy, highlighting the importance and urgency of early identification and intervention for testicular salvage (9, 10). The absence of knowledge about testicular pathology and the "watch and wait" strategy from adolescents and their parents were also adverse factors preventing timely medical help (11). Patients or their guardians should have a comprehensive and accurate understanding of the disease. Once symptoms appear, preliminary estimates can be made to avoid the neglect of testicular torsion. On the other hand, they need

Abbreviations: JAMA, journal of the american medical association; VPI, video power index.

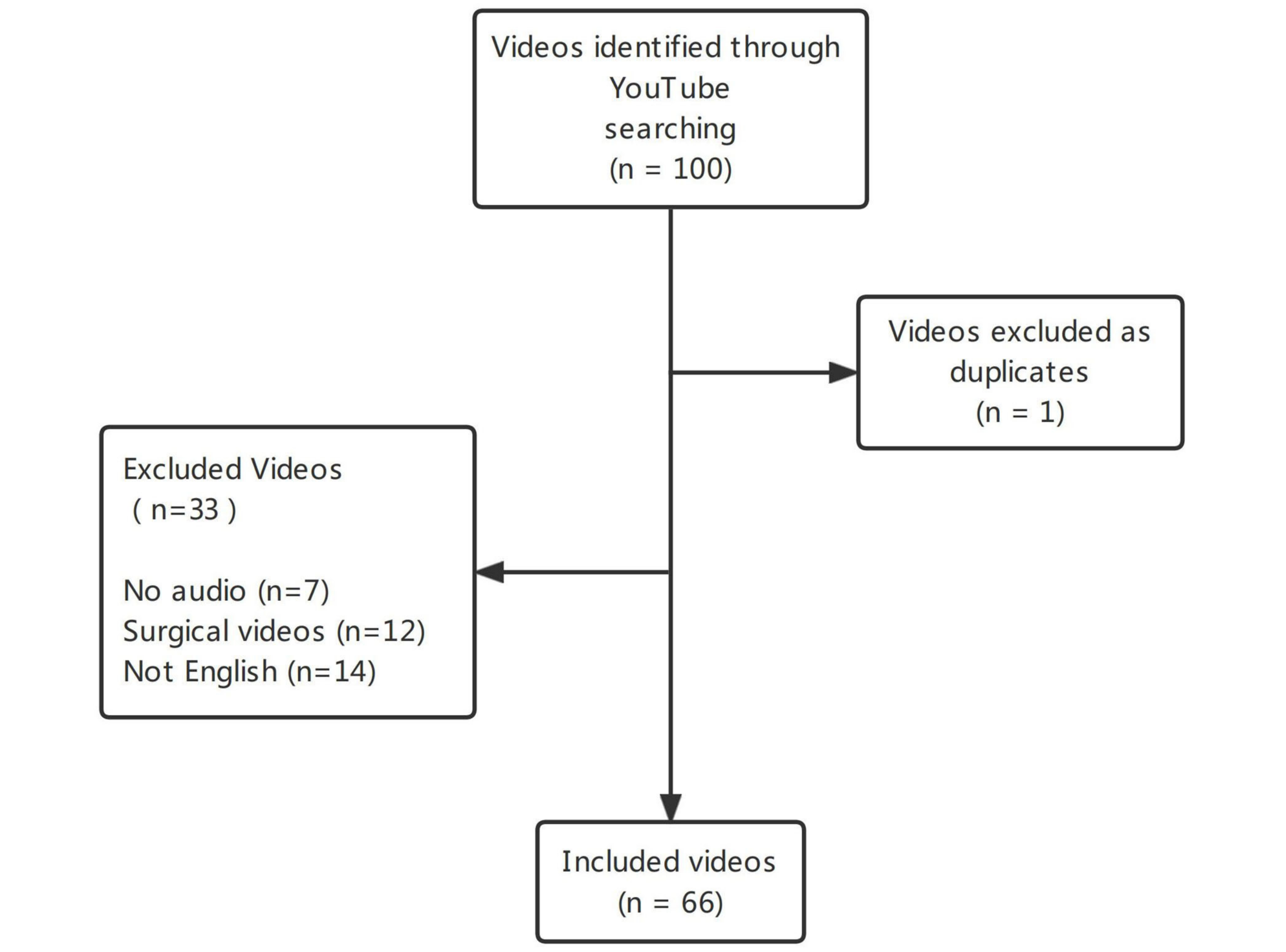

FIGURE 1 | Flowchart of the selection of YouTube videos for analysis.

TABLE 1 | Characteristics and quality assessments of YouTube videos.

Video content	Number	Percentage
General information (etiology, symptoms, and treatment)	38	57.6%
Scrotal ultrasound training	10	15.3%
Differential diagnosis compared with other scrotal diseases	9	16.4%
Case discussion	5	7.6%
Surgical teaching	4	6.1%
Video features	Mean ± SD	Min–max
Duration (s)	457.89 ± 502.54	13–3,261
Number of days online	1475.67 ± 1195.82	8–4,420
Number of views	68406.61 ± 161471.15	30–843,092
Number of views/day	1150.62 ± 8788.11	0.02–71,442
Number of likes	443.06 ± 1072.55	0–6,764
Number of likes/day	13.30 ± 104.02	0–845.5
Number of comments	89.33 ± 228.26	0–1,234
Number of comments/day	0.30 ± 1.60	0–12.88
JAMA score	2.68 ± 0.98	1–4
DISCERN reliability	19.61 ± 6.81	8–33
DISCERN treatment	16.95 ± 7.71	7–33
DISCERN quality	2.62 ± 1.26	1–5
DISCERN total	36.56 ± 13.75	16–66

TABLE 2 | Average score per DISCERN question among all included YouTube videos.

		Question	Average score
Section 1			
	1	Are the aims clear?	3.5
	2	Does it achieve its aims?	3.4
	3	Is it relevant?	3.5
	4	Is it clear what sources of information were used to compile the publication (other than the author or producer)?	1.9
	5	Is it clear when the information used or reported in the publication was produced?	1.8
	6	Is it balanced and unbiased?	2.2
	7	Does it provide details of additional sources of support and information?	1.5
	8	Does it refer to areas of uncertainty?	1.8
Section 2			
	9	Does it describe how each treatment works?	2.2
	10	Does it describe the benefits of each treatment?	2.5
	11	Does it describe the risks of each treatment?	2.2
	12	Does it describe what would happen if no treatment is used?	2.7
	13	Does it describe how the treatment choices affect overall quality of life?	2.5
	14	Is it clear that there may be more than 1 possible treatment choice?	2.2
	15	Does it provide support for shared decision making?	2.9
Section 3			
	16	Based on the answers to all of these questions, rate the publication's overall quality as a source of information about treatment choices.	2.6

good quality information to make informed decisions with their physicians.

Since the COVID-19 infection outbreak and global spread, social distancing and reduced travel have been strictly advised to control the spreading of the disease (12). Usage of medical resources has also been affected, mainly for increased critically ill patients and overcrowding of medical facilities. Reduced number of hospital visits and delays in hospitalization and operations for pediatric patients have been reported due to the parents' hesitancy for symptoms not related to COVID-19, which may lead to more complications and poor outcomes, especially for patients with testicular torsion (13–15). Such a fearful environment prompts people to access health information and try identifying early symptoms of the disease online.

The internet has developed rapidly and become an essential approach for obtaining and disseminating health information (16, 17). YouTube is the most popular media search and sharing platform globally, which has been widely utilized to search for and learn health information, especially in young adults (18). Several studies have reported that people use YouTube as a source of health information to update knowledge, seek help before visiting hospitals, or even purchase healthcare services (19, 20). However, YouTube may contain misleading or poor-quality information due to the absence of any regulations or restrictions on video content for any uploader (21, 22). To date, there are many videos about testicular torsion on YouTube, but the literature lacks a quality evaluation of YouTube's content on testicular torsion.

This study aims to quantitatively assess the quality of English YouTube video content as an information source of testicular torsion online.

MATERIALS AND METHODS

Recruitment

In this cross-sectional study, a search was performed on YouTube on March 15th, 2022, with the search term

TABLE 3 | JAMA benchmarks, number, and percentage of YouTube videos.

JAMA benchmarks	Explanation	Number	Percentage
Authorship	Authors and contributors, their affiliations, and relevant credentials should be provided.	53	80.3%
Attribution	References and sources for all content should be listed clearly, and all relevant copyright information should be noted.	19	28.8%
Disclosure	Website "ownership" should be prominently and fully disclosed, as should any sponsorship, advertising, underwriting, commercial funding arrangements or support, or potential conflicts of interest.	39	59.1%
Currency	Dates when content was posted and updated should be indicated.	66	100%

"testicular torsion." The search history was deleted before searching to reduce any impact on the search results and outcomes. The first 100 results listed by relevance were selected (default YouTube search setting). Duplicate videos, non-English, videos without audio and surgical videos were excluded.

Collection of Video Features and Source

Video features assessed include total video duration, number of days online, number of views, number of views/day, number of "likes," number of likes/day, number of comments, number of comments/day, video content type, and author's country. According to the authors, video sources were defined as physicians, patients, education and training websites, news media, medical institutes, and independent users. Video content was classified as general information (etiology, symptoms, and treatment), scrotal ultrasound training, differential diagnosis compared with other scrotal diseases, case discussion, and surgical teaching.

Assessment of Quality

DISCERN and JAMA Benchmark Criteria were used for quality analyses of the videos (23). Specialized medical issues related to the disease were based on the EAU guidelines (6).

DISCERN consisted of 16 questions in total, with each question scored from 1 to 5 points. Questions were divided into three parts: reliability (questions 1–8), quality information about treatment options (questions 9–15), and overall score (question 16). The total DISCERN score was calculated by summing up scores over questions 1–15. All videos were divided into five categories based on their total DISCERN score: very poor (<27), poor (27–38), fair (39–50), good (51–62), and excellent (63–75) (24, 25). JAMA benchmark criteria were used to evaluate online health information reliability, including four criteria (authorship, attribution, disclosure, and currency). Each satisfied criterion counted 1 point, and the maximum possible score was 4 points (26).

Two independent urologists (GB and XP) evaluated all videos. Any discrepancies between reviewers were resolved by discussion with a third author for consensus (GL).

Ethics Statement

This study focused on the quality assessment of YouTube videos contributed and viewed by the public, so ethics committee approval was not required.

Statistical Analysis

Statistical analyses were conducted using SPSS software version 26.0 (SPSS Inc., Chicago, IL, USA). Categorical variables were presented as frequency and ratios (%), and continuous variables were presented by mean ± standard deviation (SD) and median (min–max). The Kruskal-Wallis test determined statistically significant differences between more than two groups of any independent variable. Spearman's correlation coefficient was used to evaluate the correlations among variables. A $P < 0.05$ was considered statistically significant.

RESULTS

Results of Video Features and Quality Assessment

Among the 100 videos in the initial search were one duplicate video, 7 non-English videos, 12 surgical videos, and 7 videos without audio, resulting in 66 included and analyzed for this study (**Figure 1**). The 66 video contents, types and features are presented in **Table 1**. The average score per DISCERN question and percentage satisfying each JAMA benchmark criterion of all videos are summarized in **Tables 2**, **3**. The most common video content was general information about testicular torsion, including etiology, symptoms, and treatment, accounting for 57.6% of the videos. The mean video duration was 457.89 ± 502.54s (range 13–3,261), and the mean number of views was 68406.61 ± 161471.15 (range 30–843,092).

The mean DISCERN total score was 29.60 ± 9.77 (range 1–4), and the mean DISCERN total score was 36.56 ± 13.75 (range 16–66). **Figure 2** shows the distribution of authors' countries, and American authors uploaded the most videos.

Association of the Source of Videos, Video Features, DISCERN Scores and JAMA Scores

The data in **Figure 3** shows that the majority of videos were uploaded by education and training websites (30%), physicians (23%), and independent users (21%). The Kruskal-Wallis test showed that the source of videos had a significant association with number of views/day, likes, and likes/day ($P = 0.006$, 0.004 and 0.001, respectively), but no relevance to number of views.

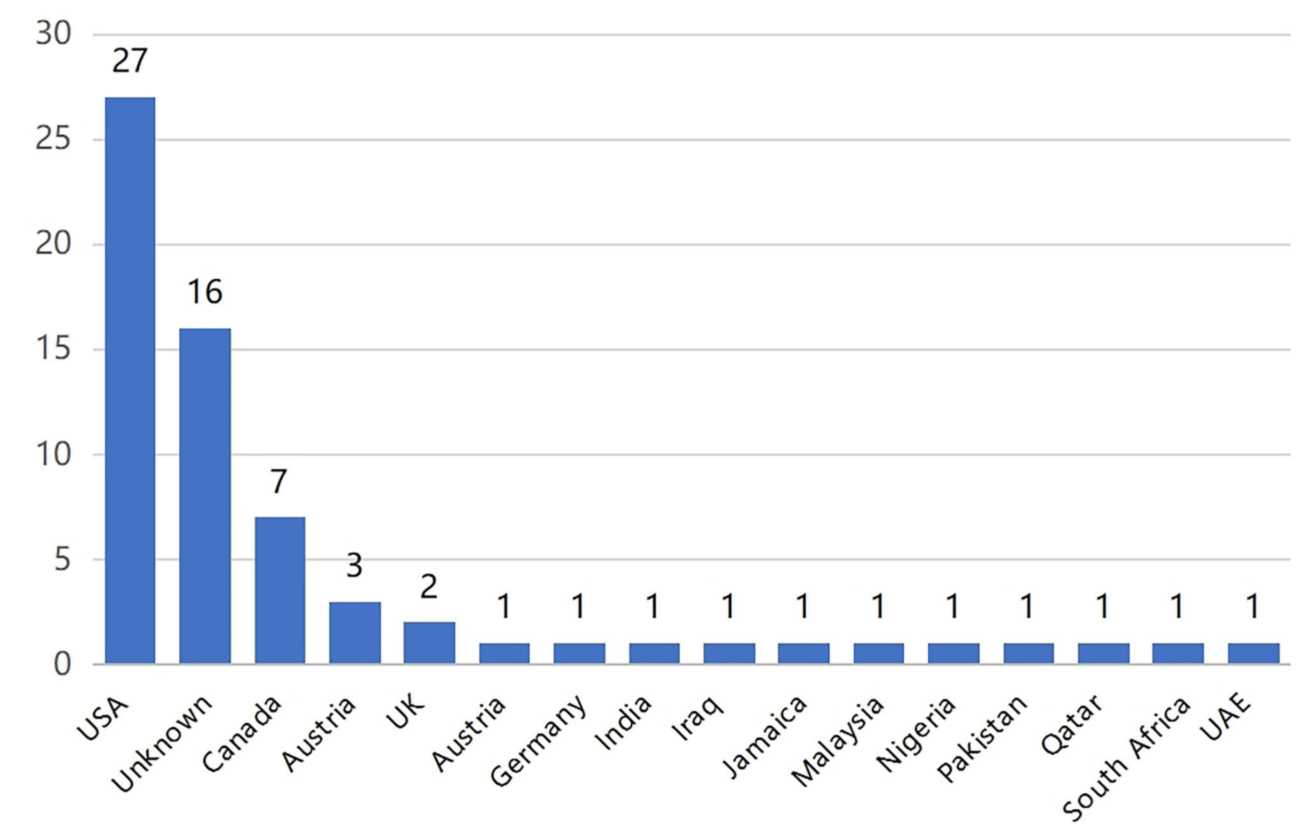

FIGURE 2 | Distribution of authors' countries of YouTube videos.

Also, reliability scores, treatment scores, quality scores, and total DISCERN scores had a significant association with the source of videos ($P < 0.001$, $= 0.002$, < 0.001 and < 0.001, respectively). According to the Bonferroni adjustment, number of views/day, likes, and likes/day were significantly more in videos uploaded by education and training websites than by independent users ($P = 0.018$, 0.008, and 0.006, respectively), and DISCERN reliability scores were significantly higher in videos uploaded by physicians than by patients and independent users ($P = 0.048$ and 0.001, respectively). Additionally, DISCERN total scores were significantly lower in videos uploaded by independent users than by physicians and education and training websites ($P = 0.001$ and 0.006, respectively). The JAMA scores had no relevance to the video source ($P = 0.813$) (see **Table 4**).

Evaluation Outcomes of DISCERN Classification

According to DISCERN classifications, 30.3% were "very poor," 30.3% were poor, 18.2% were "fair," 18.2% were "good" and 3.0% were "excellent." There was no statistically significant correlation between DISCERN classification and duration, number of views, likes, comments, views/day, likes/day, comments/day, JAMA scores (see **Table 5**).

Correlation Analysis for Any Factors Influencing JAMA and DISCERN Scores

The correlation test showed that DISCERN total scores were significantly positively correlated with video duration ($r = 0.335$, $P = 0.006$), number of views/day ($r = 0.309$, $P = 0.012$), likes ($r = 0.050$, $P = 0.043$), likes/day ($r = 0.298$, $P = 0.015$) and JAMA score ($r = 0.259$, $P = 0.036$). The JAMA scores were positively correlated with duration, number of views, views/day, likes and likes/day, but there were no statistically significant correlations (see **Table 6**).

DISCUSSION

Motivation and Meaning of This Study

Testicular torsion is an acute scrotal disease requiring urgent management. The COVID-19 crisis limits people's access to health information and increases the difficulty for patients to obtain timely treatment (12–15). As one of the largest and most visited video platforms, YouTube has become an essential channel for health information dissemination, with a user-friendly experience on computers, tablets, and smart mobile phones. The number of searches for "testicular torsion" on the Youtube and Google websites has increased in the past decade (**Figure 4**). Anyone can upload videos, and

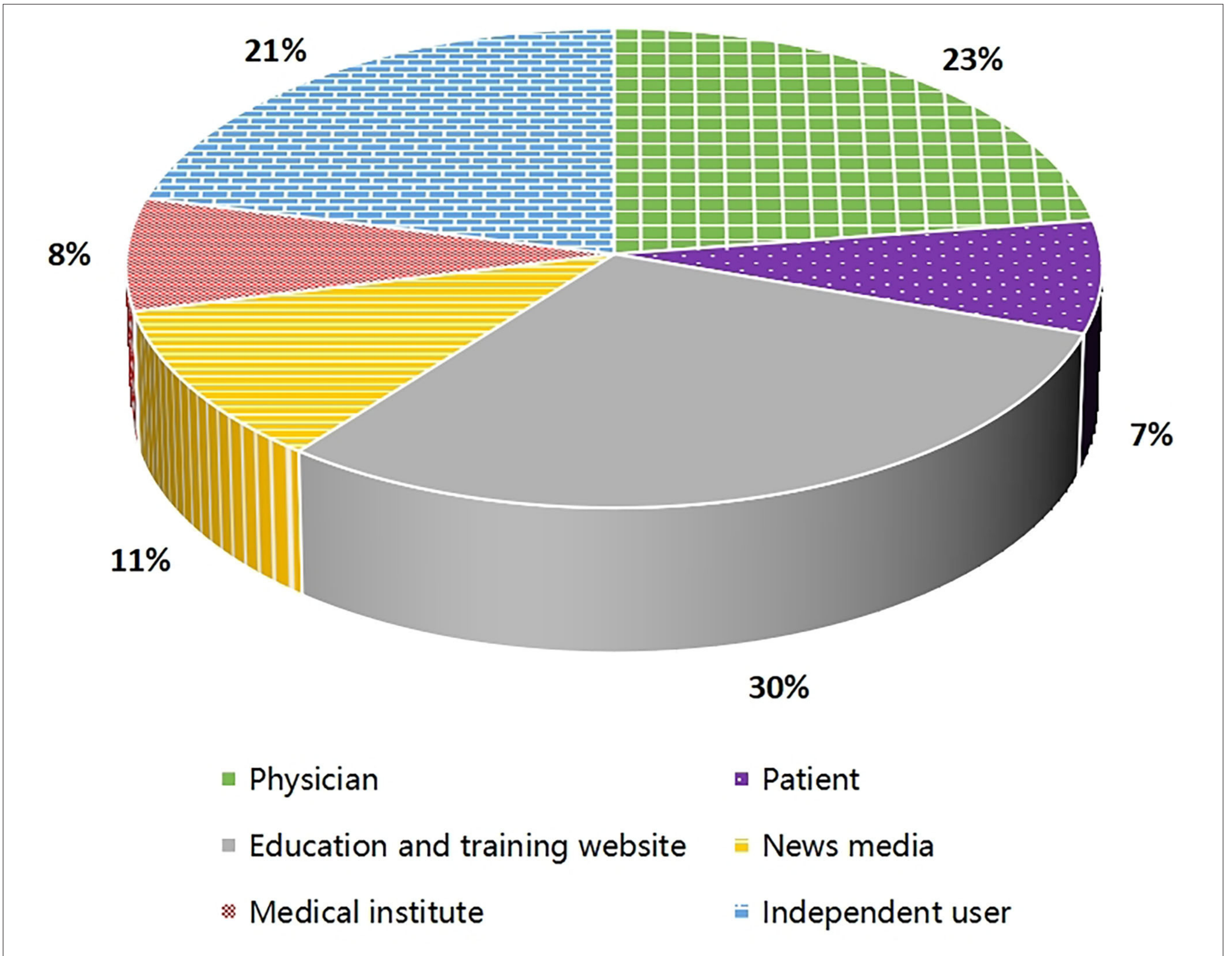

FIGURE 3 | Source of included videos.

health information is constantly updated, so the information provided by Youtube videos may be inaccurate and out of date.

When evaluating the integrity and reliability of videos related to testicular torsion on YouTube, the selection of quality assessment systems directly affects the evaluation results. The DISCERN criteria were developed to enable patients and information providers to judge the quality of information. JAMA benchmark criteria were published to evaluate the quality of internet information on health care. Both have been used to assess the quality of video information on various diseases in previous reports (23, 27, 28). Some information about these videos was collected to illustrate their fundamental characteristics and correlation with the outcome data. The research contents were discussed, and multiple physicians and researchers formulated strategies.

Principal Findings

The mean DISCERN and JAMA scores were 36.56/75 and 2.68/4. According to the DISCERN classification, 60.6% of the videos were of very poor or poor quality, and only 3.0% were assessed as excellent quality. References, sources and copyright information were not mentioned in more than two-thirds of videos, and more than one-third of videos lacked prominent and full disclosure. The low score rates reflected the videos' poor integrity and reliability regarding testicular torsion on YouTube. Keelan et al. (29) first found that 38% of analyzed videos objected to immunization but received a higher mean star rating and more views than those supporting immunization. It was worth noting that 45% of these negative videos conveyed messages that contradicted the reference standards. After that, increasing numbers of studies aroused people's concern for the frequently misleading and poor quality of videos on YouTube. Despite these downsides, the increasing popularity of this video-sharing

TABLE 4 | Video features and quality assessments according to the video source[a].

Variable	Physician	Patient	Education and training website	News media	Medical institute	Independent user	*P*-value[b]
Number of views	17,980 (122, 230,657)	13,810 (5,057–52,072)	30,331 (150, 843,092)	5,758 (90, 54,367)	6,330 (1,169, 174,227)	1387.5 (30, 69,584)	0.055
Views/day	11.42 (0.27, 74.07)	18.44 (3.49–24.20)	18.10 (0.54, 71,442)[c]	1.38 (0.29, 20.20)	16.82 (1.78, 332.49)	0.75 (0.02, 56.98)	0.006
Number of likes	152 (3, 1,329)	176 (61–727)	203.5 (3, 6,764)[d]	16 (0, 237)	14 (0, 1,119)	5 (0, 590)	0.004
Likes/day	0.13 (0.007, 0.68)	0.21 (0.04–0.44)	0.35 (0.003, 845.5)[e]	0.005 (0, 0.09)	0.08 (0, 2.14)	0.004 (0, 3.91)	0.001
JAMA score	2 (1–4)	3 (1–3)	2.5 (1–4)	3 (1–3)	4 (2–4)	3 (1–4)	0.813
DISCERN reliability	26 (12–33)[f]	14 (8–17)	22 (9–33)[g]	16 (8–22)	21 (19–23)	14.5 (8–21)	<0.001
DISCERN treatment	24 (9–33)	12 (8–17)	19 (7–62)	13 (8–24)	19 (11–29)	10.5 (7–17)[h]	0.002
DISCERN quality	4 (1–5)[i]	2 (1, 2)	3 (1–5)[j]	2 (1–3)	3 (2–4)	1.5 (1, 2)	<0.001
DISCERN total	51 (21–66)	26 (16–33)	43 (17–62)	29 (16–46)	38 (32–49)	25 (16–35)[k]	<0.001

[a]*Results are presented as median (min–max).*
[b]*Kruskal-Wallis test.*
[c]*Compared with independent user, $P = 0.018$.*
[d]*Compared with independent user, $P = 0.008$.*
[e]*Compared with news media and independent user, $P = 0.021$ and 0.006 respectively.*
[f]*Compared with patient and independent user, $P = 0.048$ and 0.001 respectively.*
[g]*Compared with independent user, $P = 0.003$.*
[h]*Compared with physician and education training website, $P = 0.003$ and 0.026 respectively.*
[i]*Compared with patient and independent user, $P = 0.024$ and < 0.001 respectively.*
[j]*Compared with independent user, $P < 0.001$.*
[k]*Compared with physician and education training website, $P = 0.001$ and 0.006 respectively.*

TABLE 5 | Distribution of DISCERN classification according to the video source and features.

Variable	Very poor	Poor	Fair	Good	Excellent	*P*-value[a]
Number of videos	20 (30.3%)	20 (30.3%)	12 (18.2%)	12 (18.2%)	2 (3.0%)	
Duration (s)	420.65 ± 716.91 (204.5)	364.80 ± 316.83 (283)	585.50 ± 512.68 (331)	467.58 ± 289.04 (381)	937.5 ± 273.65 (937.5)	0.096
Number of views	26,902.70 ± 59,449.27 (4403)	60,246.05 ± 151,868.46 (4814.5)	85,862.33 ± 155,166.84 (9262.5)	140,528.33 ± 272,728.82 (18,900)	27,586.50 ± 33,876.78 (27,586.5)	0.550
Views/day	56.02 ± 213.60 (4.63)	44.52 ± 90.42 (4.14)	63.59 ± 109.10 (6.27)	6,095.08 ± 20,583.04 (29.70)	12.85 ± 13.87 (12.85)	0.251
Number of likes	202.75 ± 392.24 (54.5)	304.25 ± 515.13 (59.5)	427.50 ± 683.01 (18.5)	1132.25 ± 2221.10 (182)	192.50 ± 205.76 (192.5)	0.559
Likes/day	0.39 ± 1.330 (0.05)	0.47 ± 0.95 (0.04)	0.38 ± 0.61 (0.03)	71.33 ± 243.81 (0.23)	0.09 ± 0.08 (0.09)	0.332
JAMA score	3 ± 1 (3)	2.5 ± 0.89 (3)	2.67 ± 1.15 (2.5)	3.17 ± 0.83 (3)	3.5 ± 0.71 (3.5)	0.224
Source of the video						
Physician	2	3	2	7	0	
Patient	3	2	0	0	1	
Education and training website	4	4	6	5	1	
News media	3	2	2	0	0	
Medical institute	0	3	2	0	0	
Independent user	8	6	0	0	0	

[a]*Kruskal-Wallis test.*

TABLE 6 | Correlation test for the factors influencing JAMA score and DISCERN score.

Variable	JAMA score		DISCERN score	
	r	*P*-value[a]	r	*P*-value[a]
JAMA score	–	–	0.259	0.036
DISCERN score	0.259	0.036	–	–
Duration (s)	0.108	0.387	0.335	0.006
Number of views	0.034	0.785	0.226	0.068
Views/days	0.106	0.395	0.309	0.012
Number of likes	0.020	0.870	0.050	0.043
Likes/days	0.112	0.369	0.298	0.015

[a]*Spearman test.*

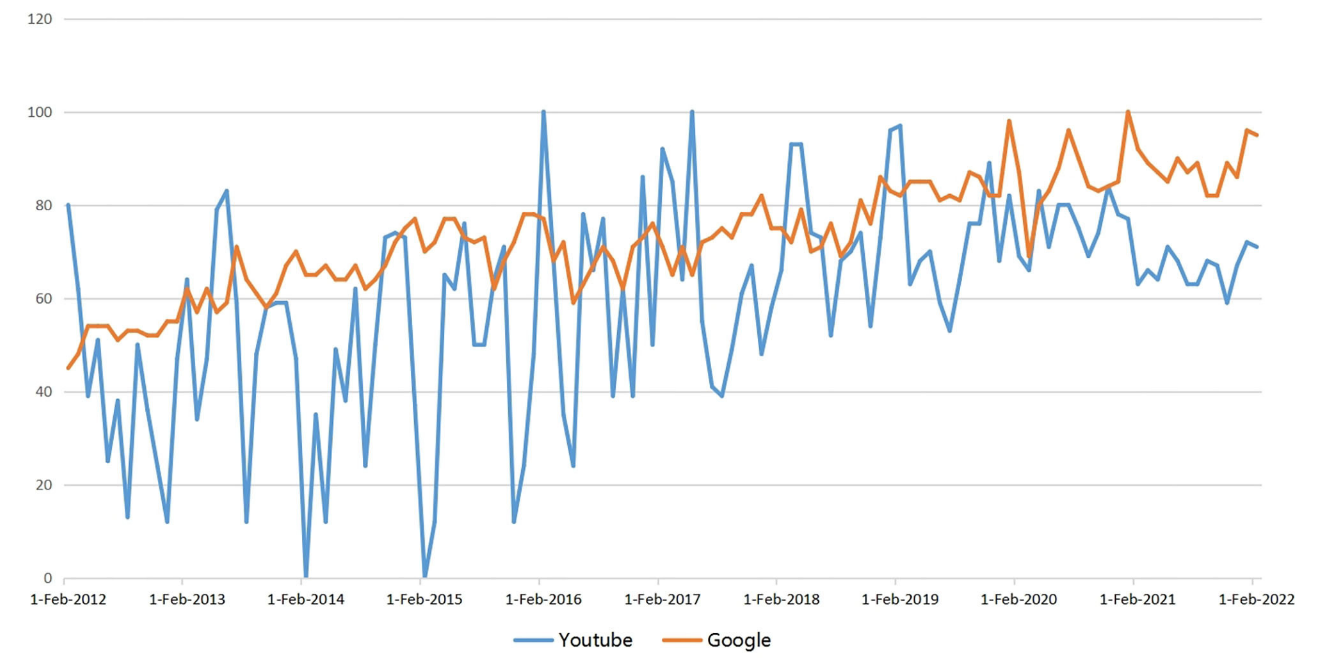

FIGURE 4 | Search trend for the term "testicular torsion" on YouTube and Google website.

platform prompts more people to use it to disseminate and acquire health information (30).

The majority of videos were uploaded by authors from the United States and Europe. More than half of the shared contents were general information videos containing etiology, symptoms, and treatment. Education and training websites and physicians were the most common source of the videos. In general, these videos had higher DISCERN scores, and tended to be rated as good or excellent quality according to the DISCERN classification, consistent with the results of other similar studies (23, 27, 28). Moreover, videos from education and training websites seemed to receive more attention than those from independent users. Such results may be because these authors had more professional and systematic knowledge about the disease and focused more on the integrity and reliability of the videos they uploaded. These findings highlight the importance of actively recommending evidence-based health education materials from relatively professional individuals and institutions.

Many users are used to clicking on the videos with higher playback first, hoping for more reliable and comprehensive information from specialized individuals or groups. However, our study found that the most popular videos did not have the highest quality, the highest valued videos were not the most popular videos, and the number of views had no relevance to the video source In addition, the Kruskal-Wallis test showed that the number of views, views/day, likes, likes/day were not correlated with the DISCERN classification, with the correlative analyses illustrating contrary results. Perhaps the artificial classification covered up some critical values. Despite the discrepancy, this interesting result deserves our attention: the public may not always view and trust high-quality health information with little discernment. Furthermore, we found that there were no statistically significant correlations between JAMA scores and recorded or calculated video data. This result reveals that viewers may not care much about the subjects of JAMA Benchmark Criteria, which are indispensable to the integrity and reliability assessment instead.

Challenges and Solutions

Testicular torsion is one of the most adversely affected diseases during the COVID-19 pandemic (13–15). More and more people are turning to YouTube for health information, but the overall quality of these videos is poor. Krakowiak et al. (31) found that the mean DISCERN/JAMA score was 28.1 ± 7.9 and 1.1 ± 0.7, respectively, and more importantly, the videos providing misleading information had a higher like ratio. This worrying state of video platforms may easily lead to patient misunderstandings and prevent them from correct choices and timely treatment, especially for acute diseases. Thus, these platforms should be responsible to the public from ethical and legal perspectives. A previous article suggested that a peer-reviewed process during submission may be an ideal solution, but this procedure is cumbersome (32). One feasible suggestion for eradicating the inaccurate information would be to ask authors to add sources and references in the introduction section of the health-related video, labeling video segments according to the specified standards. At the same time, video platforms can provide specific questionnaires for the views to assess the video quality, and improve the filtering algorithms to prioritize high-quality videos when searching, based on the continuously updated evaluation results. Overwhelmingly, specialists and academic institutions should provide more high-quality, reliable videos that follow clinical practice guidelines to YouTube.

The difference between video materials and materials obtained from internet searches is that video materials are obtained by users passively accepting recommendations from websites, whereas internet materials allow users to seek and identify them actively. High-quality videos from the platforms can support the public's self-education, which will lead to more accurate identification of health information and less adverse impact from poor-quality videos. This is a virtuous circle of promotion.

Limitations

This study has several limitations. Firstly, the search results on YouTube are dynamic over time, and the data collected and analyzed only represents one point in time. Secondly, despite deleting the search history before searching, the research results may differ according to different geographic locations, user habits, or other unknown algorithm restrictions. Thirdly, the analysis was limited to the first 100 videos for "testicular torsion," excluding data outside this domain. However, these results are relatively representative because our study aims to reflect the browsing status of ordinary users, with very few considering past the first 100 search results. Fourthly, the function to check the number of dislikes has been removed by YouTube recently, so disliked data and some interaction indexes, including like ratio and video power index (VPI), cannot be included and analyzed in this study. Finally, assessment instruments for video quality are various and constantly updated (33–36), and video quality may vary from different platforms. This study assessed videos from a single platform by two specified instruments, which may lead to biased conclusions.

CONCLUSIONS

YouTube is a popular and indispensable way for the public to learn about testicular torsion. This study is the first report to assess the quality of videos related to testicular torsion on YouTube. The data revealed that despite most of the videos on YouTube being uploaded by medical or education-related authors, the overall quality was poor. The risks of misleading, inaccurate and incomplete information cannot be ignored, especially in the era of the COVID-19 pandemic. Standards for uploading health information videos need to be established to improve the video quality. Video platforms should improve the filtering algorithms to prioritize high-quality videos when searching. Overwhelmingly, specialists and academic institutions should provide more high-quality, reliable videos which follow clinical practice guidelines. Moreover, self-education of the public promoted by high-quality information are also important.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

GB and XP designed the study, carried out data analysis, and drafted the manuscript. TZ and XC participated in data analysis, collected all relevant data, and assisted in study conception and design. GL and WF conceived the study, participated in its design and coordination, and helped draft the manuscript. All authors read and approved the final manuscript.

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Predictive Nomogram for Clinical Prognosis in Cervical Spondylotic Myelopathy With Intramedullary T2-Weighted Increased Signal Intensity: A Novel Digital Tool for Patient Prognosis Education

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Aims: To establish a predictive nomogram for clinical prognosis in cervical spondylotic myelopathy (CSM) with intramedullary T2-weighted increased signal intensity (ISI).

Methods: The clinical data of 680 patients with CSM with intramedullary T2-weighted ISI were retrospectively analyzed. The patients were divided into the modeling group (476) and the validation group (204) by using a random number table at a ratio of 7:3. The independent prognostic factors were screened using multivariate logistic regression analysis. The factors were subsequently incorporated into the establishment of the predictive nomogram. The area under the receiver operating characteristic (ROC) curve (AUC) was undertaken to estimate the discrimination of the predictive nomogram. The calibration curve and the Hosmer-Lemeshow test were used to assess the calibration of the predictive nomogram. The clinical usefulness of the predictive nomogram was evaluated by decision curve analysis (DCA).

Results: Based on the pre-operative Japanese Orthopedic Association (JOA) score, maximal canal compromise (MCC), and maximal spinal cord compression (MSCC), we established a predictive nomogram. The AUCs in the modeling group and validation group were 0.892 (95% CI: 0.861∼0.924) and 0.885 (95% CI: 0.835∼0.936), respectively, suggesting good discrimination of the nomogram. Calibration curves showed a favorable consistency between the predicted probability and the actual probability. In addition, the values of P of the Hosmer-Lemeshow were 0.253 and 0.184, respectively, suggesting good calibration of the nomogram. DCA demonstrated that the nomogram had good clinical usefulness.

Conclusion: We established and validated a predictive nomogram for the clinical prognosis in CSM with intramedullary T2-weighted ISI. This predictive nomogram could help clinicians and patients identify high-risk patients and educate them about prognosis, thereby improving the prognosis of high-risk patients.

Keywords: cervical spondylotic myelopathy, intramedullary increased signal intensity, nomogram, digital tool, patient prognosis education

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INTRODUCTION

Cervical spondylotic myelopathy (CSM) is a progressive degenerative disease defined by spondyloarthritis, congenital cervical canal stenosis, and ossification of the posterior longitudinal ligament (1–3). In the early stages of the disease, patients with CSM present mild symptoms that are easily ignored. That often causes a delayed diagnosis and irreversible neurologic damage. As the disease progresses, patients with CSM often exhibit a wide variety of symptoms and signs, such as numb hands, bilateral arm paresthesia, gait abnormality, and positive Hoffmann signs (4, 5). At present, the diagnosis of CSM is mainly based on clinical symptoms, signs, and clinical imaging. Magnetic resonance imaging (MRI) is an invaluable and irreplaceable modality for radiographic neurological assessment by visualizing the degree of spinal cord compression and the signal changes of the spinal cord (6, 7).

The presence of intramedullary increased signal intensity (ISI) was found in patients with cervical spondylotic myelopathy on T2-weighted images, suggesting spinal cord injury (8). ISI on T2-weighted MRI reflects chronic intramedullary compression lesions, such as neuronal cell death, demyelination, and reactive astrogliosis (9–11). MRI findings include intramedullary abnormal ISI on T2-weighted images indicating poor prognosis in CSM (12, 13).

At present, no consensus is reached on the independent prognostic factors of patients with CSM with intramedullary T2-weighted ISI, and it is still controversial. As a statistical predictive model, a nomogram estimates individualized risk based on independent prognostic factors. The nomogram could help clinicians and patients predict disease prognosis and timely identify the high-risk patients. Hence, we established and validated a predictive nomogram for the clinical prognosis in CSM with intramedullary T2-weighted ISI. We hope that this predictive nomogram could help clinicians and patients identify high-risk patients and educate them about prognosis, thereby improving the prognosis of high-risk patients.

PATIENTS AND METHODS

Patients

We retrospectively collected and analyzed the data of patients with CSM with intramedullary T2-weighted ISI admitted to the Second Affiliated Hospital of Xi'an Jiaotong University between January 2012 and June 2021. All patients underwent a detailed examination on admission, while their imaging included cervical spine plain X-rays and MRI. Patients were selected according to the following inclusion criteria: (1) aged 18 years and above, (2) patients with CSM, (3) cervical MRI indicated spinal cord compression, and (4) cervical MRI showed intramedullary T2-weighted ISI. Patients were excluded based on the following criteria: (1) cervical spondylotic radiculopathy, (2) acute cervical spinal cord injury, (3) amyotrophic lateral sclerosis or syringomyelia, and (4) cardiopulmonary or coagulation dysfunction. Finally, 680 patients were included in the final analysis. The patients who met the inclusion criteria were divided into the modeling group (476) and the validation group (204) by using a random number table at a ratio of 7:3. A flow diagram is shown in **Figure 1**. The modeling group was further divided into two groups based on whether the 6-month post-operative improvement rate for the Japanese Orthopedic Association (JOA) score was ≥60%, namely, the poor prognosis group (115) and the good prognosis group (361). This study was approved by the Medical Ethics Committee of the Second Affiliated Hospital of Xi'an Jiaotong University, China (approval No. 2021226). Verbal informed consent was obtained from each participant. Since the data were anonymous and the study was retrospective, no written informed consent was obtained.

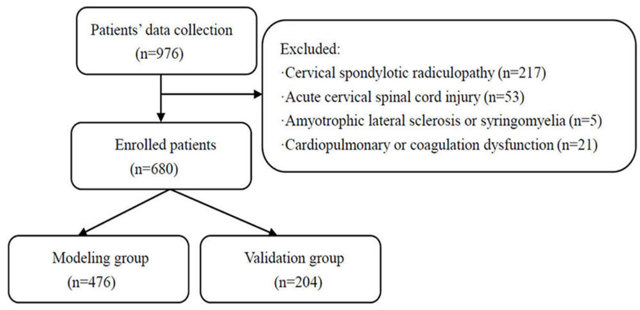

FIGURE 1 | Flowchart of patients included in this study.

Assessment of Neurological Function

The pre-operative and post-operative neurological functions were assessed by using the JOA score. Prognosis status was evaluated by a 6-month post-operative improvement rate for the JOA score. The calculation formula of the JOA improvement rate is as follows: the JOA improvement rate = (post-operative JOA score—pre-operative JOA score)/(17—pre-operative JOA score) × 100% (14). A JOA score improvement rate of more than 75% is excellent, 50–74% is good, 25–49% is acceptable, and <25% is poor (15).

Radiographic Assessment

All patients underwent MRI on admission using either a 3.0-T MRI. Maximal canal compromise (MCC) was applied to assess the maximal canal stenosis, while maximal spinal cord compression (MSCC) was used to measure the maximal degree of spinal cord compression (16). The MCC was defined as the sagittal anteroposterior spinal canal diameter at the maximal spinal canal stenosis (Di) divided by the averaged sagittal anteroposterior spinal canal diameter between the non-pathological spinal canal above (Da) and non-pathological spinal canal below (Db) (**Figure 2A**). MCC was calculated as follows: MCC (%) = [1 – Di/(Da + Db)/2] × 100%. MSCC was defined as the sagittal anteroposterior spinal cord diameter at the maximal spinal cord compression (di) divided by the averaged sagittal anteroposterior spinal cord diameter between the non-pathological spinal cord above (da) and non-pathological spinal cord below (db) (**Figure 2B**). MSCC was calculated as follows: MSCC (%) = [1 – di/(da + db)/2] × 100%. During the radiographic assessment, radiographic measurements

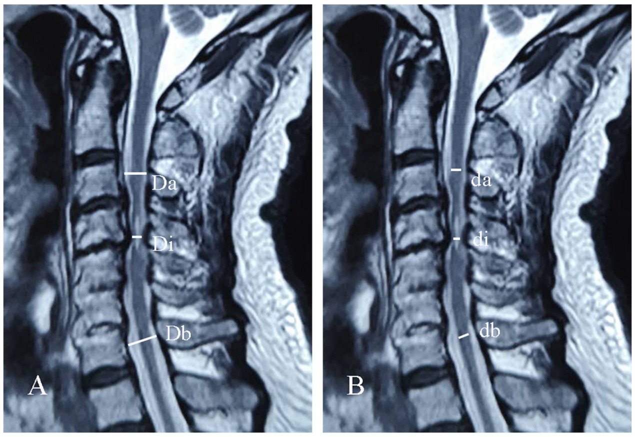

FIGURE 2 | Schematic of maximal canal compromise (MCC) **(A)** and maximal spinal cord compression (MSCC) **(B)** in sagittal cervical MRI.

were obtained by two experienced researchers measuring MRI images of each patient, respectively. Student's t-test analysis was performed on the two groups of measurements. If there was no statistical significance, the mean values of the two groups of measurements were taken as the final radiographic measurements. Otherwise, the above assessment was repeated.

Clinical Treatment

All patients underwent anterior or posterior cervical decompression surgery. Of these, 139 patients underwent anterior cervical corpectomy and fusion, and 541 patients underwent posterior cervical expansive open-door laminoplasty. All surgical procedures were performed by the corresponding author. The external head and neck stabilization was continued for 3 months after surgery. Patients underwent clinical review and evaluation of a neurological function at 6 months post-operatively.

Observed Indicators

The following patients' data were collected and analyzed: gender, age, body mass index (BMI), disease duration, hypertension, diabetes, pre-operative JOA score, MCC, MSCC, number of spinal cord compression segments, operative time, intraoperative blood loss, 6-month post-operative JOA score, and 6-month post-operative improvement rate for the JOA score.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics software version 26.0 (SPSS Inc., Chicago, IL, United States) and R software version 4.1.1. The measurement data were expressed as mean ± standard deviation (SD), and the enumeration data were expressed in percentages. Continuous variables were analyzed using Student's t-test or the Mann-Whitney U-test, and categorical variables were analyzed using the χ^2 test or Fisher's exact test. The independent prognostic factors of patients with CSM with intramedullary T2-weighted ISI were screened using univariate and multivariate logistic regression analysis in the modeling group. The independent prognostic factors were subsequently incorporated into the establishment of the predictive nomogram. The predictive nomogram was validated internally in the modeling group and externally in the validation group. The area under the receiver operating characteristic (ROC) curve (AUC) was undertaken to estimate the discrimination of the predictive nomogram. The calibration curve and the Hosmer-Lemeshow test were used to assess the calibration of the predictive nomogram. The clinical usefulness of the predictive nomogram was evaluated by decision curve analysis (DCA). The value of $P < 0.05$ denoted a statistically significant difference.

RESULTS

Patients' Characteristics

A total of 680 individuals, including 476 patients in the modeling group and 204 patients in the validation group, were included in the present study (**Table 1**). There were 361 patients whose 6-month post-operative improvement rate for the JOA score was ≥60% in the modeling group. The treatment success rate for patients with CSM with intramedullary T2-weighted ISI was 75.8%. No statistically significant differences in gender, age, BMI, and other clinical data were found between the modeling group and validation group ($P > 0.05$), which was comparable.

Univariate and Multivariate Logistic Regression Analysis

The modeling group was further divided into two groups based on whether the 6-month post-operative improvement rate for the JOA score was ≥60%, namely, the poor prognosis group (115) and the good prognosis group (361). Disease duration, pre-operative JOA score, MCC, and MSCC were statistically significant risk factors after univariate logistic regression analysis in the modeling group (**Table 2**). A multivariate logistic regression analysis was performed for statistically significant risk factors. Multivariate logistic regression analysis revealed that pre-operative JOA score [odds ratio (OR) = 1.601, $P < 0.05$], MCC (OR = 1.285, $P < 0.05$), and MSCC (OR = 1.611, $P < 0.05$) were independent prognostic factors (**Table 3**). The logistic regression model is Logit (P) = −33.322 + 0.470 Pre-operative JOA score + 0.251 MCC + 0.477 MSCC.

Development of the Predictive Nomogram

The independent prognostic factors were subsequently incorporated into the development of the predictive nomogram of patients with CSM with intramedullary T2-weighted ISI (**Figure 3**). In the predictive nomogram, the points corresponding to each independent prognostic factor were obtained, then the sum of the points was calculated as the total score, and the predicted risk corresponding to the total score was the probability of poor prognosis of patients with CSM with intramedullary T2-weighted ISI.

Validation of the Predictive Nomogram

Discrimination

The AUC of the modeling group was 0.892 (95% CI: 0.861∼0.924), $P < 0.001$ (**Figure 4A**). The cutoff value of the

TABLE 1 | Patients' characteristics in the modeling group and the validation group.

Characteristics	Modeling group (476)	Validation group (204)	$t/Z/\chi^2$	*P*-Value
Gender				
Male	312	127	0.676	0.411
Female	164	77		
Age	57.07 ± 7.13	56.65 ± 5.51	0.827	0.409
BMI				
<18.5 kg/m^2	35	19	0.925	0.630
18.5–24 kg/m^2	300	129		
>24 kg/m^2	141	56		
Disease duration				
<2 years	215	95	0.113	0.737
≥2 years	261	109		
Hypertension				
No	294	130	0.234	0.629
Yes	182	74		
Diabetes				
No	302	121	1.037	0.309
Yes	174	83		
Pre-operative JOA score	9.96 ± 1.34	9.79 ± 1.43	1.503	0.133
MCC (%)	46.87 ± 6.54	46.06 ± 5.40	1.676	0.095
MSCC (%)	39.55 ± 5.40	38.86 ± 4.95	1.636	0.103
Number of spinal cord compression segments	2.99 ± 0.75	2.90 ± 0.70	1.568	0.117
Operative time				
<3 h	225	98	0.034	0.854
≥3 h	251	106		
Intraoperative blood loss				
<100 ml	257	117	0.652	0.419
≥100 ml	219	87		

BMI, body mass index; JOA, Japanese Orthopedic Association; MCC, maximal canal compromise; MSCC, maximal spinal cord compression.

TABLE 2 | Results of univariate logistic regression analysis in the modeling group.

Characteristics	Poor prognosis group (115)	Good prognosis group (361)	$t/Z/\chi^2$	*P*-Value
Gender				
Male	68	244	2.764	0.096
Female	47	117		
Age	57.23 ± 7.06	57.01 ± 7.17	0.086	0.769
BMI				
<18.5 kg/m^2	9	26	0.093	0.761
18.5–24 kg/m^2	73	227		
>24 kg/m^2	33	108		
Disease duration				
<2 years	42	173	4.538	0.033*
≥2 years	73	188		
Hypertension				
No	78	216	2.359	0.125
Yes	37	145		
Diabetes				
No	72	230	0.046	0.831
Yes	43	131		
Pre-operative JOA score	8.80 ± 0.91	10.34 ± 1.02	1.461	<0.001*
MCC	48.31 ± 5.47	42.23 ± 3.88	0.255	<0.001*
MSCC	42.40 ± 3.42	37.30 ± 2.94	0.520	<0.001*
Number of spinal cord compression segments	3.23 ± 0.74	2.61 ± 0.59	1.211	0.271
Operative time				
<3 h	52	173	0.256	0.613
≥3 h	63	188		
Intraoperative blood loss				
<100 ml	57	200	1.196	0.274
≥100 ml	58	161		

**P <0.05. BMI, body mass index; JOA, Japanese Orthopedic Association; MCC, maximal canal compromise; MSCC, maximal spinal cord compression.*

modeling group was 0.775, $P < 0.001$. The AUC of validation group was 0.885 (95% CI: 0.835∼0.936), $P < 0.001$ (**Figure 4B**). The results of the AUC indicated that the discrimination of the predictive nomogram was good.

Calibration

The calibration curves of the predictive nomogram showed a favorable consistency between the predicted probability and the actual probability in the modeling group (**Figure 5A**) and the validation group (**Figure 5B**). In addition, the results of the Hosmer-Lemeshow in the modeling group and the validation group were $\chi^2 = 10.180$ ($P = 0.253$) and $\chi^2 = 11.319$ ($P = 0.184$), respectively, suggesting the good calibration of the predictive nomogram.

Clinical Usefulness

A DCA of the predictive nomogram in the modeling group and the validation group is shown in **Figure 6**. DCA demonstrated that the predictive nomogram in the modeling group (**Figure 6A**) and the validation group (**Figure 6B**) presented similar net benefits at the range of threshold probability, with better net benefits than the two extreme lines when the threshold probability was 0.1∼1.0. The black horizontal extreme line represented that in patients who received no intervention, the net benefit was 0. The black oblique extreme line represented that in patients who received the intervention, the net benefit was a backslash with a negative slope. The predictive nomogram had good clinical usefulness when it was in the above threshold probability. The cutoff value (0.775) obtained from the ROC curve of the modeling group was within the threshold probability range of the above two DCA curves, also indicating that the predictive nomogram has good clinical usefulness. Further analysis of the DCA curves of the predictive nomogram showed that the net clinical benefit of the modeling group and the validation group was 61 and 56%, respectively, when 0.775

TABLE 3 | Results of multivariate logistic regression analysis in the modeling group.

Variable	B	SE	Wald	OR	95% CI	*P*-Value
Pre-operative JOA score	0.470	0.197	5.702	1.601	1.088∼2.355	0.017*
MCC	0.251	0.035	50.270	1.285	1.199∼1.377	<0.001*
MSCC	0.477	0.062	59.608	1.611	1.427∼1.818	<0.001*
Constant	−33.322	3.561	87.550	0.000	/	<0.001*

**P* <0.05. JOA, Japanese Orthopedic Association; MCC, maximal canal compromise; MSCC, maximal spinal cord compression.*

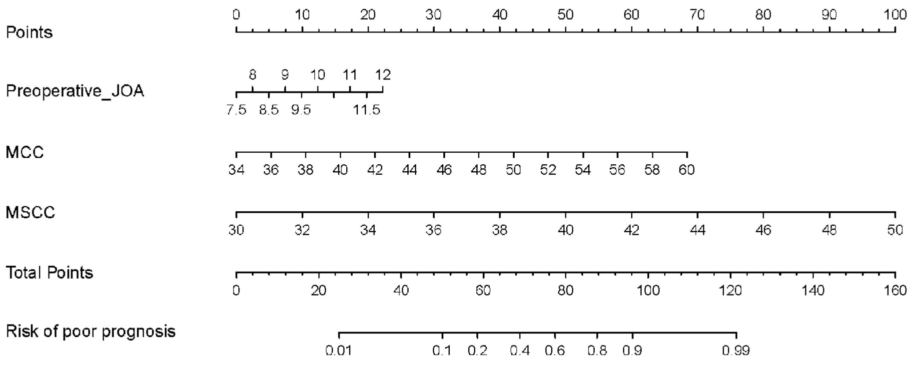

FIGURE 3 | Predictive nomogram for clinical prognosis in cervical spondylotic myelopathy (CSM) with intramedullary T2-weighted increased signal intensity (ISI).

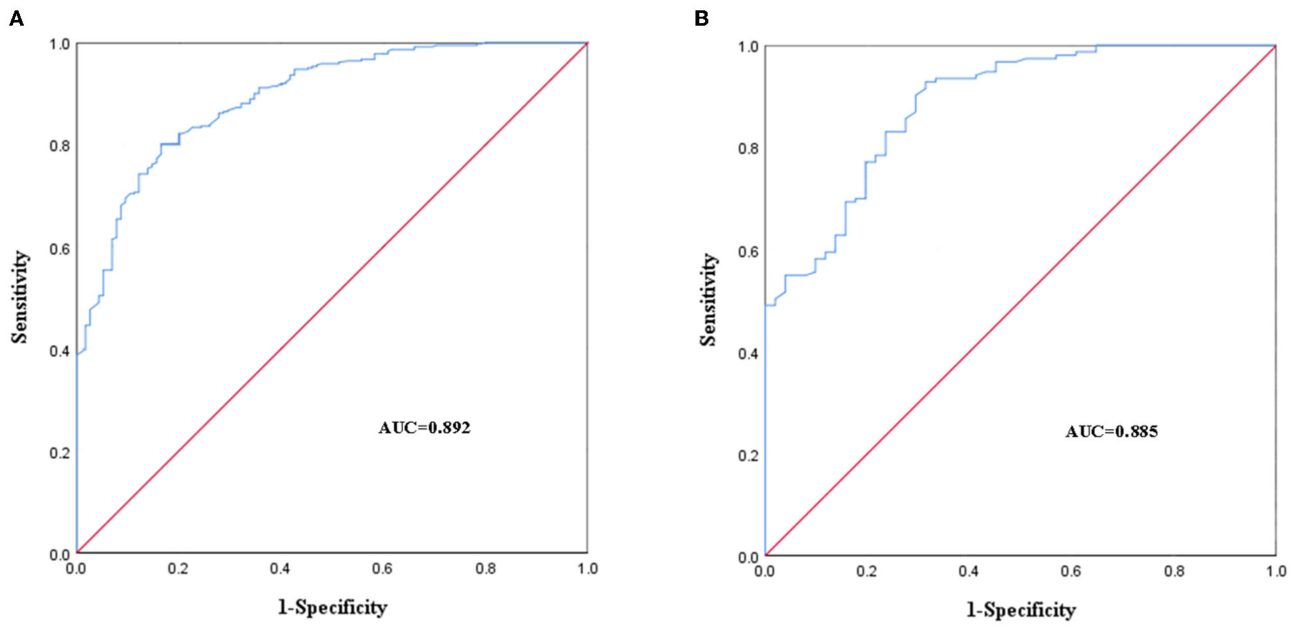

FIGURE 4 | Receiver operating characteristic (ROC) curves of the predictive nomogram in the modeling group **(A)** and the validation group **(B)**.

was set as the threshold probability value for diagnosing poor prognosis and taking intervention. In other words, 61 and 56 of every 100 patients with CSM with intramedullary T2-weighted ISI who were diagnosed with poor prognosis using the predictive nomogram in the modeling group and the validation group would respectively have clinical benefits.

Visualization Application of the Predictive Nomogram

Take a patient with CSM with intramedullary T2-weighted ISI as an example. The prognostic factors for this patient were as follows: pre-operative JOA score = 10, MCC = 46, and MSCC = 39. The risk of poor prognosis for the patient was 0.823 (>0.775)

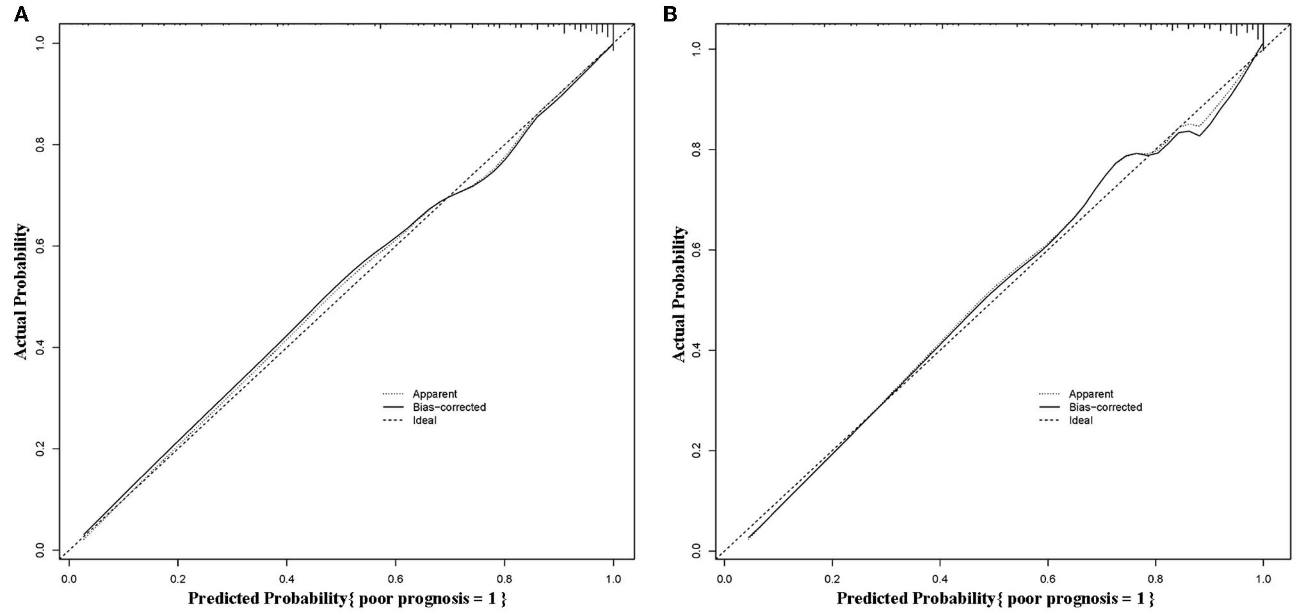

FIGURE 5 | Calibration curves of the predictive nomogram in the modeling group **(A)** and the validation group **(B)**.

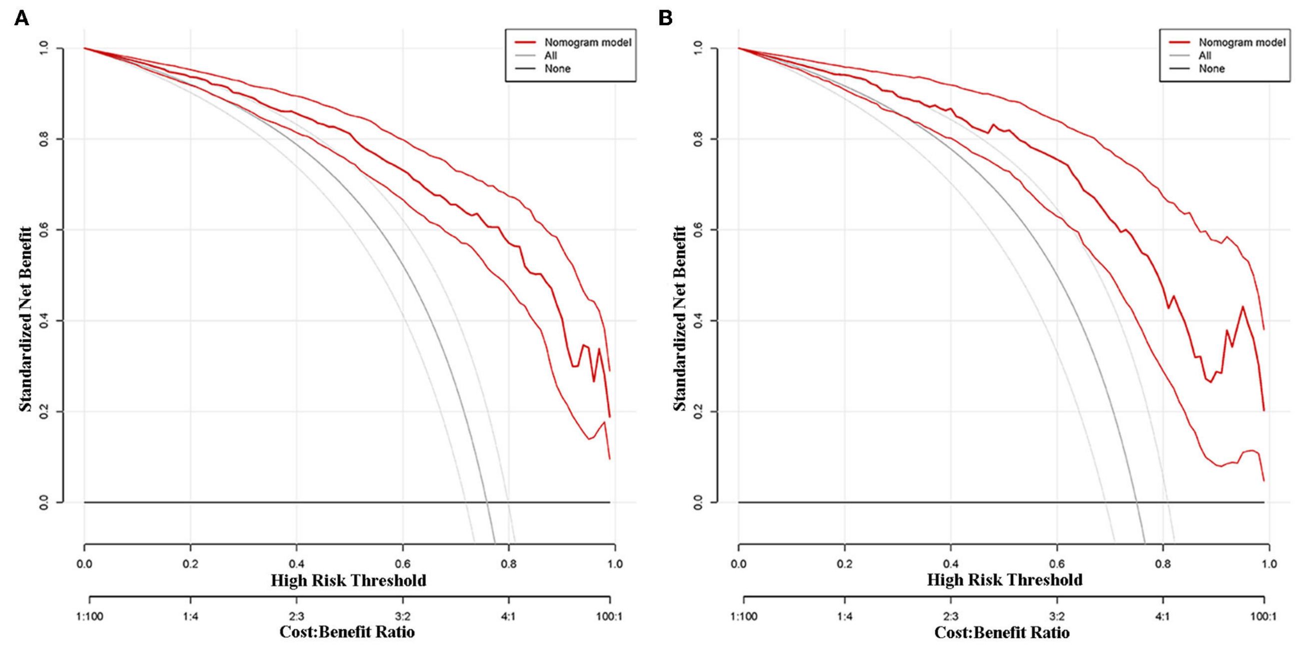

FIGURE 6 | Decision curve analysis (DCA) of the predictive nomogram in the modeling group **(A)** and the validation group **(B)**.

according to the predictive nomogram (**Figure 7**). According to the DCA curve, effective interventions should be taken to reduce the risk of poor prognosis.

DISCUSSION

Cervical spondylotic myelopathy is a progressive, degenerative spine disease, and the most common cause of spinal cord dysfunction in adults worldwide (17). An MRI revealed cervical spinal stenosis and signal change of the cervical spinal cord. T2-weighted MRI showed corresponding intramedullary ISI suggesting cervical spinal cord injury (18, 19). From a histopathological view, the intramedullary ISI reflected the severity and extent of spinal cord lesions (20, 21). Orthopedic surgeons focused on the clinical prognostic factors of the patients with CSM with intramedullary T2-weighted ISI. The clinical

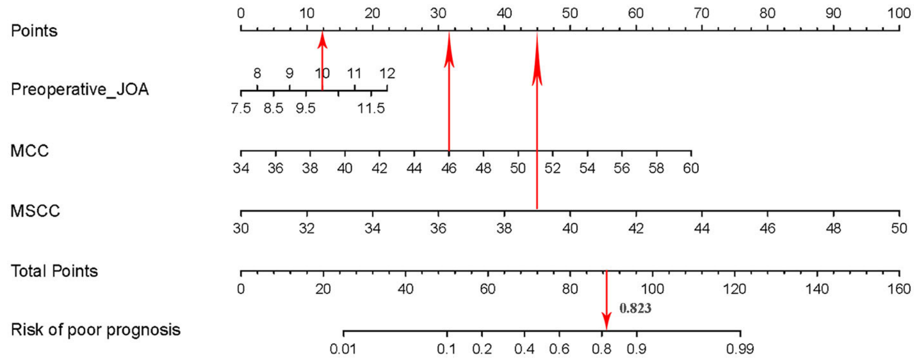

FIGURE 7 | Visualization application of the predictive nomogram.

prognosis of such patients was affected by various factors and was difficult to predict. In this study, we established and validated a predictive nomogram for the clinical prognosis in CSM with intramedullary T2-weighted ISI. Univariate and multivariate logistic regression analysis revealed that pre-operative JOA score, MCC, and MSCC were independent prognostic factors.

Patients with CSM who had intramedullary T2-weighted ISI presented with typical clinical symptoms, such as loss of hand dexterity, unstable gait, and sensory deficit in limbs (22, 23). A lot of quantitative measures that assess the severity of CSM have been developed to assess neurological function. Among them, the JOA score has been greatly popularized in spinal surgery (24). Zhang et al. (25) found that patients with CSM with intramedullary T2-weighted ISI usually had lower pre-operative JOA scores and less improved neurological function after surgery. The results of the present study revealed that the pre-operative JOA score was the independent prognostic factor of patients with CSM with intramedullary T2-weighted ISI. The pre-operative JOA score was incorporated into the development of the predictive nomogram of patients with CSM with intramedullary T2-weighted ISI. The predictive nomogram demonstrated a good degree of discrimination, calibration, and clinical usefulness. Patients with CSM with intramedullary T2-weighted ISI had lower pre-operative JOA scores and a higher probability of poor clinical prognosis after assessment by the predictive nomogram. The reasons causing the above phenomena might be that patients with lower pre-operative JOA scores usually had a poor pre-operative neurological function and delayed or even lost recovery of neurological function during the process of post-operative recovery. Therefore, it is necessary to predict the clinical prognosis of patients with CSM with intramedullary T2-weighted ISI using the pre-operative JOA score.

Maximal canal compromise is often used to evaluate the severity of cervical spinal stenosis in CSM. The measurement of MCC was that the anteroposterior canal diameter on midsagittal and axial T2-weighted images at the maximum compromise level was compared with the anteroposterior canal diameter at normal levels immediately above and below the level of injury (26, 27). Aarabi et al. (28) identified that there was a correlation between MCC and American Spinal Injury Association (ASIA) motor score recovery with a 1-year follow-up. In addition, they also found an inverse relationship between the degree of canal compromise and follow-up ASIA motor score. The results of the present study revealed that the MCC was the independent prognostic factor of patients with CSM with intramedullary T2-weighted ISI. The MCC was incorporated into the development of the predictive nomogram of patients with CSM with intramedullary T2-weighted ISI. After the validation of the predictive nomogram, it was found that patients with severe MCC had a greater risk of poor clinical prognosis. The reason for the above phenomena can be that the space between the spinal cord and spinal canal is severely limited when there issevere MCC. As a result, the spinal cord was more susceptible to ischemic injury resulting from compression. Furthermore, due to the persistent limitation of the spinal cord in severe MCC, the MCC was prone to progressive injury. Therefore, the post-operative recovery of neurological function in such patients was often unsatisfactory. Orthopedic surgeons should pay close attention to the severity of MCC in patients with CSM with intramedullary T2-weighted ISI in clinical diagnosis and treatment.

Maximal spinal cord compression is often used to evaluate the severity of cervical spinal cord compression in CSM. Tarawneh et al. (29) found that MSCC offered a certain prognostic value for the recovery of neurological function. Miyanji et al. (30) found that the extent of MSCC was significantly different between patients with complete and incomplete spinal cord injuries, with more substantial MSCC seen in the patients with complete spinal cord injury. The results of the present study revealed that the MSCC was the independent prognostic factor of patients with CSM with intramedullary T2-weighted ISI. The MSCC was incorporated into the development of the predictive nomogram of patients with CSM with intramedullary T2-weighted ISI. After the validation of the predictive nomogram, it was found that patients with more severe MSCC were more likely to have a poor clinical prognosis. The abovementioned phenomenon might be caused by the compression and the secondary ischemia of the spinal cord. That exacerbated the severity of spinal cord injury. Hence, the post-operative recovery of neurological function in such patients was often unsatisfactory. In clinical treatment, orthopedic surgeons should relieve or even remove spinal cord compression in a timely manner to improve the clinical prognosis of spinal cord injury.

There are some limitations to this study. First of all, this is a retrospective study. Further prospective studies are needed at a later stage. Second, this study was mainly carried out in one hospital at the present stage. A multi-center study has not been carried out. In future studies, the research team will conduct a prospective multi-center study. That will be the further improvement and verification of this study.

CONCLUSION

In conclusion, we established and validated a predictive nomogram for the clinical prognosis in CSM with intramedullary T2-weighted ISI. This predictive nomogram could help clinicians and patients identify high-risk patients and educate them about prognosis, thereby improving the prognosis of high-risk patients. Patients can predict their own prognosis based on their own clinical data related to the independent prognostic factors. Then, patients can consult with their doctors as early as possible and participate in the elaboration of therapeutic protocols.

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 the Medical Ethics Committee of the Second Affiliated Hospital of Xi'an Jiaotong University, China. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JW and HPL contributed to study conception and design. JW and BHY contributed to data collection, data analysis, and manuscript drafting. All authors were involved in the revision of the manuscript and approved the final version of the article.

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Is physician online information sharing always beneficial to patient education? An attention perspective

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Aims: With the development of information technology, online health platforms and physician online information sharing play an important role in public health management and patient education. Is physician online information sharing always beneficial to patient education? From the attention perspective, this study aims to explore how physician online information sharing influences patient education, considering the contingent roles of physician online reputation and offline expertise.

Methods: A 6-month panel data of 61,566 physician-month observations from an online health platform in China was used to tested the proposed hypotheses. Considering the inefficiency and estimated bias of the ordinary least squares regression model, this study conducted the fixed models to test the direct and moderating effects.

Results: The results indicate that physician online information sharing is positively related to potential patient education, while the relationship between physician online information sharing and realized patient education is an inverted U-shape. Physician online reputation enhances the positive relationship between physician online information sharing and potential patient education, but physician offline expertise weakens the abovementioned relationship. In addition, physician offline expertise flattens the curvilinear effect of physician online information sharing on realized patient education.

Conclusion: This study contributes to the literature about attention theory and information sharing for patient education, and provides implications for practice.

KEYWORDS
online information sharing, patient education, attention theory, online health platforms, online reputation, offline expertise

Introduction

With the advancement of online technologies, online health platforms (OHPs) have become one of the most convenient channels for patients to obtain health-related information and for physicians to spread their knowledge, experiences, and skills (1–3). On some OHPs, physicians impart their knowledge to patients by publishing health articles (4), and patients browse pages, search for useful information, and read health articles to improve their health behaviors and status (5). Physicians' information sharing on OHPs transcends temporal and geographic restrictions, and thus helps mitigate the unbalanced distribution of medical resources and promote patient outcomes (5–7). Existing research has examined the outcomes of physicians' information sharing on OHPs. Bryant et al. (8) found that information sharing improves physician–patient relationships and health service quality; Meng et al. (5) indicated that information sharing can increase physicians' online revenue by attracting paid consulting. In fact, patients are target receivers of physicians' shared information, playing a crucial role in achieving the beneficial outcomes of information sharing (5). In this vein, one of the most important outcomes of physicians' information sharing is patient education.

Patient education refers to the activities designed to improve patients' health behaviors and health status (9). It is distinguished as potential patient education through patients' visiting and realized patient education by patients' reading. With the prevalence of OHPs, physicians' online information sharing has become an available way to implement patient education. However, the constantly increasing volumes of health information cause processing problems for patients seeking relevant knowledge and give rise to competition for limited attention (10, 11). As a selective mechanism to allocate cognitive resources (12, 13), limited attention influences individuals' information behaviors significantly (11). For instance, when searching for medical guidance on OHPs, a patient might only pay attention to some of the articles presented on the first few webpages because the patient does not have enough time or cognitive resources to focus on all results. In spite of the richness of attention research (14, 15), the literature does not provide sufficient insights in explaining the relationship between information sharing and patient education on OHPs from the attention perspective. For a better understanding of this issue, limited attention as a fact should be taken into account.

Actually, the information decision-making process is a trade-off between the benefits and the costs of limited attention (14), and such behaviors are not independent of the context. On OHPs, online reputation is previous patients' evaluations of physicians' performance (16). In comparison, expertise is indicated by the clinic title, which is obtained after years of clinical work and professional assessment (17). Both online reputation and offline expertise are available signals about a physician's experience and competence, and might modify patients' perceived value of health information shared by the physician (1, 18). Therefore, online reputation and offline expertise may reshape the trade-off relationship between benefits and costs of attention, playing a contingent role in the process where physician online information affects potential and realized patient education. To obtain a better understanding of information sharing and patient education on OHPs, this study aims to explore the following research questions:

How does physician online information sharing influence potential patient education and realized patient education?
Are the above relationships moderated by online reputation and offline expertise?

According to attention theory, attention functions as an information filter for human beings to allocate limited perceptual and cognitive resources (12, 19). Commonly, attention processes can be either stimulus-driven or goal-driven (20–22). As a more stimulus-driven process, patients' visiting is expected to increase with an increase of physician information sharing since patients' attention could be captured by topics of interest in health articles (12, 23). However, patients' reading is a more goal-driven process where information overload dampens patients' attention to physicians' articles (24). Hence, the relationship between physician online information sharing and realized patient education is expected to be an inverted U-shape pattern. Online reputation acts as a trustable signal to increase patients' perceived information value (15, 25) and anticipated benefits from reading health articles (26, 27). Therefore, online reputation may strengthen the relationship between information sharing and potential patient education, and steepen the inverted U-shape relationship between online information sharing and realized patient education. Offline expertise is obtained after years of clinical work and professional assessment, and may amplify the worth of information and heighten the expected attention cost of reading health articles (17, 28, 29). Therefore, offline expertise may weaken both the relationships between information sharing and patient education mentioned above.

For testing of our hypotheses, a 6-month panel data of 61,566 physician-month observations from an OHP in China are collected. The results provide empirical support for most of our hypotheses, with an only exception that the moderating role of online reputation in the relationship between physicians' online information sharing and realized patient education was not supported. To be more specific, physician online information sharing positively affects potential patient education, while having an effect on realized patient education in an inverted U-shape pattern. Physician online reputation promotes the positive relationship between physician information sharing and potential patient education, but physician offline expertise weakens the abovementioned relationship. Moreover, physician offline expertise flattens the curvilinear relationship between physician online information sharing and realized patient education.

This study also makes several contributions to the literature. First, this study contributes to the attention literature by introducing the attention theory to track the mechanism of physician online knowledge sharing and patient education. By applying an attention perspective, this study clarified how physician online knowledge sharing influences potential and realized patient education in different patterns. Second, this study contributes to the online reputation and patient education literature by uncovering the contingent effect of online reputation in the process of patient education. The accomplishment of patient education by physicians' information sharing is actually a decision-making process for patients, which depends on the context (14, 30). Our study clarifies how physicians' online reputation reshapes patients' decision-making on acquiring knowledge from physicians. Finally, this study contributes to the extant offline expertise and patient education literature by revealing the contingent effect of offline expertise in the process of patient education. In spite of the recent focus on physicians' expertise (5, 31), more insights on its role in patient education are needed. Therefore, this study sheds light on the moderating role of physicians' offline expertise on the trade-off between the benefits and the costs of limited attention to online health information, complementing the understanding of the effect of expertise.

The article is structured as follows: after the introduction, theory background and hypotheses are proposed in Section Theory background and hypotheses. Section Methodology illustrates the method and Section Results presents results. Moreover, findings, contributions, implications, limitations and conclusion are detailed in Section Discussion.

Theory background and hypotheses

Attention theory

Early research on the essence of consciousness and volition highlights the importance of the concept of attention (22). According to previous attention literature, attention has been defined as the allocation of limited cognitive processing capacity toward selective concentration on particular information (32, 33). Limited attention implies information cost and constrained choices (34). In fact, attention functions as an information filter, selecting some information for further processing while inhibiting others from being processed (19, 35). The mechanism of attention is the most efficient way for human beings to allocate limited perceptual and cognitive resources, enabling information receivers to become active seekers and processors as well (12). Commonly, attention processes can be either stimulus-driven or goal-driven (20–22). The former refers to the case when one's attention is captured by some external event, while the latter happens when one's attention is controlled voluntarily for a certain goal (12).

Attention theory is well-established with an expansion of research examining the mechanism of attention and identifying it as an important driver of various outcomes over the past few decades (36). These works identified the fundamental principle that attention is a limited cognitive resource (37, 38), and individuals selectively ignore some of the information that competes for their attention (36, 39). There is also a wide range of management researchers focusing on various types of attention, including consumer attention, investor attention, employee attention, user attention, and regulatory attention (14, 24, 36). Moreover, with the prevalence of online platforms, several recent studies try to enhance the understanding of user behaviors and information networks from the perspective of attention (24, 40).

The widespread information explosion now-a-days on online platforms, including OHPs, leads to competition for limited attention, which has a significant effect on individuals' information decisions and behaviors (11). On OHPs, physicians publish online articles for the purposes of health promotion and patient education, while patients seek relevant and useful information such as medical knowledge and professional advice (5, 41). Physicians' information sharing benefits both patients and physicians themselves, promoting the prosperity of the OHPs (5, 42). However, given the ever-increasing shared information on OHPs causes difficulties in accessing and absorbing knowledge, which may affect the achievement of public health management and patient education (11). An attention perspective is therefore needed and vital to enhance the understanding of physician information sharing and possible patient education.

The attention theory helps uncover the mechanism through which patients decide whether to allocate or not their limited cognitive resources to health articles shared by physicians (12). It thus offers a visualized framework to enhance the understanding of how physician online information sharing provokes potential patient education by patients' visiting and realized patient education by patients' reading. According to attention theory, patients' visiting is similar to a stimulus-driven attention process, and the information sharing by physicians may initiate potential patient education as patients' attention could be captured by contents of interest in shared health articles (12, 23). However, patients' reading is a goal-driven process where the patients' information decision is the trade-off between the benefits and the costs of attention, and information overload dampens patients' attention to physicians' articles (24). Moreover, online reputation and professional expertise, as easily accessible signals on OHPs for physicians' experience and competence, may reshape patients' perceived value of health articles, and thus affect their information decisions (16, 43). Therefore, it is necessary to consider the contingent role of physicians' online reputation and offline expertise in the process of physician online information sharing and patient education.

Online information sharing and patient education

Online information sharing refers to physicians' health and medical information sharing that is available for patients on OHPs (44). Patient education refers to the activities designed to improve patients' health behaviors and health status (9), and is distinguished as potential patient education through patients' visiting and realized patient education by patients' reading. Patients' visiting is defined as the total number of a physician's homepage visits by patients on the OHP (45). Patients' reading is defined as the amount of reading of a physician's shared health articles by patients (5). Within OHPs, shared health content is so extensive that patients have access to an almost limitless selection of information, which competes for their limited time and cognitive resources (36). However, limited attention implies that patients' visiting is caught only by a certain subset of the available articles, and their further reading happens only when the perceived benefits exceed the costs of attention (14, 36).

Physicians' online information sharing positively influences potential patient education. The more health articles a physician has on an OHP, the more likely their articles are to be included in patients' subset of alternatives identified by limited attention from the full spectrum of alternative information during browsing the webpage (36, 46). Further, with the increase of articles published, more health topics are covered, leading to a higher possibility of addressing patients' information needs and filling their specific knowledge gaps (47). In other words, the more the physician's health articles are shared, the more likely a valuable article exists to catch patients' attention and trigger their visiting. On the basis of the above argument, we propose the following hypothesis:

> **H1:** *Physicians' online information sharing is positively related to potential patient education.*

Physicians' online information sharing is associated with realized patient education in a non-linear pattern, and this is because patients' decision to read the article on the OHP or not depends on the trade-off between the benefits and the costs of attention (14). As reading articles on the benefits from reading a shared health article outweigh the cost (48). The benefits of attention to the shared articles include gains such as learning health knowledge and addressing health problems, while the costs could be attributed to the information-processing time, cognitive resources, and opportunity costs (14).

As the number of shared articles by a physician gradually increases from low to moderate, the value of the shared information perceived by patients increases. For instance, the articles may discuss the patients' specific health issues, fill their relevant knowledge gaps, and help to improve their health behaviors. There is also a growing cost for the attention to select an article from all the alternatives and then read it as the volume of information increases (36). However, at this stage, the attention is at a relatively low level because the quantity of information is under the threshold of personal cognitive capacity and information overload has not yet occurred (24, 49). Therefore, physicians' online information sharing positively affects realized patient education as the perceived benefits of attention outweigh the cost.

However, when the number of shared articles is greater than a certain threshold, the cost of attention becomes more conspicuous. In essence, the attention allocated to a health article comes at the expense of attention allocated to all other articles in the patient's subset of alternatives (36, 50). As a result, the opportunity cost of attention increases with an increasing quantity of information available (51). Moreover, information overload occurs when the number of shared articles exceeds what a patient can deal with (24, 49). Information overload causes a sense of fatigue, hampers the capability to process information, and distorts the real value of information, thus downplaying the patient's original interest in the health articles (52). When the quantity of shared articles exceeds a certain threshold, the perceived cost of attention is higher than the benefit. Therefore, in this phase, physicians' online information sharing negatively affects realized patient education. From the above arguments, we propose the following hypothesis:

> **H2:** *There is an inverted U-shape relationship between physicians' online information sharing and realized patient education.*

The moderating effect of online reputation

Online reputation is defined as patients' evaluations of physicians' performance, reflecting their capability and popularity (16). Reputation plays a signaling role to reduce patients' concerns about quality risk and uncertainty on OHPs where there is severe health information asymmetry between physicians and patients (5). Online reputation is a trustable signal because it is an extrinsic cue about the social approval of physicians' competence (18, 53). Moreover, reputation represents a valuable and rare resource, and is thus a common source of competitive advantage (25, 53). Online reputation might modify patients' perception of information value and have a contingent effect on their information decisions.

Online reputation positively moderates the relationship between physicians' online information sharing and potential patient education. First, as a valuable and rare resource, a good online reputation makes the information shared by the physician more interesting and attractive to patients (53, 54). In this case, physicians' shared articles are more likely to attract patients' attention and induce their visiting. Second, a good reputation is a reliable signal about high quality and value of health articles shared by the physician (18, 43). In this condition, with their attention caught by health articles, patients are more inclined to believe that their health issues could be addressed, and are thus more willing to visit the physician's homepage to obtain more information. On the basis of the above arguments, we propose the following hypothesis:

> **H3:** *Online reputation strengthens the positive relationship between physicians' online information sharing and potential patient education.*

Online reputation also moderates the inverted U-shape relationship between physicians' online information sharing and realized patient education. As discussed before, reading articles on an OHP is a more goal-driven process, which is implemented only when expected profits can be realized (14, 48). When the total number of articles shared is under a certain threshold, online reputation acts as both a source of competitive advantage and a signal about expertise and capacity, increasing perceived benefits of attention to the information shared by the physician (18, 25, 53). Under this circumstance, the trade-off between benefits and costs of attention inclines to the side of benefits, and patients are more willing to read shared health articles. As a result, online reputation strengthens the positive relationship between physicians' online information sharing and realized patient education.

However, good online reputation may also be regarded as a means to attract patients and consultations, and increases patients' expectations of the value and benefits of reading shared information, especially when there is a large amount of shared articles (10, 26). If patients cannot obtain the anticipated profits from reading the health articles, it is hard for them to keep their attention focused there (14). In this case, a good reputation magnifies the difficulties for the physician's shared information to meet patients' expectations and gain their attention. As a consequence, online reputation strengthens the negative relationship between physicians' online information sharing and realized patient education when the volume of shared information is relatively high. From the above arguments, we propose the following hypothesis:

> **H4:** *Online reputation steepens the inverted U-shape relationship between physicians' online information sharing and realized patient education.*

The moderating effect of offline expertise

Offline expertise refers to the experience of continuous health service and medical capability, and is indicated by the clinic title, which is classified into four hierarchical levels (1, 17). The clinic title is obtained after a long period of clinical work and professional assessment. It is an authoritative signal of physicians' experience and competence, which is not affected by their online activities (1, 29). Generally, physicians with a high clinic title have high incomes from hospitals and are more respected and trusted by patients (17). Offline expertise is expected to reshape patients' perception of information from physicians, and thus play a contingent role in their information decisions.

Offline expertise weakens the positive relationship between physicians' online information sharing and potential patient education. Physicians with higher clinic titles are regarded as experts in their medical field, and their articles are perceived as more rewarding to patients (55, 56). Valuable information receives attentional priority, and once the shared information enters patients' browsing range, it draws the patients' attention (23). Further, physicians with higher professional titles are more likely to obtain active goal-driven attention from patients because patients tend to choose medical services from higher-titled physicians, and are thus inclined to seek health knowledge shared by them as well (1, 29). Therefore, for those physicians who have higher clinic titles, the growth of their page visits is less dependent on the total amount of articles. On the basis of the above arguments, we propose the following hypothesis:

> **H5:** *Offline expertise weakens the positive relationship between physicians' online information sharing and potential patient education.*

Offline expertise also moderates the inverted U-shape relationship between physicians' online information sharing and realized patient education. To read or not depends on the trade-off between benefit and cost of attention (14). When the total quantity of articles shared is relatively small, offline expertise weakens the positive relationship between physicians' online information sharing and realized patient education. This is because information sharing from experts (physicians with high professional titles) is considered more valuable guidance (17). Patients tend to believe that they will benefit from reading experts' shared health articles even if few topics are covered and they are not immediately relevant. Thus, for physicians with higher professional expertise, the benefits of attention will not be hampered so much as the number of shared articles decreases.

When the total number of articles shared is relatively high, offline expertise alleviates the negative relationship between physicians' online information sharing and realized patient education. First, professional title is an authoritative signal of physicians' experience and competence (1, 29). There is

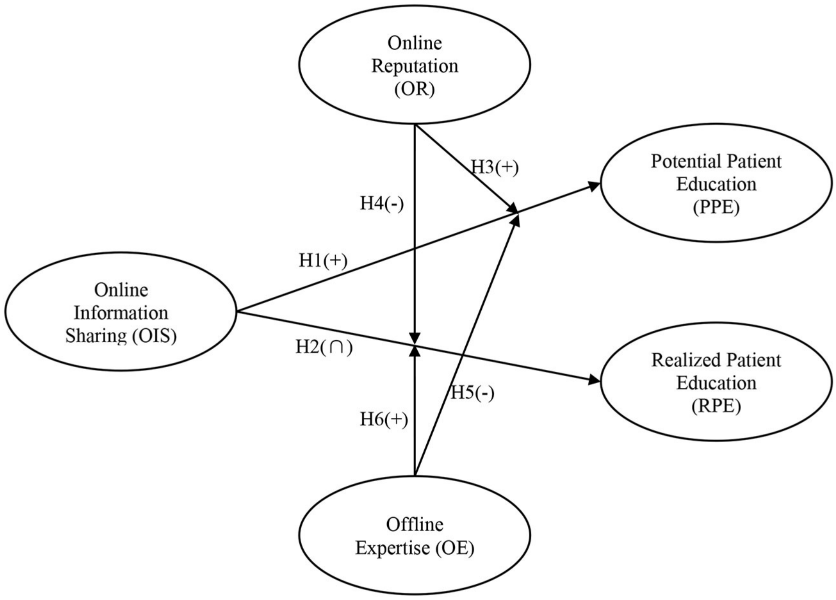

FIGURE 1
Research model.

higher perceived benefit from attention to information shared by physicians with higher professional titles. Second, patients hope to obtain medical service from experts, but experts are essentially scarce in the medical and health market, especially when the disequilibrium of medical resources impedes the accessibility to expert treatment (28, 29). The scarcity of experts heightens the expected attention cost patients are willing to pay. In this instance, patients gain perceived profits from reading health articles, and are thus more likely to read them even when there is a large amount of shared information. On the basis of the above arguments, we propose the following hypothesis:

> **H6:** *Offline expertise flattens the inverted U-shape relationship between physicians' online information sharing and realized patient education.*

In summary, the research model is presented in Figure 1.

Methodology

Data collection

We choose the OHP "haodf.com" as our data source because the data collected from this online platform are objective and avoid self-reporting bias effectively (5). Additionally, the database haodf.com provides us with the following advantages. First, the platform has a large number of users and physician–patient interactions, which enables us to obtain abundant data for the study. It is reported that this platform brings together more than 200,000 physicians from different hospitals across the whole country and offers service to more than 58,000,000 patients online (5). Second, this online platform makes it possible for us to explore physicians' online information sharing and patient education. We focused on public information sharing and patient education for research purposes. The free and public characteristics of the published articles on the online platform make it convenient for patients to access and absorb; hence, patient education can be identified and achieved.

Using a Java-based web crawler, we successfully collected the article publications and website data statistics of 66,563 physicians over 6 months (February 2017 to July 2017). After deleting some incomplete data, we finally obtained an unbalanced panel of 19,022 physicians with 61,566 physician-month observations.

Measures

Dependent variables

Patient education refers to the activities designed to improve patients' health behaviors and health status (9), and is segmented into potential patient education through patients' visiting and realized patient education by patients' reading. We used the number of patients visiting physicians' homepages to measure potential patient education. As for realized patient education, we measured it by the number of article readings of physicians on the OHP.

TABLE 1 The overview of all variables.

Variables	Description	Mean	SD	Min	Max
Potential patient education	The number of patients visiting a physicians' homepage	11.571	1.754	5.024	17.719
Realized patient education	The number of article readings of physicians	7.777	1.170	1.099	12.891
Online information sharing	The number of free health-related articles shared by physicians	1.745	1.263	0.000	7.550
Online reputation	The number of patients received by physicians	4.584	2.116	0.000	10.672
Offline expertise	The offline tittles of physicians	2.986	0.908	1	4
Online time	The opening time of physicians	7.221	0.817	2.303	8.030
Gift	The number of online gifts from patients	1.744	1.599	0.000	7.920
Vote	The number of votes physicians received	2.195	1.321	0.000	7.046
Thank-you	The number of online thank you letters from patients	1.181	1.187	0.000	6.084

Independent variables

Online information sharing is defined as physicians' health and medical information sharing that is available for patients on the OHP (44). From previous studies (5, 31), we chose the number of free health-related articles shared by physicians on the online platform as the measure of this variable. Online reputation refers to patients' evaluations of physicians' performance, reflecting their capability and popularity (16). We used the number of patients received by physicians to measure online reputation. Offline expertise refers to the experience of continuous health service and medical capability (1, 17). It was measured by the offline titles of physicians, from the lowest to the highest rankings; the offline titles in China are resident physician, attending physician, associate chief physician, and chief physician (5). In this study, we ranked this variable from 1 to 4 to represent the physicians' offline title.

Control variables

Following previous studies (5, 31), we added several variables as controls. First, Online time refers to the length of time the physicians had been using the OHP. We used the time in months that each physician had been using the OHP for measuring this variable. Second, the number of online gifts and votes that physicians receive may influence patient education. Therefore, we controlled Gift and Vote variables for more realistic results. Finally, the number of online thank-you letters from patients was used to measure the last control variable—Thank-you.

Considering the magnitude of the original data, according to Kafouros et al. (57), we used the logarithm of all variables except offline expertise. Table 1 lists an overview of all the variables in this study.

Data analysis

In testing our hypotheses, we introduced the following equations to estimate the effects of online information sharing (*OIS*) on potential patient education (*PPE*) and realized patient education (*RPE*):

$$\begin{aligned} PPE_{it} = {} & \beta_0 + \beta_1 Onlinetime_{it} + \beta_2 Gift_{it} + \beta_3 Vote_{it} \\ & + \beta_4 Thank-you_{it} + \beta_5 OIS_{it} + \beta_6 OIS_{it}^2 + \beta_7 OR_{it} \\ & + \beta_8 OR_{it} \times \beta_9 OIS_{it} + \beta_{10} OR_{it} \times \beta_{11} OIS_{it}^2 \\ & + \beta_{12} OE_{it} + \beta_{13} OE_{it} \times \beta_{14} OIS_{it} + \beta_{15} OE_{it} \\ & \times \beta_{16} OIS_{it}^2 + \mu_{it} \\ RPE_{i,t} = {} & \beta_0 + \beta_1 Onlinetime_{it} + \beta_2 Gift_{it} + \beta_3 Vote_{it} \\ & + \beta_4 Thank-you_{it} + \beta_5 OIS_{it} + \beta_6 OIS_{it}^2 + \beta_7 OR_{it} \\ & + \beta_8 OR_{it} \times OIS_{it} + \beta_{10} OR_{it} \times \beta_{11} OIS_{it}^2 \\ & + \beta_{12} OE_{it} + \beta_{13} OE_{it} \times \beta_{14} OIS_{it} + \beta_{15} OE_{it} \\ & \times \beta_{16} OIS_{it}^2 + \mu_{it} \end{aligned}$$

where i indicates the number of observations, the β parameters are the coefficients that can be estimated in the hierarchical regression model, and the μ parameter is the error term in each equation.

Considering the inefficiency and estimated bias of the ordinary least squares regression model, this study conducted the fixed models to test the direct and moderating effects (58, 59).

Results

Regression analysis

The correlation results of this study are presented in Table 2. Since this study involves moderating effects, following previous studies (5, 60, 61), we used hierarchical regression to test our hypotheses. The results of hypothesis testing are presented in Table 3.

H1 proposed the positive relationship between physicians' online information sharing (OIS) and potential patient education (PPE). The results in Model 1 indicate that OIS ($\beta = 0.340$, $p < 0.001$) is positive and significantly related to

TABLE 2 Correlation matrix.

Variables	1	2	3	4	5	6	7	8	9
1. Potential patient education	1.000								
2. Realized patient education	0.383	1.000							
3. Online information sharing	0.531	0.133	1.000						
4. Online reputation	0.794	0.248	0.456	1.000					
5. Offline expertise	0.367	0.119	0.174	0.200	1.000				
6. Online time	0.632	0.250	0.203	0.182	0.374	1.000			
7. Gift	0.645	0.218	0.373	0.795	0.199	0.137	1.000		
8. Vote	0.600	0.231	0.302	0.658	0.3889	0.246	0.731	1.000	
9. Thank-you	0.582	0.214	0.318	0.654	0.298	0.195	0.750	0.899	1.000

PPE. Thus, H1 is supported. As for the control variables, the coefficients of all are significant and positive (Online time, $\beta = 1.076$, $p < 0.001$; Gift, $\beta = 0.440$, $p < 0.001$; Vote, $\beta = 0.104$, $p < 0.001$; Thank-you, $\beta = 0.055$, $p < 0.001$).

H2 proposed the inverted U-shape relationship between online information sharing (OIS) and realized patient education (RPE). To test the hypothesized inverted U-shape relationship, we followed the suggestions of Haans et al. (62) to evaluate the coefficient estimates, slope significance, and turning point against data range. First, the results in Model 5 show that the coefficient of OIS is positive and significant ($\beta = 0.187$, $p < 0.001$), whereas the squared term of online information sharing (OISS) is negative and significant ($\beta = -0.041$, $p < 0.001$). We then tested the slopes of the OIS effect at both the low and the high ends of OIS. The slopes at the low (OIS=0; $\beta = 0.187$, $p < 0.001$) and the high (OIS=7.550; $\beta = -0.438$, $p < 0.001$) ends are both sufficiently steep and statistically significant. Third, the turning point of the curvilinear effect is calculated at OIS = 2.257, with a 95% confidence interval from 2.162 to 2.351, which is well within the data range. We also plotted the relationship between OIS and RPE (see Figure 2). Altogether, these results satisfy the inverted U-shape testing criteria of Haans et al. (62), rendering support for our H2. In addition, the effects of control variables are positive (Online time, $\beta = 0.299$, $p < 0.001$; Gift, $\beta = 0.086$, $p < 0.001$; Vote, $\beta = 0.074$, $p < 0.001$) and significant except for Thank-you.

H3 and H4 argued the moderating effect of physicians' online reputation (OR). In Model 2, the positive moderating effect of OR on the positive relationship between OIS and PPE is examined. The coefficient of the interaction term (OIS × OR) is significant and positive ($\beta = 0.026$, $p < 0.001$). Following Meyer et al. (63), we plotted the marginal effect of physicians' information sharing on potential patient education at different levels of physicians' online reputation (Figure 3). The results show that as the values of online reputation increase from 0 to 10.672, the slope of the relationship between physicians' information sharing and potential patient education becomes steeper. Thus, H3 is supported. Meanwhile, the negative moderating effect of physicians' OR on the inverted U-shape relationship between OIS and RPE is tested in Model 6. The relationship between the interaction of the squared term (OISS×OR) is not significant ($\beta = 0.002$, $p > 0.050$). Thus, H4 is not supported.

H5 and H6 posit the moderating effect of physicians' offline expertise (*OE*). H5 is tested in Model 3, the results show that the coefficient of the interaction term (*OIS*×*OE*) is negative and significant ($\beta = -0.012$, $p < 0.001$). Figure 4 illustrates the marginal effect of physicians' information sharing on potential patient education at different levels of physicians' offline expertise. The moderating effect shows that as the value of offline expertise increases from 1 to 4, the slope of the relationship between physicians' information sharing and potential patient education becomes flatter. Therefore, H5 is supported. As for the testing of H6, the results are presented in Model 7. The coefficient of the interaction term (*OIS*×*OE*) is negative and significant ($\beta = -0.077$, $p < 0.001$). Meanwhile, the coefficient of interaction of the squared term (*OISS*×*OE*) is positive and significant ($\beta = 0.011$, $p < 0.001$). Figure 5 shows the moderating effects of offline expertise (*OE*) on the relationship between online information sharing (*OIS*) and realized patient education (*RPE*). With the increase of *OE*, the inverted U-shape curve relationship between *OIS* and *RPE* becomes significantly flatter. Under the impact of physicians' offline expertise, realized patient education is less affected by physicians' information sharing. Thus, H6 is supported.

Supplementary analysis

To test the robustness of our findings, following the suggestions of Guo et al. (64) and Wang et al. (65), this study applied full models to further test our moderating effects in Table 3. In terms of potential patient education, all moderators and interaction terms were entered according to Model 1, and the results are presented in Model 4. The coefficients of the interaction terms are significant (*OIS*×*OR*, $\beta = 0.028$, $p < 0.001$;

TABLE 3 Results of hierarchical regression.

Potential patient education (PPE)	Model 1	Model 2	Model 3	Model 4
	PPE	PPE	PPE	PPE
Online information sharing	0.340***	0.059***	0.376***	0.100***
(OIS)	(0.003)	(0.005)	(0.010)	(0.007)
Online reputation (OR)		0.467***		0.467***
		(0.002)		(0.002)
OIS×OR		0.026***		0.028***
		(0.001)		(0.001)
Offline expertise (OE)			0.063***	0.102***
			(0.007)	(0.005)
OIS×OE			−0.012***	−0.017***
			(0.003)	(0.002)
Online time	1.076***	1.035***	1.062***	1.012***
	(0.005)	(0.003)	(0.005)	(0.003)
Gift	0.440***	0.0175***	0.444***	0.022***
	(0.003)	(0.003)	(0.003)	(0.003)
Vote	0.104***	−0.013***	0.085***	−0.044***
	(0.006)	(0.004)	(0.006)	(0.004)
Thank-you	0.055***	0.052***	0.062***	0.064***
	(0.007)	(0.005)	(0.007)	(0.005)
Constant	2.152***	1.546***	2.091***	1.469***
	(0.030)	(0.022)	(0.033)	(0.023)
R^2	0.773	0.893	0.773	0.895
Realized patient education (RPE)	**Model 5**	**Model 6**	**Model 7**	**Model 8**
	RPE	RPE	RPE	RPE
Online information sharing	0.187***	0.151***	0.410***	0.357***
(OIS)	(0.010)	(0.024)	(0.033)	(0.036)
Online information sharing	−0.041***	−0.063***	−0.071***	−0.087***
squire (OISS)	(0.002)	(0.007)	(0.008)	(0.009)
Online reputation (OR)		0.061***		0.055***
		(0.005)		(0.005)
OIS×OR		0.011**		0.017***
		(0.004)		(0.004)
OISS×OR		0.002		0.001
		(0.001)		(0.001)
Offline expertise (OE)			0.050***	0.062***
			(0.010)	(0.010)
OIS×OE			−0.077***	−0.080***
			(0.010)	(0.011)
OISS×OE			0.011***	0.010***
			(0.002)	(0.003)
Online time	0.299***	0.289***	0.308***	0.296***
	(0.006)	(0.006)	(0.006)	(0.006)
Gift	0.086***	0.012*	0.086***	0.012*
	(0.004)	(0.005)	(0.004)	(0.005)

(Continued)

TABLE 3 (Continued)

Realized patient education (RPE)	Model 5	Model 6	Model 7	Model 8
	RPE	RPE	RPE	RPE
Vote	0.074***	0.059***	0.080***	0.064***
	(0.008)	(0.008)	(0.008)	(0.008)
Thank-you	0.007	0.000	0.008	0.001
	(0.009)	(0.009)	(0.009)	(0.009)
Constant	5.165***	5.134***	4.945***	4.924***
	(0.040)	(0.044)	(0.047)	(0.049)
R^2	0.106	0.114	0.108	0.116

*p < 0.050, **p < 0.010, ***p < 0.001 (2-tailed test).

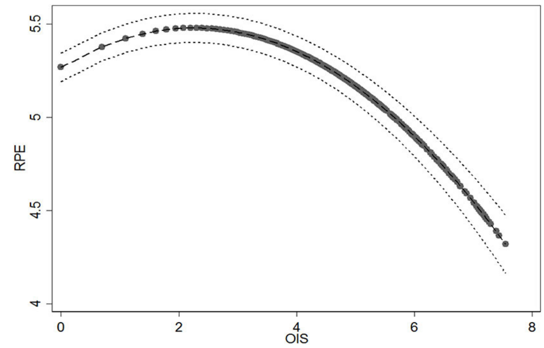

FIGURE 2
The relationship between online information sharing (OIS) and realized patient education (RPE).

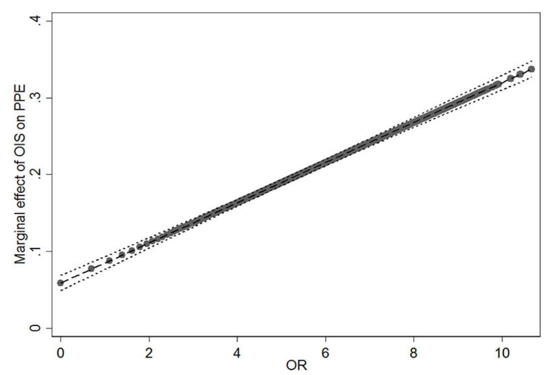

FIGURE 3
Moderating effect of online reputation (OR) on the relationship between online information sharing (OIS) and potential patient education (PPE).

OIS×OE, $\beta = -0.017$, $p < 0.001$). The results are consistent with Model 2 and Model 3, and H3 and H5 are further supported. In terms of realized patient education, all moderators and

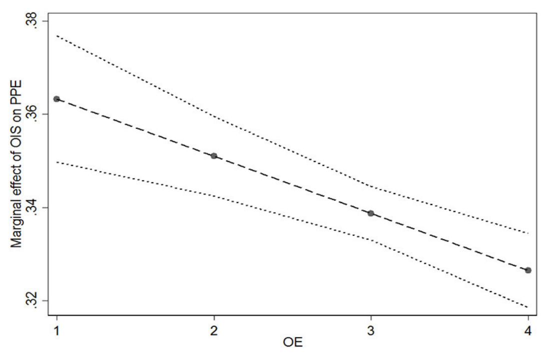

FIGURE 4
Moderating effect of offline expertise (OE) on the relationship between online information sharing (OIS) and potential patient education (PPE).

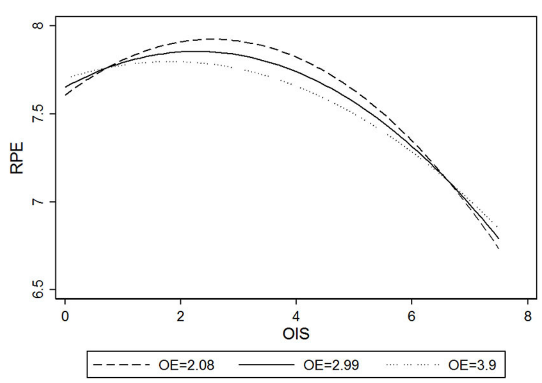

FIGURE 5
Moderating effects of offline expertise (OE) on the relationship between online information sharing (OIS) and realized patient education (RPE).

interaction terms were entered according to Model 5, and the results are presented in Model 8. The coefficient of the squared term about online reputation is insignificant ($\beta = 0.001$, $p > 0.05$), while that about offline expertise is significant ($\beta = 0.010$, $p < 0.001$). The results are consistent with Model 6 and Model 7, thereby further rejecting H4 and supporting H6.

We further conducted random effects regression models as supplementary analysis following previous studies (66, 67). The results are demonstrated in Table 4. Model 9 shows that the relationship between *OIS* and *PPE* is positive and significant ($\beta = 0.340$, $p < 0.001$), supporting H1. In Model 13, the coefficient of *OIS* is positive and significant ($\beta = 0.186$, $p < 0.001$), whereas the squared term (*OISS*) is negative and significant ($\beta =-0.041$, $p < 0.001$). Thus, H2 is also supported. Model 10 and Model 11 confirm the moderating effects of *OR* ($\beta = 0.026$, $p < 0.001$) and *OE* ($\beta =-0.012$, $p < 0.001$) on the relationship between *OIS* and *PPE*, and Model 12 also confirms the abovementioned relationship ($OIS\times OR$, $\beta = 0.028$, $p < 0.001$; $OIS\times OE$, $\beta = -0.017$, $p < 0.001$). The results provide evidence for supporting H3 and H5. Similar to the main analysis, the coefficient of the interaction of the squared term ($OISS\times OR$) is not significant ($\beta = 0.002$, $p>0.001$) in Model 14. Model 15 reports that the coefficient of the interaction term ($OIS\times OE$) is negative and significant ($\beta = -0.077$, $p < 0.001$) and the coefficient of the interaction of the squared term ($OISS\times OE$) is positive and significant ($\beta = 0.010$, $p < 0.001$). Model 16 also indicates that the interaction of the squared term $OISS\times OR$ is not significant ($\beta = 0.001$, $p > 0.050$), but the interaction of the squared term $OISS\times OE$ is significant ($\beta = 0.010$, $p < 0.001$). Thus, H4 is rejected and H6 is supported. In summary, the results are similar to the fixed effects and our results are robust.

Discussion

Key findings

This study analyzed how physician online information sharing affects patient education by considering the contingent effects of physicians' online reputation as well as physicians' offline expertise. Based on a 6-month panel data of 61,566 physician-month observations collected from an OHP in China, this study generated three significant findings.

First, support for the attention hypotheses was found. Physicians' information-sharing behaviors are positively related to the potential patient education. As we know, patients are more likely to acquire valuable information for them when doctors post more medical or treatment instructions in OHCs (68, 69). Patients' attention may be drawn by themes of interest in health articles and patient visits will grow as physician information exchange increases (14). Also, an inverted-U shape curvilinear relationship exists between physician online information sharing and realized patient education. Patient has limited attention (37, 70), although at first they read online information carefully. As a process of goal-driven when patients read physician's online articles, information overload makes patients less interested in the articles written by doctors (24).

Second, this study verified the moderating effect of physician online reputation. Physician online reputation strengthens the effect of health information sharing on potential patient education. Reputation serves as an intangible asset for physicians, which reflects their popularity on the online health platform (71). In such cases, patients seeking information to understand a diagnosis will be attracted by that popular health information. Previous studies have also confirmed that patients prefer to trust doctors who have a higher medical quality and service attitude (71). Unfortunately, the hypothesis that physicians' online reputation steepens the inverted U-shape relationship between physician online information sharing and realized patient education is not supported. One possible

TABLE 4 Results of the robust test.

Potential patient education (PPE)	Model 9	Model 10	Model 11	Model 12
	PPE	PPE	PPE	PPE
Online information sharing (OIS)	0.340***	0.059***	0.376***	0.100***
	(0.003)	(0.005)	(0.010)	(0.007)
Online reputation (OR)		0.467***		0.467***
		(0.002)		(0.002)
OIS×OR		0.026***		0.028***
		(0.001)		(0.001)
Offline expertise (OE)			0.063***	0.102***
			(0.007)	(0.005)
OIS×OE			−0.012***	−0.017***
			(0.003)	(0.002)
Online time	1.076***	1.036***	1.063***	1.012***
	(0.004)	(0.003)	(0.005)	(0.003)
Gift	0.439***	0.017***	0.443***	0.022***
	(0.003)	(0.003)	(0.003)	(0.003)
Vote	0.103***	−0.014***	0.085***	−0.045***
	(0.006)	(0.004)	(0.006)	(0.004)
Thank-you	0.054***	0.052***	0.062***	0.064***
	(0.007)	(0.005)	(0.007)	(0.005)
Constant	2.148***	1.543***	2.087***	1.466***
	(0.030)	(0.022)	(0.033)	(0.023)
R^2	0.773	0.893	0.773	0.895

Realized patient education (RPE)	Model 13	Model 14	Model 15	Model 16
	RPE	RPE	RPE	RPE
Online information sharing (OIS)	0.186***	0.150***	0.409***	0.355***
	(0.010)	(0.024)	(0.033)	(0.036)
Online information sharing squire (OISS)	−0.041***	−0.063***	−0.070***	−0.087***
	(0.002)	(0.007)	(0.008)	(0.009)
Online reputation (OR)		0.061***		0.055***
		(0.005)		(0.005)
OIS×OR		0.012**		0.017***
		(0.004)		(0.004)
OISS×OR		0.002		0.001
		(0.001)		(0.001)
Offline expertise (OE)			0.050***	0.062***
			(0.010)	(0.010)
OIS×OE			−0.077***	−0.080***
			(0.010)	(0.010)
OISS×OE			0.010***	0.010***
			(0.002)	(0.003)
Online time	0.299***	0.289***	0.308***	0.296***
	(0.006)	(0.006)	(0.006)	(0.006)
Gift	0.086***	0.012*	0.086***	0.012*
	(0.004)	(0.005)	(0.004)	(0.005)
Vote	0.075***	0.060***	0.081***	0.064***
	(0.008)	(0.008)	(0.008)	(0.008)
Thank-you	0.006	−0.001	0.007	0.000
	(0.009)	(0.009)	(0.009)	(0.009)
Constant	5.162***	5.131***	4.942***	4.922***
	(0.040)	(0.044)	(0.047)	(0.049)
R^2	0.106	0.114	0.108	0.116

*p < 0.050, **p < 0.010, ***p < 0.001 (2-tailed test).

explanation is that patients tend to read articles that could improve their health behaviors and health status regardless of the physicians' online reputation (72). Thus, the relationship between physician online information sharing and realized patient education is almost not influenced by physicians' online reputation.

Finally, the moderating effect of physician offline expertise was also identified in this study. Physician offline expertise weakens physician online information sharing and patients' visit. As we know, higher-level professionals have a larger chance of attracting patients' engaged, goal-driven attention (29). The number of articles they published has less of an impact on their page visits growth. Also, the curvilinear effect of physician online information sharing and realized patient education is flattened by physician offline expertise. This reveals that the trade-off between benefit and cost of attention determines patients whether or not to read (7). Information sharing from experts (physicians with high professional titles) is considered more valuable guidance (17); in this context, patient will visit the experts' personal page regardless of few paper publications or a large amount of shared information.

Theoretical contributions

This study provides three theoretical contributions to the current literature. First, the study extends the attention literature by introducing the attention theory to track the mechanism of physician online knowledge sharing and patient education. Although the attention theory has been widely explored in the fields of user behaviors and information networks (24, 40), this theory is rarely used in OHPs to explore online patient education. As far as we know, we are among the first to apply attention theory to track the mechanism of physician online knowledge sharing and patient education on OHPs. It is worthwhile to emphasize that physician online information sharing and potential patient education is a linear relationship, while there is an inverted U-shape between online information sharing and realized patient education. According to attention theory, patients' visiting is similar to a stimulus-driven attention process, and the information sharing by physicians may stimulate potential patient education as patients' attention could be captured by the contents of interest in shared health articles (12, 23). However, realized patient education (patients' reading) is a goal-driven process where patients' information decision is the trade-off between the benefits and the costs of attention. As a result, information overload reduces patients' interest in reading articles by doctors (24). This study applies attention theory to uncover the different effects of physician online knowledge sharing on potential and realized patient education, which makes contributions to physician online knowledge sharing and patient education.

Second, this study extends the online reputation and patient education literature by uncovering the contingent effect of online reputation in the process of physicians' online information sharing. The physician online information sharing effect on patient education is a decision-making process depending on context (14, 30). However, few studies have explored how physicians' online information sharing affected patient education, considering the context (73, 74). Our study considers the contingent effects of physicians' online reputation and finds that physicians' online reputation positively moderates the effect of physicians' online knowledge sharing on patients' potential education. A high online reputation elevates the information supplied by the physician and attracts patients as a valuable and uncommon resource (53) in this context, physician online knowledge sharing is more likely to attract patient visiting for potential education. Therefore, our discoveries contribute to the studies of online information sharing and patient education.

Finally, this study enriches the offline expertise and patient education literature by uncovering the contingent effect of offline expertise in the process of physicians' online information sharing. The information decision-making process is the trade-off between the benefits and the costs of limited attention, and such behaviors are not independent of the context (14, 30). During the influence of stimulus-driven and goal-driven attention (22), offline expertise will increase the value of the information and raise the anticipated attention cost of reading health articles (29). Thus, we find that physician online expertise weakens the positive effect of physician online information sharing and potential patient education and flattens the curvilinear effect of physician online information sharing and realized patient education. In other words, this study reveals the moderating effects of offline expertise on potential and realized patient education, thereby contributing to the literature on offline expertise and patient education.

Practical implications

This study has several practical implications for patients and physicians, as well as platform managers. First, patients should visit physicians' homepages and read physicians' articles to improve their health education. As we know, physician online information sharing provides information support, suggestions, and guidance to patients (5), which is important to potential patient education and realized patient education. To effectively conduct health management and improve medical knowledge, for instance, patients can visit doctors' homepages and read some recent or most accessed medical articles.

Second, physicians should rationally engage in online information sharing by publishing health articles. According to our findings, physician online information sharing positively affects potential patient education, while it has an inverted U-shape relationship with realized patient education. In the early stages, it is necessary for physicians to publish more health articles to attract patient visiting and reading, which is beneficial to improve potential and realized patient education. As the published articles increase to a certain level, physicians need to control the quantity of published health articles and improve the quality of articles to better educate patients. For example, when physician's volume of articles reaches a high level, they can focus on publishing high quality and attractive medical papers.

Finally, platform managers should provide physicians with guidance about online information sharing to improve patient education (75, 76). The results of this study show that physicians' online reputation intensifies the positive relationship between physician online information sharing and potential patient education. Platform managers should encourage physicians with high online reputations to publish more papers or articles to better educate patients. In addition, physicians' offline expertise hinders the positive relationship between online information sharing and potential patient education and flattens the inverted relationship between online information sharing and realized patient education. Thus, platform managers may encourage young or junior doctors (e.g., rewarding or monetary incentives) to share multiple articles in the early stages to strengthen potential and realized patient education at the same time.

Limitations and future research

Although this research has produced interesting findings and contributed to both theory and practice, there are still some limitations that reveal where future research is needed. First, the findings of this research are based on data from the Chinese context, which may restrict the applicability to other nations. Second, this study only adopted physician online reputation and physician online expertise as moderators; other contexts that could be taken into account in the analysis of physicians' online knowledge sharing are neglected, such as information uncertainty (42). Future study may consider the context to further track our study. Finally, this study does not include mediators. In fact, the readability (e.g., exceeding patients' average reading level) of online resources may affect education of patients (77). Future research could introduce readability as a mediator to instigate online knowledge sharing and patient education.

Conclusion

This study shed light on patient education on OHPs from the attention perspective. The results indicate that physician online information sharing influences potential patient education and realized patient education in different patterns due to the differences between patients' attention mechanisms in visiting pages and reading articles on OHPs. Moreover, physicians' online reputation and offline expertise play important contingent roles in the above process. Therefore, to improve patient education and public health management, proper guidance for physicians about rational engagement in online information sharing should be provided.

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/s.

Author contributions

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

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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.

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The impact of online health community engagement on lifestyle changes: A serially mediated model

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Background: Due to reduced physical labor and increased food availability, making healthy lifestyle changes is becoming increasingly challenging. Prior studies have suggested that strong ties (such as friends or family members) help promote positive lifestyle behavior changes while weak ties like online friends hardly make a difference in activating healthy lifestyle changes. More recent studies have found evidence of positive lifestyle changes brought about by health APPs. Yet, the process through which online health community (OHC) engagement is related to healthy lifestyle changes has not been fully explored.

Methods: Drawing on social network theory and the self-efficacy literature, we argued that the information and emotional support which users obtained from OHCs is positively associated with health self-efficacy, which in turn is positively associated with lifestyle changes. Then we constructed a serially mediated model between OHC engagement and healthy lifestyle changes and collected 320 valid questionnaires through an online survey. We tested the model by applying structural equation modeling *via* Mplus 8.3, which uses bootstrapping (5,000 samples) to test the significance of the mediated paths.

Results: This study demonstrated that the informational and emotional support that users receive from OHC engagement positively affects healthy lifestyle changes *via* the mediating role of health self-efficacy. We also found that healthy lifestyle changes are an outcome of enhanced health self-efficacy through the effect of informational and emotional support from OHC engagement.

Conclusions: Our findings help explain how OHC users make healthy lifestyle changes by utilizing the informational and emotional support to develop health self-efficacy. The results also highlight the value of informational and emotional support as important resources which users acquire from OHC engagement. Thus, we suggest that OHC users utilize the informational and emotional support to enhance health self-efficacy and facilitate healthy lifestyle changes. Future research could explore the dynamic process through which OHC engagement influences lifestyle changes by designing longitudinal research and addressing the limitations of the present study.

KEYWORDS

online health community engagement, informational support, emotional support, health self-efficacy, lifestyle changes, social network theory

Introduction

It has long been known that lifestyle changes are crucial in the prevention and management of chronic illnesses like cardiovascular (CVD) and coronary heart disease (1). Lifestyle improvement not only contributes to the effectiveness of chronic disease treatment but also prevents chronic diseases and delays their progression. However, due to reduced physical labor and increased food availability, making healthy lifestyle changes has become even more challenging as the instinct to prefer high sugar and fat is difficult to change (2).

Although it is not easy to make healthy lifestyle changes for many, researchers have found that socially supportive conditions help promote positive lifestyle behavior changes (3, 4). Based on social network theory, studies have suggested that maintaining a good lifestyle (such as moderately intense physical activity, a balanced diet) often requires supervision and encouragement from strong ties, which generally refer to friends or family members (5, 6). Online friends, on the other hand, are traditionally seen as weak ties (7). Yet, as the epidemic continues and information technology evolves, people are spending increasing time online, and friends in online communities may become even more intimate and trustworthy than friends and relatives in real life. This leads to a question: do information and encouragement from OHC engagement help promote lifestyle changes? OHC studies have found evidence that OHCs provide social support (i.e., informational support, emotional support, and companionship) to their users (8, 9) and social support from OHCs promote beneficial health outcomes such as weight loss (10), users' health knowledge (11), reduced uncertainty regarding the diagnosis and treatment (12), health attitude toward chronic diseases (11), and rural–urban health disparities (13). These studies suggest that social support derived from OHCs helps promote users' health literacy, attitudes, and behaviors. Yet, to our knowledge, there are few studies directly examining the relationship between OHC engagement and healthy lifestyle changes. It remains unknown whether OHC users acquire the psychological resources to make lifestyle changes. As noted by Jarbøl et al. (1), it takes not only health knowledge and attitude but also strong motivation and willpower to maintain lifestyle changes. Furthermore, although studies have suggested that OHC users' health behavioral changes are influenced by their peers in the community (14, 15), few have explored the process through which OHC engagement affects health behaviors. Understanding the mechanisms underlying the relationship between OHC engagement and health behaviors can help guide people at high risk of various diseases to make better use of OHCs and achieve sustained lifestyle improvement.

To address the gap, we developed a serially mediated model of the relationship between OHC engagement and healthy lifestyle changes drawing on social network theory, which suggests that people embedded in social networks are generally influenced by their peers' thoughts and behaviors. Our empirical test, which used 320 valid questionnaires from an online survey, found that the informational and emotional support that users receive from OHC engagement affects healthy lifestyle changes *via* the mediating role of health self-efficacy. The present study advances OHC research by explaining how OHC engagement leads to positive lifestyle changes and enriches the research on the antecedents of health self-efficacy. Moreover, this study also contributes to social network theory by exploring its validity in virtual social networks. Our findings suggest that OHC users actively utilize the informational and emotional support to enhance health self-efficacy and facilitate healthy lifestyle changes.

Theory background and hypotheses

Social network theory

Social network theory, which can be traced back to 1930s as a new paradigm of sociological research, becomes popular in explaining various behaviors (including individual, organization) in the network context (16, 17). A key tenet of social network theory is that people in social situations think and act in similar ways because of their relationship to each other (18). According to social network theory (19), the strength of social network relationships depends on the amount of time and energy, emotional intensity, and reciprocity that individuals invest in their social networks. Strong ties may provide individuals with emotional support and substantial help while the strength of weak ties mainly lies in heterogeneous information involved (20). Granovetter suggested that weak relationships between individuals may be a more important factor than strong relationships in influencing the attitudes and behaviors of members of a society (20). Social ties, either strong ties or weak ties, have been found to be beneficial to the physical and mental wellbeings of individuals according to many psychosocial studies (21, 22).

Health self-efficacy

Self-efficacy was first introduced by Bandura and is defined as an individual's beliefs about his or her ability to exert control over the events that affect him or her (23). Individuals with a high level of self-efficacy are more likely to complete a given task because they are able to perform positively over a longer period, work harder in the face of challenges and difficulties, and have more specific and clear plans and strategies for accomplishing their intended goals (24). Health self-efficacy is an application of self-efficacy in the health domain and refers to people's beliefs about their ability to control what affects their health (25, 26). Individuals with a high level of self-efficacy are more likely to participate in healthy activities, which is consistent with the domain-specific nature of self-efficacy (27). Health self-efficacy has been found to be an important factor in predicting health behaviors and health outcomes.

OHC engagement and lifestyle changes

OHCs are online platforms for users to share health experiences, post-health queries, seek, and/or offer support (28). People concerned about health issues can search for health knowledge, consult with doctors, and interact with other users to obtain or share information and experiences through OHCs. The rapid development of OHCs is important for individuals' health management and have aroused academic attention (29, 30). Many scholars have explored the sharing behavior (31), information seeking or adoption behavior (32), and continuous usage of OHC users (33) from different theoretical perspectives. For instance, Zhou et al. analyzed the antecedents of knowledge sharing intentions and behaviors of OHC users from the perspectives of community quality and social support (34). Mirzaei and Esmaeilzadeh evaluated the impacts of perceived channel richness and social exchange on patient engagement in OHCs applying the theoretical lens of social exchange theory and channel expansion theory (32). Although there have been extensive studies on the antecedents of OHC knowledge sharing and social support [e.g., (35, 36)], less work concerns what this social support from OHCs leads to. Indeed, prior studies have identified apparent and important benefits of OHCs such as informational and emotional support, yet more long-term benefits need to be further explored (37). After all, the long-term benefits for users are crucial for the value and sustainability of OHCs.

Although members of OHCs may maintain weak ties, they are more likely to exchange in-depth personal experiences and emotional support compared with traditional weak ties that formed offline due to the anonymity of virtual health communities (23). On the one hand, users who invest time and effort in browsing and participating in discussions in OHCs may gradually develop trust in other members. On the other hand, there is less concern about being judged in virtual communities as in reality. User interactions in OHCs may not only yield the benefit of heterogeneous information from weak ties but are also more likely to promote emotional support and companionship previously only derived from strong ties.

Therefore, individuals' health attitudes or behaviors may be changed because of the behaviors of other members in OHCs, which is known as peer effects (38). Peer effects among social networks have long been established and used to explain mutual influence in fields such as education, management, sociology, and finance. For example, research in education has found that the qualities and behaviors of peers are the most important factors predicting student achievement (39). Similarly, health researchers have also found that obesity is transmitted among friends and siblings, demonstrating the role of the network effect (40, 41). Moreover, Kim found that upward comparison has a significant positive effect on the self-efficacy of fitness App users (42).

Since people are inclined to present their positive images and achievements on social media, OHC users are more likely to be exposed to healthy behavior sharing, which in turn may activate their psychological energy and drive them to make positive healthy lifestyle changes. Consistent with our arguments, Anderson-Bill et al. found that communication in OHCs helps individuals gain health knowledge and emotional support, which promotes positive lifestyle changes (3). Thus, we propose:

Hypothesis 1: OHC engagement is positively associated with healthy lifestyle changes.

Health self-efficacy and lifestyle changes

Many studies have found that individuals' health behaviors are influenced by the peers in their social network, yet how OHC engagement affects health behaviors should be further explored. Drawing on recent work in self-efficacy, we argue health self-efficacy plays a mediating role in the relationship between OHC engagement and healthy lifestyle changes.

Health self-efficacy—an individual's belief in his or her capabilities to manage self-health conditions—has been found to play an important role in predicting health behaviors and health outcomes. For example, Pálsdóttir found that individuals with high levels of health self-efficacy were more likely to participate in physical activity (43). Using a sample of women with heart disease, Clark and Dodge found that health self-efficacy significantly influenced people's disease management behaviors, including medication use, exercise habits, and ability to cope with stress (44). Prior studies have suggested that the higher the level of health self-efficacy, the more effective the use of health information and external support, and thus the more likely it is to make positive lifestyle changes. Thus, we propose:

Hypothesis 2: Health self-efficacy is positively associated with healthy lifestyle changes.

OHC engagement and informational/emotional support

Recent studies in social psychology have showed that gaining social support is the main motivation for users to participate in online communities (6, 45). Social support refers to an individual's feeling that he or she is cared for, valued, and that his or her wellbeing is the responsibility of others in the social network (46). According to OHC literature, social support in OHCs consists of three main categories: informational support, emotional support, and companionship (47) and the social support people obtain from OHCs is very similar to the support they receive from offline social networks (45, 48). Due to the development of information technology, the links in online communities break the boundaries of time, geographic distance, and even social class (49) and allow people with similar health conditions around the world to connect and communicate. Thus, OHC users can share and seek informational and emotional support conveniently and candidly as they can use virtual identities to avoid any embarrassment or judgment. Through convenient and candid interaction (Q&A, reflection, advice-seeking, feedback), OHCs enable individuals to acquire more targeted health knowledge and emotional support. Thus, we propose:

Hypothesis 3: OHC engagement is positively associated with informational support.

Hypothesis 4: OHC engagement is positively associated with emotional support.

Informational support, health self-efficacy, and lifestyle changes

Compared to offline visits and web searches, OHCs have unique advantages in terms of information access. First, compared with offline medical consultations, health information acquisition from OHCs is quick and relatively inexpensive (50). Second, compared with web search, OHCs break through deficiencies such as information overload, conflicting information, and lack of critical information (30, 51). Studies have found that people may become more anxious after searching online for information about diseases related to their symptoms (52). However, the experience and information offered by physician users and other OHC members with similar medical conditions has the characteristics of accuracy, relevance, and timeliness (53, 54). For instance, Kim and Mrotek found that OHCs provide up-to-date and accurate information that is not available on other websites (55). Because people tend to protect their health privacy, private health experience sharing in real life may only occur between people with solid trust rather than strangers who have just met. In contrast, the anonymity of the virtual environment facilitates the sharing of tacit and private health experience, and thus more valuable personal coping experiences are shared. Studies have demonstrated that users tend to communicate with OHC peers who have similar backgrounds (56). Therefore, OHC users are able to discuss real, concrete daily events and mental states, which helps inspire individual self-reflection and develop health strategies that are appropriate for themselves, thereby enhancing health self-efficacy (57). A study including 3,014 persons in the United States found that more than half of the population with chronic illnesses participated in OHC interactions, with 18%

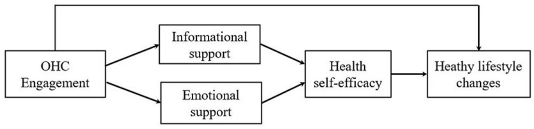

FIGURE 1
Research model.

of all internet users reporting going online to find others who have similar medical conditions (7). The access to relevant health knowledge and experience leads to OHC users' awareness about their own health risks and possible advantages of preventive measures, which in turn may promote health self-efficacy and drive them to initiate changes.

In addition, the algorithms of OHCs can recommend more accurate content for individuals, thus helping them to obtain customized health information more easily and to receive real-time guidance from professional doctors if needed (32). Taken together, OHC engagement helps individuals access informational support and construct personalized health programs more efficiently, which positively affects health self-efficacy and healthy lifestyle changes. Thus, we propose:

Hypothesis 5: Informational support from OHC engagement is positively associated with health self-efficacy, which in turn is positively associated with lifestyle changes.

Emotional support, healthy self-efficacy, and lifestyle changes

Online communities not only facilitate fast and convenient information exchange but also help individuals with previously niche needs overcome spatial and time constraints to find each other and develop supportive relationships. Through an analysis of users' fitness programs posted in OHCs, Centola, and van de Rijt found that active participants in OHCs typically selected friends by gender, age, and BMI similarity (58). Online communities reduce social costs substantially, and OHC users are able to avoid low-quality superficial socialization without embarrassment and develop high-quality relationships based on common goals, allowing users to communicate with people with similar health concerns (59). Therefore, people are more likely to gain emotional support (i.e., recognition, companionship, and attention) through OHC engagement compared with traditional ways of socializing (56, 57). Through interacting OHC members with similar experiences or the same medical condition, OHC users may gain emotional support that help them reduce the stress and/or refill psychological energy. For example, when users with weight control goals feel hungry, they may join OHCs to browse the diet diaries of users they follow to motivate themselves; they may even actively seek supervision

TABLE 1 Sample characteristics.

Characteristics	Levels	Frequency	Proportion (%)
Gender	Male	86	26.88
	Female	234	73.12
Age	<25	313	97.82
	26–35	5	1.56
	36–45	1	0.31
	>46	1	0.31
Education	High school	4	1.25
	College	263	81.93
	Undergraduate	49	15.26
	Postgraduate	4	1.25
Marital status	Married	11	3.43
	Unmarried	309	96.57

or psychological support from other community friends with similar goals to counteract instinctive cravings for food and thus help themselves achieve health goals (60). Thus, we propose:

Hypothesis 6: Emotional support from OHC engagement is positively associated with health self-efficacy, which in turn is positively associated with lifestyle changes.

In summary, Figure 1 shows the theoretical model summarizing the hypotheses.

Methodology

Sample

To test our hypotheses, we collected data through an online survey in June 2022. The online survey was conducted on Sojump (http://www.sojump.com/). We used a snowball sampling method, which presents a link directing users to the questionnaire through referrals on WeChat. Respondents were offered a small amount of money (RMB 1) to encourage participation. We received 427 questionnaires initially. After removing invalid questionnaires (i.e., where all the answers were the same or obviously contradictory), we obtained a total of 320 valid questionnaires, with a valid return rate of 74.94%. The demographic information of the sample is shown in Table 1.

Measurements

We adapted measures from prior studies to test the conceptualized model. Online health community engagement was assessed with the one-item measure following Mirzaei and Esmaeilzadeh (32). The other measures, including lifestyle changes, informational support, emotional support, and health self-efficacy, use five-point Likert scales ranging from 1 "strongly disagree" to 5 "strongly agree". To prepare the questionnaire, the authors first independently translated the English version of the questionnaire into Chinese to verify that there were no differences between the Chinese and English versions of the constructs. Next, we invited a panel of peer researchers to examine the content validity and any semantic ambiguity. Last, the Chinese version of the questionnaire went through one round of pilot testing with 5 respondents before administration of the official survey. Participants were asked to rate the items based on their own experiences or attitudes. Appendix A lists the items for the primary measures in this study.

Online health community engagement

Following Mirzaei and Esmaeilzadeh (32), OHC engagement was measured by the question, "How often do you use online health communities? (OHCs include Bo He Health, KEEP, Ping'an Health, Ding Xiang Doctor, Good Doctor or other health platforms). Never/ Once every few months/1–2 times a month/1–2 times a week/Almost daily." (1 = Never, 5 = Almost daily).

Lifestyle changes

Lifestyle changes (LC) were measured with a three-item scale developed by Chen et al. (61). A sample item is "I am currently increasing physical activity". Cronbach's alpha for this measure was 0.870.

Informational support

Informational support (IS) was assessed using a four-item scale adapted from Shirazi et al. (57). A sample item is "The information provided by the online health community meets my needs." Cronbach's alpha for this measure was 0.937.

Emotional support

Emotional support (ES) was measured with a scale adapted from Johnson and Lowe (63), which contains four items such as "Other users in the OHC provide encouragement to me." Cronbach's alpha for this measure was 0.935.

Health self-efficacy

Health self-efficacy (HSE) was measured with a scale developed by Oh et al. (62), which contains four items such as "I have been able to meet the goals I set for myself to improve my health." Cronbach's alpha for this measure was 0.936.

TABLE 2 Scale properties.

Variables	Items	Factor loading	Cronbach's α	KMO	CR	AVE
Lifestyle changes (LC)	LC1	0.858	0.870	0.719	0.920	0.794
	LC2	0.918				
	LC3	0.896				
Health self-efficacy (HSE)	HSE1	0.819	0.936	0.864	0.904	0.703
	HSE2	0.877				
	HSE3	0.836				
	HSE4	0.821				
Informational support (IS)	IS1	0.800	0.937	0.856	0.907	0.710
	IS2	0.843				
	IS3	0.842				
	IS4	0.884				
Emotional support (ES)	ES1	0.808	0.935	0.849	0.905	0.704
	ES2	0.885				
	ES3	0.800				
	ES4	0.861				

Control variables

To rule out any influence from the demographic characteristics, we controlled for age, education level, gender, and marital status for the following reasons. First, existing research suggests that age is related to the difficulty of lifestyle changes (64). We categorized respondents into four groups according to their age (i.e., <25 is set to 1, 26–35 is set to 2, 36–45 is set to 3, >46 is set to 4). Second, previous research on lifestyle changes found that education level is an important antecedent for lifestyle changes (61). Thus, we controlled for respondents' education level (education was assigned the value of 1, 2, 3, and 4 for high school and below, junior college, undergraduate, graduate and above, respectively). Third, Teachman found that both gender and marital status affect individuals' lifestyle habits (65). We thus controlled for gender and marital status. Gender is assigned a value of 1 if the respondent is male, and 2 if the respondent is female. Marital status takes the value of 1 if the respondent is married or cohabited, and 2 otherwise.

Results

Reliability and validity

The reliability and validity of lifestyle changes, health self-efficacy, informational support, and emotional support were tested using SPSS 24.0, and the results are shown in Table 2. The KMO and AVE values are higher than 0.7, and the CR values are higher than 0.9, indicating that all the variables selected in this study have good reliability and validity.

Common method bias and confirmatory factor analysis

First, in order to test whether there is common method bias, we used Harman's one-way test to examine common method bias on the sample data, and conducted an unrotated principal component analysis on all question items. We found that the variance explained by the first factor was 38.408% (<40%), indicating there was no serious common method bias problem that a single factor explained most of the variance. Second, to verify the structural validity of the model, we conducted a confirmatory factor analysis of all the variables using AMOS 25.0. As shown in Table 3, all the indicators meet the fit requirements, and the five-factor model achieves optimal fitness among the alternative models.

Descriptive statistical analysis

Table 4 presents the means, standard deviations, and correlation coefficients between variables for all variables. The correlation analysis showed that (1) online health community participation and lifestyle improvement were significantly positively correlated ($r = 0.256$, $p < 0.01$); (2) health self-efficacy was significantly positively correlated with lifestyle improvement ($r = 0.608$, $p < 0.01$); (3) informational support was significantly positively correlated with health self-efficacy ($r = 0.567$, $p < 0.01$), and emotional support was significantly positively correlated with health self-efficacy ($r = 0.584$, $p < 0.01$). The correlation analysis provided preliminary supporting evidence for our hypotheses.

TABLE 3 Results of confirmatory factor analysis.

Model	X^2	Df	X^2/df	NFI	CFI	GFI	RMSEA
Model 1: one-factor model All five variables combined	1,371.166	104	13.184	0.711	0.726	0.586	0.195
Model 2: two-factor model LC + (OHC, IS, ES, HSE combined)	1,184.594	103	11.501	0.750	0.766	0.621	0.181
Model 3: three-factor model LC + HSE + (OHC, IS, ES combined)	468.985	101	4.643	0.901	0.920	0.808	0.107
Model 4: four-factor model LC + HSE + IS + (OHC and ES combined)	200.478	98	2.046	0.958	0.978	0.926	0.057
Model 5: four-factor model LC + HSE + ES + (OHC and IS combined)	192.719	98	1.967	0.959	0.980	0.929	0.055
Model 6: five-factor model LC + HSE + ES + IS + OHC	147.289	89	1.958	0.988	0.985	0.973	0.044

TABLE 4 Means, standard deviations, and correlations.

Variable	1	2	3	4	5	6	7	8	9
1. OHC	1								
2. IS	0.329***	1							
3. ES	0.277***	0.791***	1						
4. HSE	0.202***	0.567***	0.584***	1					
5. LC	0.265***	0.642***	0.659***	0.608***	1				
6. Gender	0.088	0.046	0.104	0.110*	0.037	1			
7. Age	0.204***	−0.010	0.011	0.064**	0.026	−0.026	1		
8. Edu	0.115**	−0.123***	−0.123**	−0.014	−0.003	−0.003	0.179***	1	
9. Mar	−0.021	0.068	0.050	−0.010	−0.026	−0.026	−0.224**	−0.234**	1
Mean	2.153	3.320	3.201	3.409	3.251	1.735	1.033	2.170	1.971
SD	1.067	0.815	0.824	0.830	0.853	0.446	0.278	0.451	0.182

***, **, *Denote significance levels at 1, 5, and 10%, respectively.

Hypothesis testing

We tested the mediating effects with a Bootstrap method based on the structural equation modeling *via* Mplus 8.3. The results of the Bootstrap test and the results of the theoretical model are shown in Table 5 and Figure 2.

Hypothesis 1 predicted that OHC engagement is positively associated with lifestyle changes. The path coefficient of OHC participation → lifestyle change (e2) is 0.218, $p < 0.01$, indicating that OHC participation can significantly and positively predict lifestyle change. Thus, Hypothesis 1 is supported.

Hypothesis 2 predicted that health self-efficacy is positively associated with lifestyle changes. The path coefficients (d1 and d2) of health self-efficacy → lifestyle change are 0.368 ($p < 0.01$) and 0.366 ($p < 0.01$) respectively, indicating that health self-efficacy positively predicted lifestyle change. Thus, Hypothesis 2 is supported.

Hypothesis 3 predicted that OHC engagement is positively associated with informational support. The path coefficient (a1) of OHC participation → informational support is 0.271 ($p < 0.01$), indicating that OHC participation positively predicted informational support. Therefore, Hypothesis 3 is supported.

Hypothesis 4 predicted that OHC engagement is positively associated with emotional support. The path coefficient (a2) of OHC involvement → emotional support is 0.233 ($p < 0.01$), indicating that OHC involvement positively predicted emotional support. Thus, Hypothesis 4 is supported.

Hypothesis 5 predicted that informational support from OHC is positively associated with health self-efficacy, which in

TABLE 5 Tests of mediation effects using bootstrapping.

Paths	Indirect effects	95% confidence interval	
		LL	UL
OHC → IS → HSE	0.156	0.106	0.216
OHC → IS → LC	0.180	0.124	0.244
OHC → HSE → LC	0.089	0.038	0.149
IS → HSE → LC	0.213	0.141	0.301
OHC → IS → HSE → LC	0.057	0.108	0.248
OHC → ES → HSE	0.137	0.083	0.200
OHC → ES → LC	0.155	0.096	0.220
ES → HSE → LC	0.217	0.132	0.295
OHC → ES → HSE → LC	0.051	0.092	0.227

turn is positively associated with lifestyle changes. The path coefficient (b1) of informational support → health self-efficacy is 0.576 ($p < 0.01$), indicating that informational support had a significant positive predictive effect on health self-efficacy. The path coefficient (d1) of health self-efficacy → lifestyle change is 0.368 ($p < 0.01$), indicating that health self-efficacy positively predicted lifestyle change. Moreover, the partial mediating effect of health self-efficacy between informational support and lifestyle change was significant ($\beta = 0.213$, $p < 0.01$), and the 95% confidence interval for Bootstrap = 5,000 is (0.141, 0.301) excluding 0. Thus, Hypothesis 5 is supported.

Hypothesis 6 predicted that emotional support from OHC is positively associated with health self-efficacy, which in turn is positively associated with lifestyle changes. The path coefficient (b2) for emotional support → health self-efficacy is 0.589 ($p < 0.01$), indicating a significant positive predictive effect of emotional support on health self-efficacy. The path coefficient (d2) of health self-efficacy → lifestyle change is 0.368 ($p < 0.01$), indicating that health self-efficacy is positively associated with lifestyle change. Moreover, the partial mediating effect of health self-efficacy between emotional support and lifestyle change is significant ($\beta = 0.217$, $p < 0.01$), and the 95% confidence interval for Bootstrap = 5,000 is (0.132, 0.295) excluding 0. Thus, Hypothesis 6 is supported.

To evaluate the statistical significance of the mediated paths, the structural equation modeling *via* Mplus 8.3 (which uses bootstrapping, 5,000 samples) was used to test the serial mediation model in Hypotheses 5 and 6. The empirical tests, using 320 valid questionnaires collected through an online survey, showed that the informational and emotional support that users receive from OHC engagement affects healthy lifestyle changes *via* the mediating role of health self-efficacy. Our serially mediated model was approved.

In addition, consistent with Teachman (65), the results show that gender is positively associated with health self-efficacy and lifestyle changes. Females have higher levels of health self-efficiency and more lifestyle changes. Age was positively associated with self-efficacy but negatively associated with lifestyle changes, suggesting that older people have higher levels of health self-efficacy but fewer lifestyle changes. Education level is positively associated with lifestyle changes, indicating that the higher the education level, the more significant the lifestyle changes, consistent with the findings of Chen et al. (61).

Discussion

Drawing on social network theory and the self-efficacy literature, we argued that the informational and emotional support which users obtained from OHC engagement is positively associated with health self-efficacy, which in turn is positively associated with lifestyle changes. Our empirical study, which analyzed 320 valid questionnaires collected on an online survey, supported the arguments. This study demonstrated that the informational and emotional support that users receive from OHC engagement affects healthy lifestyle changes *via* the mediating role of health self-efficacy. Since scholars have focused largely on the antecedents of OHC knowledge-sharing and other forms of participation, our study advances the extant literature on the outcomes of OHC engagement.

Theoretical contributions

This study makes three contributions to the extant research. First, our study enriches the OHC literature. Although prior OHC research has demonstrated that OHC users can receive informational support and emotional support from community interactions, more long-term benefits to users need to be further investigated. Our study examines the impact of OHC engagement on healthy lifestyle changes, thus contributing to the OHC. Moreover, through constructing a serially mediated model, our study helps explain how OHC engagement leads to positive lifestyle changes, echoing the call from Prochnow and Patterson (4).

Second, this study enriches the health self-efficacy literature by examining the effect of OHC engagement on health self-efficacy. Compared to the research on the consequences of health self-efficacy, the body of literature on the antecedents of health self-efficacy is relatively thin. By investigating the relationship between OHC engagement and health self-efficacy and the mediating roles of informational and emotional support, our results showed that informational support and emotional support are positively associated with health self-efficacy, thus contributing to the health self-efficacy literature.

Third, our study extends the application of social network theory to virtual social networks. While previous social network studies have tended to consider online friends as weak ties, this study found a positive effect of OHC engagement on

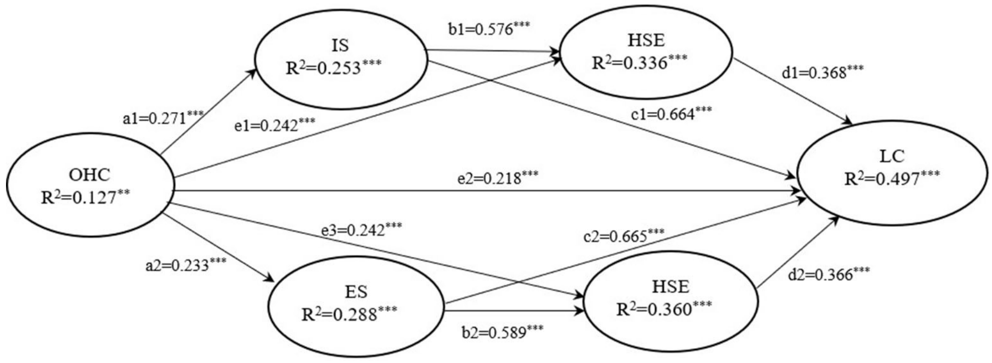

FIGURE 2
The serially-mediated relationship between OHC engagement and lifestyle changes. ***, **, *Denote significance levels at 1, 5, and 10%, respectively.

users' health self-efficacy and lifestyle changes, suggesting the strength of online community peers (e.g., in-depth information-sharing and emotional support), which challenges the viewpoint that social ties formed in virtual communities generally function as weak ties to mainly provide diversified experiential information (7). Our study develops a better understanding of the role of virtual networks, thus complementing the research of social networks. Moreover, our study demonstrated that the underlying mechanism through which OHC engagement affects healthy lifestyle changes was informational support and emotional support, thus enriching social network theory in terms of its effectiveness in virtual networks.

Practical implications

Promoting individual health management with digital technologies is a hot topic in public health literature, and our study suggests some practical implications by examining the role of OHC engagement in making healthy lifestyle changes.

First, our findings showed that the informational and emotional support is important mediating mechanisms for OHC users to make lifestyle changes. Therefore, through purposeful engagement in OHCs (i.e., gaining high-quality, highly relevant information and/or emotional support through interaction with other users), OHC users may enhance health self-efficacy and facilitate healthy lifestyle changes. Especially when individuals feel low on energy and stressed, they may browse informative and inspirational posts by other positive OHC users and proactively seek help from OHC peers to obtain health knowledge and phycological energy and maintain a healthy lifestyle.

Second, our results show that the informational and emotional support which users acquired from OHC engagement is important antecedents of health self-efficacy and healthy lifestyle changes. Thus, the platform managers of OHCs could make incentive rules to encourage users to exchange more valuable informational and emotional support to each other, so as to inspire them to achieve their health management goals. For example, in-depth personal experience sharing (e.g., disease-related diagnosis and recovery experience) is rewarded with community points and thank-you messages that recognize the value of members' positive engagement. Additionally, platform administrators of OHCs may develop a warm, trusting, inclusive community culture and hold events to promote community cohesiveness so that users can discuss their health issues openly and honestly and seek emotional support from other users without concerns of being judged. To be specific, OHC managers may employ human or automatic moderators to promote constructive sharing and eliminate unfriendly content that inhibits a cooperative community atmosphere in the OHC as suggested by James et al. (28). Moreover, OHC managers may optimize algorithms that allow users with similar health conditions to find each other and benefit from highly relevant health experience and emotional support.

Third, physicians could guide their patients to use OHCs to improve patient compliance with lifestyle behavior changes. As OHCs can provide users with informational and emotional support in an efficient way, patients using OHCs may have a higher level of health self-efficacy and less difficulty in maintaining lifestyle changes that physicians advise. If physicians could collaborate with OHCs in encouraging healthy lifestyle changes among patients with higher risks of chronic diseases, many medical resources could be saved.

Limitations and future directions

With its theoretical and practical implications, the study has some limitations which should be considered by future studies. First, this study used cross-sectional data, which makes it difficult to rigorously examine the dynamic process of OHCs' impact on lifestyle changes. Future studies may consider adopting a longitudinal method to explore the mechanism through which OHC engagement influence lifestyle changes. Second, this study used self-reported data to measure healthy lifestyle changes, and respondents may be influenced by social desirability and conceal the truth. Therefore, future research may fruitfully attempt to measure lifestyle changes with more precise data through multiple sources. For example, collecting data from wearable devices can directly measure the volunteers' lifestyle improvement. Third, the sample coverage was inadequate, as the data mainly consists of young people, which also limits the generalization of our findings to other age groups. Future studies may attempt to confirm the results with data from different age groups.

Data availability statement

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

Author contributions

PZ: conceptualizing the research idea and writing–original draft. YZ: revising the paper. SX: processing data and visualizing. KZ: data-collecting and providing revised advice. All authors contributed to the article and approved the submitted version.

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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.

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APPENDIX A Measurement scales

Construct	Items	
Lifestyle changes (LC)	LC1: I am currently increasing physical activity	(61)
	LC2: I am Currently reducing fat/calories in my diet	
	LC3: I am Currently participating in weight control	
Health self-efficacy (HSE)	HSE1: I am confident I can have a positive effect on my health	(62)
	HSE2: I am actively working to improve my health	
	HSE3: I have set some definite goals to improve my health	
	HSE4: I have been able to meet the goals I set for myself to improve my health	
Informational support (IS)	IS1: I will ask others for help with health information through the online health community	(57)
	IS2: Other users provide good advice based on my request for help	
	IS3: The information provided by the online health community meets my needs	
	IS4: I take my health more seriously because I participate in the online health community	
Emotional support (ES)	ES1: Other users in the community understand my situation	(63)
	ES2: Other users in OHC show me empathy	
	ES3: Other users in OHC provide encouragement to me	
	ES4: I feel a sense of connectedness when I see posts from the community	
OHC Engagement (OHC)	How often do you use online health communities?	(32)
	Never/ Once every few months/ 1-2 times a month/ 1-2 times a week/ Almost daily	

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How does physicians' educational knowledge-sharing influence patients' engagement? An empirical examination in online health communities

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Online health communities (OHCs) are popular channels increasingly used by patients for acquiring professional medical knowledge to manage their own health. In OHCs, physicians provide not only consultation services but also educational medical knowledge to improve patient education. So far, it remains unknown regarding how the educational medical knowledge sharing influence engagement of patients in OHCs. Drawing on the signaling theory, we examined the effects of paid vs. free knowledge-sharing of physicians on patients' engagement behaviors (i.e., patient visit and patient consultation). Data collected from one of the largest OHCs in China show that both paid and free knowledge-sharing are favorable for patients' engagement. Particularly, these two types of knowledge-sharing vary in their impacts. Moreover, physicians' registration duration in OHCs has a positive moderating effect on the relationship between physician's knowledge-sharing and patient engagement. Managers seeking to engage patients at OHCs are advised to share educational medical knowledge to entice them and the patient engagement is more salient for the knowledge shared by physicians active at the platforms for longer time history.

KEYWORDS

patients' engagement, physicians' educational knowledge-sharing, registration duration, online health communities, signaling theory

Introduction

The growth of medical care demand coupled with the shortage of medical resources have become a thorny global issue in many countries. In recent years, the emergence and development of online health communities (OHCs) provide possibility to ease this problem (1). OHCs allow physicians to provide medical services to any patient on electronic platform without time limits and geographic barriers encountered in delivering offline medical services (2). Especially in China, patients in remote areas can access physicians who have registered in OHCs virtually and consult them directly, saving the travel cost and time (3). Meanwhile, patients are enabled to acquire professional medical knowledge from OHCs to better manage their health. Due to these practical advancements, OHCs have become popular service channel to benefit both physicians and patients. For example, registered physicians in OHCs can gain personal benefits and reputations through offering online medical consultation services to patients (4), while patients are enabled to get medical advice, medical information and knowledge, and social support conveniently.

Despite these benefits, OHCs still face some operational challenges for patient engagement. Studies have shown that more than 90% of patients only browse the website without any further engagement behavior (5). Broadly, user engagement behavior can be viewed at two levels, namely shallow engagement and deep engagement (6). In the context of OHCs, patient engagement behavior for medical services includes two steps, visiting physicians' home page (i.e., patient visit) and purchase consultation services (i.e., patient consultation), which correspond to these two levels of engagement. As the consumers of OHCs, visit and consultation behaviors of patients are crucial indicators of success and sustainability of OHCs. Thus, it is critical to understand what factors are desired to facilitate patients' engagement behavior in OHCs.

Most of existing studies on patient engagement in OHCs focused on the effect of patients' psychological perceptions (7, 8). However, OHCs are driven by physicians, thus whether and how physician's activities influence patients' engagement need managerial and research attention. There is also research indicating that information asymmetry between physicians and patients is the key barrier preventing patients from visiting or consulting a physician (3), while physicians' behavior in OHCs can effectively alleviate information asymmetry. In addition to providing consultation services, physicians also share some educational medical knowledge in OHCs. High-quality consultation service obviously attracts more patients, but little is known about how sharing educational medial knowledge influences patient engagement. Physicians' knowledge-sharing in OHCs enables patients to better understand medical knowledge and take proper actions to manage their health, which is extremely valuable for patient education. Based on this significant role, this study aims to explore the impacts of physicians' knowledge-sharing on patients' engagement in OHCs.

Knowledge-sharing has been widely examined in the literature on Q&A platforms and broadly classified into two types: paid knowledge-sharing and free knowledge-sharing (9, 10). In the former case, consumers need to pay for the shared knowledge while everyone can access the shared knowledge freely in case of the latter. In OHCs, physicians' knowledge-sharing refers to the physicians' behavior of publishing educational articles to share medical knowledge to patients, including both paid and free knowledge-sharing. The paid knowledge-sharing behavior of a physician indicates his/her service quality and ability while the free knowledge-sharing behavior represents his/her kindness of offering help. Based on the signaling theory, the knowledge-sharing behaviors can be regarded as signals to diminish the information asymmetry between physicians and patients, thus are supposed to influence patients' choice and behavior decisions (11).

However, most of current research paid more attention on the factors motivating knowledge-sharing behavior but neglected what effects that knowledge-sharing brings, especially in the context of OHCs (12, 13). Moreover, little extant research has empirically examined the effects of these two kinds of knowledge-sharing behaviors within a study. Since paid knowledge-sharing and free knowledge-sharing represent distinct signals, whether they vary in their effects on patients' engagement is unknown. Furthermore, numerous research has emphasized that physicians' characteristics, such as the seniority (14), the ranking (4), and the image (15), play important contingent roles in determining patients' decisions. Nonetheless, the length of physicians' registration duration in OHCs has received little attention. The registration duration demonstrating a physician's level of online service innovation and qualification in OHCs, which may affect patients' evaluation on physicians' behaviors and further influence patients' decisions to engage further with the platform services. Therefore, to fill these research gaps, we address the following specific questions in this study:

Q1: How do both paid and free knowledge-sharing of physicians influence patients' engagement behaviors (e.g., patient visit and patient consultation)?
Q2: What role does physicians' registration duration play in the relationship between physicians' knowledge-sharing and patients' engagement?

To answer these questions, we built up a research model and examined hypotheses by collecting data from the Good Physician Online (www.haodf.com), one of the largest OHCs in China. The results show that both physicians' paid and free knowledge-sharing promote patient visit and patient consultation, but difference exists in the positive effects. In addition, the registration duration has been verified to play significant positive moderating roles. This study provides several contributions to both theory and practice. First, as far as we know, this study is the first to examine patient engagement in OHCs from the perspective of physicians' knowledge-sharing, enriching research on user engagement and literature on OHCs as well. Second, through introducing the signaling theory, this study not only reveals the influence mechanism of physicians' knowledge-sharing on patients' engagement but also contributes insights on applying the signaling theory in OHCs context. Third, by investigating the moderating role of registration duration, this study identifies the boundary of the impact of physicians' knowledge-sharing on patients' engagement. This study also provides practical guidance for physicians and OHCs platform managers on how to effectively attract patients through publishing educational articles.

Literature review

Physicians' knowledge-sharing in OHCs

Knowledge-sharing in OHCs is defined as the knowledge exchange between physicians and patients in online health communities (16). Knowledge-sharing has gradually become the driving force for the sustainable development of virtual communities, and even the driving force for their success or failure (2). There are two types of physicians' knowledge-sharing, namely paid sharing (private-sharing) and free sharing (public-sharing) (17). The former refers to the private interaction between physicians and patients to meet the health information needs of patients through paid diagnosis and treatment consultation. The latter means that physicians provide free health and medical information by writing popular scientific articles and replies in the community (2, 17).

Scholars have used multiple perspectives to investigate the antecedents of physicians' knowledge-sharing in OHCs (9). Both Lin et al. (18) and Imlawi and Gregg (19) found reputation, shared vision, altruism, self-efficacy positively influenced knowledge-sharing of medical professionals. Similarly, Zhang et al. (13) found that knowledge-sharing willingness of medical professionals was positively correlated with intrinsic and extrinsic motivations. In addition, some scholars have studied the beneficial impact of knowledge-sharing in online health communities. For instance, Bryant et al. (16) found that knowledge-sharing in OHCs can improve physician-patient relationships and health service quality. Similarly, Chen et al. (20) indicated that physicians can benefit from patients and build long-term positive relationships with them when they share knowledge in OHCs.

The literature has some limitations in physicians' knowledge-sharing in OHCs. First, how knowledge-sharing by physicians in OHCs affects patient engagement has received limited research attention. Second, scholars have largely ignored the comparative effects of paid knowledge-sharing and free knowledge-sharing. To address the above research gaps, this study explores the effects of both paid knowledge-sharing and free knowledge-sharing on patient engagement and examines the difference between these effects.

Patient engagement in OHCs

User engagement has always been a focus issue by scholars and an operational challenge for managers (21). Scholars have defined and explained this concept. For instance, Youngdahl et al. (22) proposed that user engagement is the behavior that users seek in order to get their own satisfaction with the service in term of the level of happiness and participation in activities. Wasko and Di Gangi (23) introduced user engagement as the kind of mind that can ensure enhanced participation and bring meaningful personal benefits.

In addition, many scholars have conducted deeper research, i.e., divide user engagement into levels. Muntinga et al. (24) introduced consumers' brand related activities (COBRAs) to divide the hierarchy of user engagement. In this model, users can perform one or more participation behaviors in consumption, contribution and create. Lagun and Lalmas (25) used taxonomy to divide user engagement into four levels, i.e., bounce, shallow, deep, and complete. Aroused by Lagun's taxonomy and COBRAs framework, Alwash et al. (6) propose two levels of user engagement with brand value propositions—shallow and deep user engagement.

User engagement can effectively improve the development and growth of an OHC platform (26). Therefore, many scholars began to study user engagement in OHCs. Previous studies mainly studied user engagement from two aspects, namely, the physicians' and patients' engagement (21). Although OHC is a physician driven platform (27), many scholars have begun to explore patient engagement in OHCs. For instance, Bansal et al. (28) found that psychological factors are important drivers of patient engagement in OHCs. Besides, Li et al. (29) showed that the status, reputation, and self-representation of physicians promote patient engagement in OHCs. In addition, there may be interaction between physician engagement and patient engagement. There is evidence that patients' participation also stimulates physicians' participation (21, 30).

Madupu and Cooley (31) distinguished active participation and inactive participation in online communities. Inactive participation was simply browsing or reading information in online communities, while active participation involved posting new messages or replying to others' messages. Similarly, some scholars have distinguished patient visit and patient consultation in OHC (32, 33). Patients' visit to physician's homepage was the beginning of getting to know the physician (34), which is a shallow engagement; while patients engage at a deeper level when they comment and consult (35). Many scholars have put patient visit and patient consultation into their researches. Meng et al. (9) took patient visit as the reputation of physicians and explored its impact on physicians' special knowledge sharing. Shah et al. (36) explored the impact of online and offline signals and disease risk on patient consultation. Although scholars have distinguished between patient visit and patient consultation and conducted some studies based on them, only a few scholars have made comparative analysis on them. Therefore, this study introduced patient visit and patient consultation as variables to measure patient engagement, and then examine how educational knowledge-sharing by physicians can vary patient engagement at different levels.

Signaling theory

Signaling theory can be used to explain the behavior of enterprises or organizations sending relevant signals to reduce the information asymmetry between them and stakeholders, and then obtain the support of stakeholders to improve their benefits (37). The theory is composed of three primary elements, i.e., signaler, receiver, and signal (11). In this theory, the signal is private and can be separated into positive and negative signal information (38). In addition, the signaler possesses more information that the receiver cannot get, and they can decide whether, when, and how to transmit information to the receiver (39, 40). The receiver must take measures to understand the information and distinguish whether the information is efficacious. The efficacious signal usually has two characteristics: observability and cost (40, 41).

Signaling theory has been applied in different research contexts such as e-commerce and hotel management. For instance, Choi et al. (42) introduced reputation, newness, retro features as the internal signal, and proposed review valence, product popularity, price, user engagement as the external signal to explore the impact of these signals on digital video games. Filieri et al. (43) analyzed the moderating role of product quality signals in the relationship between extremely negative ratings and review helpfulness.

Online health communities are the area of significant information asymmetry. In this area, physicians publish free or paid consultations in the platform. Physicians possessing professional medical knowledge have a deeper understanding of the quality of services they provide, so they belong to the information advantage group (44). Patients lacking professional knowledge are unable to assess the quality of the service that they have obtained, so they belong to the information vulnerable group (45).

Due to the high information asymmetry of online medical platform, scholars gradually introduce signal theory into this field. Zhang et al. (4) took online free services and reputation as signals, and found that both can improve physicians' private benefits. Liu et al. (46) found that there was a significant positive correlation between personal reputation, organizational reputation (i.e., signals of physicians), and the amount of physicians' inquiries. Li et al. (47) found that offline status, online reputation, and self-presentation act as signals showing a positive impact on the number of physicians' orders. Educational knowledge-sharing of a physician reflects his/her service competence and benevolence and can be regarded as signals helping patients make choice decisions.

Based on the above review, this study takes a leading OHC in China as the research object, introduces physicians' paid knowledge-sharing and free knowledge-sharing as two signals of physicians' self-representation, then compares the impact of the two signals on patient engagement in OHCs.

Research model and hypotheses development

The objective of this study is to identify the effects of paid and free educational knowledge-sharing of physicians on patient engagement in OHCs. Particularly, we specified patient

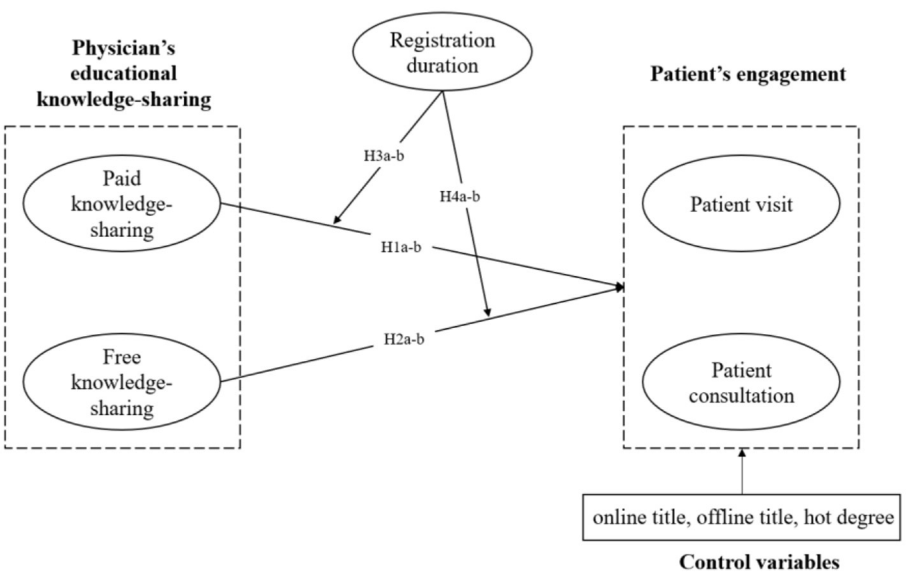

FIGURE 1
Research model.

engagement as patient visit and patient consultation. The role of physician's registration duration in the relationship between knowledge-sharing and patient engagement was also examined. The research model is proposed as Figure 1.

Direct effects of knowledge-sharing on patient engagement

Knowledge is a kind of characteristic service (48). Especially, the educational knowledge, can be regarded as a service transferred from individuals with rich professional knowledge to individuals lacking related knowledge. Sharing educational knowledge can fill information asymmetry between offers and receivers. In OHCs, physicians publish some educational articles to spread and share medical knowledge with patients. Research indicated that such knowledge-sharing is important for patient engagement (13). On the one hand, it not only empowers patients with more medical knowledge but enables them to reduce redundant learning efforts (49). On the other hand, through sharing knowledge to patients, physicians can demonstrate their expertise as well as attracting more patients. According to the signaling theory, signalers (i.e., physicians) provide signals (i.e., educated articles) to receivers (i.e., patients) to share their expertise and services, while patients can utilize these signals to make suitable decisions (11, 50).

In this study, paid knowledge-sharing refers to physicians sharing the educational articles that require payment. Patients who want to read the educated articles and learn the medical knowledge need to pay according to the price. Through reading the paid articles, patients can receive high quality medical information, suggestions, or guidance from physicians, which has been found to significantly influence patients' behavior in OHCs (9). From the perspective of signaling theory, physicians' paid knowledge-sharing is a signal to present their expertise to patients (51). Since there is great information symmetry in professional medical knowledge between physicians and patients, it is difficult for patients to evaluate the expertise and professional competence of physicians before engaging in OHCs service. However, the paid knowledge-sharing of physicians is a critical indicator to measure physicians' ability due to the high-quality knowledge. In this regard, patients are likely to form their evaluation on physicians based on the shared knowledge. Specifically, patients are likely to believe physicians who share paid knowledge have strong professional ability. Previous research indicated that professional ability of knowledge contributors has significant influence on user engagement (52). For instance, the more patients trust a physician's ability, the more willing they are to engage in the physician's medical services (53). Specific to this research context, paid knowledge-sharing facilitates patients to trust physicians' professional ability, inducing more patients to visit OHCs services (i.e., patient visit) and purchase OHCs services (i.e., patient consultation). Thus, we propose that:

> H1a: Paid knowledge-sharing is positively related to patient visit.
> H1b: Paid knowledge-sharing is positively related to patient consultation.

Free knowledge-sharing refers to the sharing of free educational articles by physicians in OHCs. Anyone (including all patients and physicians) can browse and read these articles without payment. Physicians' free knowledge-sharing is a voluntary help and service offered to patients, aside from an egocentric profit motive (54). In previous studies, such free service is regarded as a signal of physicians' positive participation in OHCs, which will influence how patients think about physicians' services (4). Similarly, free knowledge-sharing acts as a signal demonstrating how much physicians are willing to participate in OHCs and offer help. Apparently, in the process of sharing free knowledge, physicians do attract more patients to engage in OHCs. On one hand, physicians' positive participation in OHCs means that they are likely to offer prompt and reliable services, which may draw more traffic to their home pages. On the other hand, sharing free knowledge shows a physician' kindness and benevolence, which may enhance patients' trust in him/her, and thus it is more likely that patients will be willing to select this physician for consultation (55). Thus, it is reasonable that physicians' free knowledge-sharing on OHCs will facilitate patients to visit their home pages and purchase their consultation services. Based on this, we propose that:

> H2a: Free knowledge-sharing is positively related to patient visit.
> H2b: Free knowledge-sharing is positively related to patient consultation.

Moderating effects of physicians' registered duration

Information asymmetry between physicians and patients has been stressed as a critical issue in OHCs due to the medical profession (4, 46). In this context, the paid or free knowledge shared (i.e., educational articles) by physicians send a signal to patients that the physician has the potential to provide satisfactory services. However, the signal may not be the only factor influencing patients when they make decisions about visiting or consulting a physician. Since the signal is sent from signaler (i.e., physicians) to receivers (i.e., patients), characteristics of signalers may affect how receivers process the signal.

The registration duration of a physician refers to how early and long physicians offer service at OHCs. Early service time shows that physicians are innovative in providing multichannel services and long service time indicates that physicians are more qualified to provide online services. Thus, registration duration can be regarded as an indicator reflecting the physician's online service innovation and qualification. Since signalers' identity and characteristics denote how credible and reliable of their signals (11, 51), registration duration of physicians may influence patients' understanding of physicians' signals. Thus, registration duration of physicians may play an important role in the relationship between physicians' knowledge-sharing and patient engagement. For example, for a physician registered at OHCs for a long time, patients are prone to believe that his/her signal is more credible. In this case, compared with physicians registered at OHCs in later time, the knowledge (i.e., the signal) shared by physicians registered at OHCs earlier is likely to bring stronger impacts on patient engagement.

In this study, paid knowledge-sharing of a physician is a signal reflecting his/her service quality and competence (56), and physician's registration duration may influence how patients interpret the signal. The length of duration for a physician registered at OHCs indicates the online service qualification level of this physician, which will enhance patients' trust on the physician and attract more visits by patients. When a physician shared paid knowledge (i.e., sending a signal) on OHCs, a long registration duration may strengthen the impact of this signal. That is to say, patients are more likely to believe that the paid knowledge shared by a physician registered at OHCs for a long time is more trustworthy and useful, and thus, they will be motivated to visit the physician's home page. Moreover, based on the high quality sharing of paid knowledge, the long registration duration of a physician can entrust patients with greater confidence that the physician has adequate competence and qualification to provide satisfactory services (54). In this case, when patients decide to consult a physician after reading the shared paid knowledge, they are prone to select a physician registered at OHCs for a long time. Thus, the longer a physician' registration duration, the greater the impacts of paid knowledge-sharing on patient engagement. Thus, we propose that:

> H3a: Physician's registration duration can strengthen the effect of paid knowledge-sharing on patient visit.
> H3b: Physician's registration duration can strengthen the effect of paid knowledge-sharing on patient consultation.

Similarly, physicians' registration duration may also moderate the effects of free knowledge-sharing on patient engagement. Free knowledge-sharing of a physician is a signal indicating his/her willingness to offer help and benevolence in providing medical services (57). Although the free knowledge-sharing can attract patients to visit the physician's home page, a long registration duration makes physician's benevolence more credible and thus bring more traffic on service visit. In addition, for a physician who newly registers at OHCs, sharing free knowledge may be an operating strategy to attract patients. Thus, it is lacking the clue that this physician will behave friendly during the consultation service. However, for a physician who has registered at OHCs for a long time, he/she is still active in sharing free knowledge is largely a sign of kindness. As such, patients are prone to trust that this physician can provide satisfactory services and prefer him/her for consultation (55). Thus, compared with physicians newly registered at OHCs, free knowledge-sharing of earlier physicians has stronger impacts on patient engagement. Based on this, we propose that:

> H4a: Physician's registration duration can strengthen the effect of free knowledge-sharing on patient visit.
> H4b: Physician's registration duration can strengthen the effect of free knowledge-sharing on patient consultation.

Research methodology

Data collection

This research was based on data collected from a leading online health community in China. As of December 2021, nearly 3,00,000 physicians have entered the community, and more than 70 million patients have also registered on the community. The main reasons for choosing this platform as the research object are explained as follows: (1) the community has a large number of physicians and patients, which can collect rich data; (2) physicians in this community can choose to publish paid articles and free articles, which is consistent with our research context; (3) patients in this community can choose to visit physicians' home pages or consult a physician for medical services. Thus, the OHC is a suitable context to examine our research model and hypotheses.

On this community, physicians provide links to their home pages, through which patients can learn about physicians' basic information (e.g., name, hospital, title, and registration duration). Patients can choose to consult physicians for personalized diagnose and treatment. The number of patients who visited and consulted a physician will be displayed on the home page of the physician. At the same time, physicians also publish some educational articles about medical knowledge in community. There are some paid articles that requires a fee to read, and some free articles provided for the public freely.

We collected data of article publishing and home pages information of physicians in the community using a Java-based program. Finally, data of 1,68,377 physicians were obtained. For the research model, we used the number of shared paid articles as the measure of physicians' paid knowledge-sharing behavior and the number of shared free articles as the measure of physicians' free knowledge-sharing behavior. Moreover, patient

TABLE 1 Overview of variables.

Variables		Description	Mean	SD	Min	Max
Dependent variables	Patient visit	No. 10 of thousands of patient visits of physician	112.558	368.7878	0.0016	14948.56
	Patient consultation	No. 10 of thousands of patient consultations of physician	0.1523	0.3056	0.0001	5.9934
Independent variables	Particles	No. paid articles of physician	0.414	14.28	0	4,716
	Farticles	No. free articles of physician	2.816	8.991	0	1,748
Moderator variables	Time	Registration duration of physician's account	96.129	46.263	3.933	162.233
Control variables	doc_title	No. titles of physician	0.0316	0.306	0	8
	doc_hot	Hot degree of physician	2.439	1.400	0	8
	doc_prof	No. offline titles of physician	2.550	1.186	1	4

TABLE 2 Correlation matrix of the measures.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Patient visit	1.000							
(2) Patient consultation	0.810	1.000						
(3) Farticles	0.015	0.019	1.000					
(4) Particles	0.012	0.044	0.111	1.000				
(5) Time	0.298	0.228	−0.018	−0.005	1.000			
(6) doc_title	0.377	0.536	0.005	0.008	0.095	1.000		
(7) doc_hot	0.314	0.463	0.008	0.002	0.245	0.135	1.000	
(8) doc_prof	0.171	0.171	0.007	−0.005	0.497	0.065	−0.104	1.000

visit was reflected by the number of patients who have visited the physician's home page, and patient consultation was measured by the number of patients who have consulted the physician. Registration duration was defined as the length of time a physician has been affiliated with the OHCs, which was measured by the data capture time minus the time the physician opened an account. Overview of variables was in Table 1.

In addition, we tested the discriminant validity of the measures. The correlation matrix of the measures was in Table 2. The results show that most of the correlations between any two variables were <0.700 (except the correlation between patient consultation and patient visit). These results indicate the discriminant validity of the measures.

Data analysis and results

To test the hypothesis that different types of physicians' knowledge-sharing will affect patients' engagement, two empirical models were developed as follows:

$$\begin{aligned} patient\ visit = {} & \beta 0 + \beta 1 Particles + \beta 2 Farticles \\ & + \beta 3 Particles^{*} time + \beta 4 Farticles^{*} time \\ & + \beta' Z \end{aligned} \quad (1)$$

$$\begin{aligned} patient\ consultation = {} & \beta 0 + \beta 1 Particles + \beta 2 Farticles \\ & + \beta 3 Particles^{*} time + \beta 4 Farticles^{*} time \\ & + \beta' Z \end{aligned} \quad (2)$$

where β is the coefficient, and Z is the variable that controls Particles and Farticles, include doc_title, doc_hot and doc_prof. Model (1) tests the effect of paid and free knowledge-sharing on patient visit as well as the effect of physician's registration duration on the relationship. Model (2) tests the effect of paid and free knowledge-sharing on patient consultation as well as the effect of physician's registration duration on the relationship.

In this paper, the fixed effect model is used to test the model. In the first stage, Model (1) and Model (2), only with control variables, were tested for comparison purposes. In the second stage, Model (1) and Model (2), without moderator variables, were tested to explore the impact of free knowledge-sharing and paid knowledge-sharing on patient visit and patient consultation. In the third stage, Model (1) and Model (2), with interactive items, were tested to verify its moderating effect. The results are given in Table 3.

In Stage 1, we only introduced control variables as control group to facilitate the exploration of direct and moderating effects. In Stage 2, we found that Particles ($\beta = 0.2063,\ t = 3.61,\ p < 0.001$) and Farticles ($\beta = 0.4440$, $t = 4.89, p < 0.001$) positively and significantly influence patient visit. Therefore, H1a and H2a (both free knowledge-sharing and

TABLE 3 Hierarchical regression results.

	Stage1		Stage2		Stage3	
	Patient visit	Patient consultation	Patient visit	Patient consultation	Patient visit	Patient consultation
Particles			0.2063***	0.0011***	−0.6443*	0.0017***
			(0.0572)	(0.0001)	(0.3455)	(0.0003)
Facticles			0.4440***	0.0003***	−8.079***	−0.0039***
			(0.0909)	(0.0001)	(0.2563)	(0.0002)
doc_title	0.2626***	0.0002***	0.2625***	0.0002***	0.2613***	0.0002***
	(0.0020)	(0.0000)	(0.0020)	(0.0000)	(0.0023)	(0.0000)
doc_hot	0.1333***	0.0002***	0.1333***	0.0002***	0.1140***	0.0002***
	(0.0020)	(0.0000)	(0.0020)	(0.0000)	(0.0024)	(0.0000)
doc_prof	0.3175***	0.0001***	0.3174***	0.0002***	0.3716***	0.0001***
	(0.0094)	(0.0000)	(0.0094)	(0.0000)	(0.0122)	(0.0000)
ParticlesXtime					0.0148***	−5.54e-06**
					(0.0034)	(0.0000)
FarticlesXtime					0.1348***	0.0001***
					(0.0034)	(0.0000)
Constant	−431.77***	−0.5212***	−432.9***	−0.5222***	−385.4***	−0.5140***
	(5.9633)	(0.0054)	(5.9664)	(0.0054)	(7.5833)	(0.0054)
N	1,68,372	1,15,231	1,68,372	1,15,231	1,33,822	1,15,230
R-squared	0.1836	0.3677	0.1838	0.3689	0.1836	0.3727

*p < 0.05, **p < 0.01, ***p < 0.001.

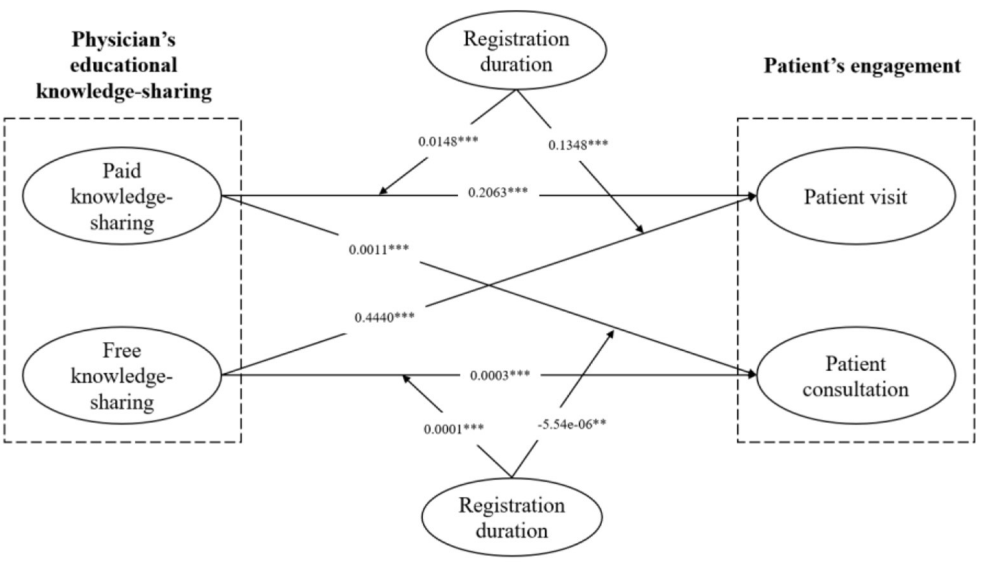

FIGURE 2
Results diagram.

paid knowledge-sharing are positively related to patient visit). In addition, we found that Particles ($\beta = 0.0011$, $t = 14.1$, $p < 0.001$) and Farticles ($\beta = 0.0003$, $t = 3.62$, $p < 0.001$) positively and significantly influence patient consultation. Therefore, H1b and H2b (both free knowledge-sharing and paid knowledge-sharing are positively associated with patient consultation).

In Stage 3, we tested the moderator effect of physician's registration duration. We found that, for patient visit, the

TABLE 4 Summary of hypotheses support.

Hypotheses	Influence route	*P*-value	Hypotheses support
H1a	Paid knowledge-sharing → patient visit	***	Supported
H1b	Paid knowledge-sharing → patient consultation	***	Supported
H2a	Free knowledge-sharing → patient visit	***	Supported
H2b	Free knowledge-sharing → patient consultation	***	Supported
H3a	Paid knowledge-sharing*registration duration → patient visit	***	Supported
H3b	Paid knowledge-sharing*registration duration → patient consultation	**	Not supported
H4a	Free knowledge-sharing*registration duration → patient visit	***	Supported
H4b	Free knowledge-sharing*registration duration → patient consultation	***	Supported

*p < 0.05, **p < 0.01, ***p < 0.001.

TABLE 5 Dominance analysis results.

	Patient visit	Patient consultation
Particles	0.000118	0.00180
Farticles	0.000219	0.000267
N	1,68,377	1,15,236

interaction term ParticlesXtime ($\beta = 0.0148$, $t = 4.37$, $p < 0.001$) and FarticlesXtime ($\beta = 0.1348$, $t = 39.07$, $p < 0.001$) were positive and significant; while for patient consultation, the interaction term ParticlesXtime ($\beta = -5.54$e-06, $t = -2.07$, $p < 0.01$) was negative and significant and FarticlesXtime ($\beta = 0.0001$, $t = 25.99$, $p < 0.001$) was positive and significant. Therefore, H3a, H4a, and H4b (physician's registration duration can strengthen the impact of paid knowledge-sharing on patient visit; physician's registration duration can strengthen the impacts of free knowledge sharing on both patient visit and patient consultation) were supported. H3b (physician's registration duration can strengthen the impact of paid knowledge sharing on patient consultation) was rejected. Figure 2 presents the relationships between variables and Table 4 shows how all the hypotheses are supported.

Additional analysis

To further clarify the effects of the two types of knowledge-sharing and verify whether there is difference between these two kinds of effects statistically, we conducted additional analyzes to compare the impacts of free knowledge-sharing and paid knowledge-sharing on patient visit and patient consultation, respectively. According to Flannery and Rangan (58), we calculated the dominance impact of free knowledge-sharing and paid knowledge-sharing. The results are presented in Table 5. The results show that for patient visit, free knowledge-sharing has a greater positive impact than paid knowledge sharing; while for patient consultation, paid knowledge sharing has a greater positive impact than free knowledge sharing.

Discussion

Key findings

There are several key findings in this study. First, the results indicated that physicians' educational knowledge-sharing has significant direct impacts on patients' engagement in OHCs. Particularly, both paid knowledge-sharing and free knowledge-sharing not only encourage patients to visit physician's home page but also lead them to purchase consultation service. These results are consistent with the mechanism of the signaling theory, which indicates that signal receivers (i.e., patients) utilize signals (i.e., knowledge-sharing) to help them make decisions (i.e., engagement in OHCs) (51).

Second, through comparing the effects of paid knowledge-sharing and free knowledge-sharing on patient engagement, we found that two types of knowledge-sharing show relative importance in inducing patient visit and patient consultation. This study complements prior research confined to one type of knowledge-sharing (54, 59). Specifically, paid knowledge-sharing shows stronger impact than free knowledge-sharing on patient consultation, while free knowledge-sharing plays more important roles than paid knowledge-sharing in facilitating patient visit. This is reasonable since paid knowledge-sharing signals physicians' service competence, while free knowledge-sharing signals physicians' kindness and benevolence. When patients need to consult a physician, they pay more attention to the physician's service ability and competence. In contrast, when patients only visit home pages to learn physicians' information, they prefer kind and friendly physicians.

Third, the results verified the moderating role of physician's registration duration to engage patients in OHCs. The findings show that for physicians who has registered at OHCs for a longer time, their free knowledge-sharing has stronger impacts on patient visit and patient consultation.

However, for paid knowledge-sharing, registration duration shows different moderating effects. Specifically, registration duration strengthens the impact of paid knowledge-sharing on patient visit but weakens the impact of paid-knowledge-sharing on patient consultation. This means that for physicians with high level of service innovation and qualification, through publishing paid article, they perform better in attracting patients visit but perform worse in attracting patients consultation. Also, the results are in line with the signaling theory, which asserts that signalers' characteristics influence receivers' understanding of signals (11, 51).

Theoretical implications

This study contributes knowledge to the literature in several ways. First, this study extends current research on patient engagement in OHCs. Different from prior research which failed to conceptualize specific patient engagement behavior in OHCs (7), this study identifies physicians' shallow (i.e., patient visit) and deep (i.e., patient consultation) engagement behavior. Furthermore, to the best of our knowledge, this study is the first to explore the effects of physicians' educational knowledge-sharing on patient engagement in OHCs. Although factors of patient engagement in OHCs have been studied, they only focused on patients' perceptions lacking attention on the role of physicians' behavior (7, 60). This leaves a research gap to consider how physicians' behavior influence patient engagement since physicians and patients are the two main participants of OHCs. Through addressing the educational knowledge-sharing of physicians in OHCs, this study not only fills up the research gap but also provides a new direction for future research on patient engagement in OHCs.

Second, through drawing upon the signaling theory, this study reveals how physicians' educational knowledge-sharing influence patients' engagement and contributes to the signaling theory in the OHCs context as well. We found that paid knowledge-sharing has stronger effect on patient deep engagement while free knowledge-sharing has stronger effect on patient shallow engagement. It is one of the first studies that empirically compared the impacts of different types of knowledge-sharing on patient engagement, echoing (11) appeal that further research should pay more attention on how to signal to reach an optimal effect. Accordingly, introducing the signaling theory, this study provides a deeper understanding of the effects of physicians' educational knowledge-sharing. Moreover, it also enriches the signaling theory in OHCs context by demonstrating the effects of signals generated from physicians' educational knowledge-sharing behavior.

Third, this study identifies the critical role of physicians' registration duration in the relationship between physicians' educational knowledge-sharing and patient engagement in OHCs. Physicians' characteristics, such as seniority and ranking, have been well-testified to play important role in previous OHCs research (4, 14). However, physicians' registration duration, one of physician's characteristics representing the online service innovation and qualification of a physician, has rarely been examined. Taking physicians' registration duration as a moderator, we found that the educational knowledge-sharing of physicians who has entered OHCs for a longer time shows stronger impacts on patient engagement. That is, a long registration duration will strengthen impacts of a physician's educational knowledge-sharing. The results clarify the boundaries of the effects of knowledge-sharing as a signal on patient engagement. In this regard, this study provides an insight into the signaling theory by considering boundaries and guides future research to keep their eyes on the effect of physicians' registration duration.

Practical implications

This study provides some insights for practitioners, especially for physicians and OHCs platform managers. First, this study suggests physicians and platform managers to pay more attention to patient engagement in OHCs, which is the foundation of platform development. Patient engagement is specified into two different types: patient visit and patient consultation. Thus, physicians and platform managers are supposed to notice the difference and take corresponding measures to promote each kind of engagement.

Second, this study has verified that educational knowledge-sharing of physicians has significant positive impacts on patient engagement in OHCs, including patient visit and patient consultation. Thus, to attract more patients, physicians are suggested to share knowledge actively. For example, the platform can develop incentive to encourage physicians publishing more educational articles. Moreover, since paid knowledge-sharing and free knowledge-sharing show relative impacts on patient visit and patient consultation, physicians can adjust their knowledge-sharing behavior for different purposes. For instance, when they aim to attract more patients to purchase consultation services, they should pay more attention to publishing paid educational articles.

Third, the results indicated that the length of physicians' registration duration can strengthen the impacts of knowledge-sharing on patient engagement. That is to say, physicians who have long-lasting registration at OHCs perform better than those newly registered physicians in attracting patients with sharing educational articles. Particularly, platform managers and physicians should notice that for sharing paid educational articles, long time-registered physicians and newly registered physicians perform equally in attracting patient consultation but differently in attracting patient visit. The results can guide platform managers and physicians to formulate strategies in publishing educational articles according to physicians' registration time.

Limitations and directions for future research

There are several limitations for interpreting the results in this study. First, the data were collected from only one OHC in China. Although the community is one of the largest OHCs in China, the generation of research findings is limited for other health systems and cultural contexts. Therefore, future research is suggested to collect data from different platforms in various cultural contexts for replication. Second, the research model and hypotheses were examined with cross-sectional data. To increase the robustness of research findings, future research can use panel data to test the hypotheses with a dynamic perspective. Third, this study only examined the moderating effect of physicians' registration duration. Whether physicians' other characteristics play a role in the relationship between physician knowledge-sharing and patient engagement is another direction to extend this line of research.

Conclusion

This study empirically examined the effects of physicians' educational knowledge-sharing on patient engagement in OHCs and identified the moderating role of physicians' registration duration. The results verified that both paid and free knowledge-sharing have positive effects on patients' shallow engagement (i.e., visiting physicians' home pages) and deep engagement (i.e., consulting medical service). Particularly, we found that paid knowledge-sharing shows stronger impact on deep engagement while free knowledge-sharing has greater effect on shallow engagement. This finding extends our understanding of the relationship between physicians' educational knowledge-sharing and patients' engagement. The results regarding the moderating effect of physicians' registration duration indicate that knowledge-sharing of physicians who have registered at OHCs for a longer time plays more important roles in inducing patient engagement. These results not only notably contribute to literature on engagement and signaling theory but also provide practical suggestions for physicians and OHCs platform managers on attracting patient engagement in OHCs.

Data availability statement

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

Author contributions

XM and PZ: conceptualization, methodology, and writing. FM: conceptualization, writing, and editing. K-hL: review, editing, and supervision. All authors contributed to the article and approved the submitted version.

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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.

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Encouraging physicians' continuous knowledge-sharing in online health communities: A motivational perspective

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Online health communities (OHCs) as an essential means of patient education can significantly improve patients' health literacy and treatment outcomes. However, sustaining these social benefits brought by OHCs establishes the prerequisite that physicians can continuously share their knowledge on OHCs. Although previous studies have explored physicians' knowledge-sharing in OHCs, scholarly knowledge related to the means of motivating physicians to continue sharing their knowledge remains limited. Therefore, this study developed a research model based on motivation theory to explore the influence of practical benefits, psychological rewards, and perceived connectedness with OHCs on physicians' continuous knowledge-sharing behaviors and the contingent role of physicians' online seniority status. The research model and relevant hypotheses were examined using objective data from one of the leading OHCs in China. The empirical results reveal that both practical benefits and psychological rewards positively affect physicians' continuous knowledge-sharing behaviors. However, an unexpected finding is that perceived connectedness is negatively associated with physicians' continuous knowledge-sharing behaviors. In addition, physicians' online seniority status strengthens the relationship between practical benefits and continuous knowledge-sharing behaviors but weaken the role of psychological rewards and perceived connectedness on continuous knowledge-sharing behaviors. This study contributes to the understanding of the motivational mechanisms underlying physicians' continuous knowledge-sharing behaviors in OHCs and provides significant practical implications for practitioners of OHCs.

KEYWORDS

online health community, practical benefit, psychological reward, perceived connectedness, online seniority status, continuous knowledge-sharing

Introduction

Online health communities (OHCs) refer to web-based platforms that provide all segments of the population with freely accessible health information and services for improving patients' health outcomes and reducing the health disparity between urban and rural residents (1–3). As a significant complement to traditional health services, OHCs allow physicians to share free health knowledge that promotes patient education and provides social support for patients (4, 5). However, a major challenge in the sustainable development of OHCs is physicians' under-contribution (6–8) since the sustainability of OHCs significantly relies on all members' active participation, especially physicians' continuously sharing free health-related knowledge (9, 10). The lack of such contributions on the part of physicians threatens to weaken the real value of OHCs (11). In other words, an OHC's ability to motivate physicians to persistently contribute their knowledge to the online platform is likely to determine its competitive advantages. Therefore, examining the motivational factors of physicians' continuous knowledge-sharing behaviors in OHCs is essential.

Abundant prior research has extended the scholarly understanding of factors influencing physicians' participation and knowledge-sharing behaviors in OHCs. These motivators can be classified in terms of two main perspectives: practical benefits and psychological rewards. The former term denotes the tangible rewards that physicians receive from their participation in the network, while the latter represents the non-tangible benefits that physicians receive from their participation. To be more specific, the goal of physician participation is to obtain enjoyment and satisfaction. From the perspective of practical benefits, the associated motivators include financial incentives (12, 13) and online reputation (14–16). In contrast, motives relating to psychological rewards consist of enjoyment in helping others (14) and psychological satisfaction (13, 17). Furthermore, since OHCs incorporate features of both online relational communities and online transactional communities, physicians have developed their social networks to some extent through their connections with OHCs (18). Individuals who feel highly connected with a virtual community are more likely to have a positive view of that community and contribute more to it (19). According to the work of Chou et al. (20), we may postulate that when physicians have a higher level of perceived connectedness with an OHC, they will maintain a long-lasting relationship with it and continuously contribute knowledge, thus improving the sustainability of OHCs. However, to our best knowledge, the role of physicians' perceived connectedness as it relates to their continuous knowledge-sharing remains obscure, and the combined effects of practical benefits, psychological rewards, and perceived connectedness on physicians' continuous knowledge-sharing in OHCs have received scant examination. Based on these considerations, therefore, the first research question of this study is as follows: *How do practical benefits, psychological rewards, and perceived connectedness jointly motivate physicians' continuous knowledge-sharing behaviors in OHCs?*

Besides the above-mentioned motivators, physicians' characteristics (e.g., seniority status) play a critical moderating role in shaping the relationship between motivators and knowledge-sharing. Previous research has found physicians' offline professional status to relate positively to their prestige and financial status and identified this status as a primary characteristic influencing physicians' behavior in OHCs (18). Physicians with higher offline seniority status (i.e., professional titles in hospitals) are highly motivated by reputation and psychological rewards and less motivated by monetary rewards related to participating in and contributing their knowledge to OHCs (13, 18, 21). However, compared to this offline seniority status, physicians' online seniority status (honorary title) in OHCs has drawn less academic attention in previous investigations examining physicians' knowledge-sharing, particularly in the context of continuous knowledge-sharing. Physicians' online seniority status, as indicated by a platform-generated honorary title, also reflects patients' high-tier recognition of and trust in their healthcare service quality in the online context (22). However, different from physicians with higher offline status, those with a higher online honorary title may reveal varying levels of response in the form of continuous knowledge-sharing behaviors when they are motivated by practical benefits, psychological rewards, or perceived connectedness with OHCs. Therefore, it is necessary to investigate how physicians' online seniority status (honorary title in OHCs) shapes the relationship between the various motivators and continuous knowledge-sharing. Based on the above discussion, another research question for this study is: *Are the effects of practical benefits, psychological rewards, and perceived connectedness on physicians' continuous knowledge-sharing behaviors contingent on physicians' online seniority status?*

To address the above two research questions, this study draws upon motivation theory and the relevant literature on knowledge-sharing in OHCs to develop a research model and related hypotheses. Next, we collected data from the "Good Doctor Online" website (www.haodf.com) to test our hypotheses. This study makes three contributions. From the perspective of the sustainability of OHCs, this study is one of the first to investigate the motivational mechanism of physicians' continuous knowledge-sharing behaviors that previous studies have significantly overlooked. As its second contribution, this paper provides additional insight into the factors that motivate physicians to continuously share knowledge in OHCs through examining the integrated effect of practical benefits, psychological rewards, and perceived connectedness on continuous knowledge-sharing behaviors. Another key contribution of this study is its examination of the contingent role of a physician's online seniority status, as generated by the OHC where he or she is participating, in terms of the relationship between three-dimensional motivators and continuous knowledge-sharing, which further enriches the existing literature regarding the motivational factors behind physicians' knowledge-sharing in OHCs.

The remainder of this paper is organized as follows. First, we discuss the existing literature on physicians' knowledge-sharing behaviors, motivations for knowledge-sharing, and physicians' online seniority status. Then follows a description of the theoretical structure and relationships. Next, we discuss the research methodology and data analysis process. Finally, we present the main findings, implications for theory and practice, and conclusions of the study.

Literature review

Physicians' knowledge-sharing in OHCs

Knowledge-sharing in OHCs is defined as the transferability of knowledge among the key participants (e.g., physicians and patients) (23). Knowledge-sharing can generally be described as taking one of two forms: general (public) knowledge-sharing and specific (private) knowledge-sharing (15). Physicians' knowledge-sharing in OHCs could increase their social and economic returns (18) and provide informational and emotional support for patients (24), leading to improved physician–patient relationships (25, 26) and narrowing rural–urban health disparities (3, 27). Most importantly, in physician-driven OHCs, physicians—as crucial sources of general knowledge—attract visits from patients, maintaining the sustainability of the OHC (18).

Extensive studies have explored the antecedents and outcomes of physicians' knowledge-sharing in OHCs from various perspectives. Some scholars found that motivation to help, self-efficacy, moral obligation, and reputation directly and indirectly (through satisfaction) influence health professionals' willingness to continue knowledge-sharing to OHCs (21, 28). Moreover, Yan et al. combined social exchange theory and Maslow's hierarchy of needs theory to analyze that professional users can receive tangible rewards (e.g., bounties, gifts, etc.) and intangible rewards (e.g., reputation, self-esteem, etc.), both of which positively affect their knowledge-sharing behaviors while sharing costs weaken their sharing intentions (15). Similarly, Zhang et al. demonstrated that physicians' professional and material motivations were important in predicting their free health information-sharing in OHCs (17). In addition, Meng et al. indicated that physicians' specific knowledge-sharing behaviors are determined by their general knowledge-sharing behaviors through online reputation (5).

Although studies on knowledge-sharing in the context of OHCs are abundant, the existing literature neglected to explore physicians' continuous knowledge-sharing behaviors from the perspective of the sustainability of OHCs. Physicians' continuous knowledge-sharing are valuable assets to OHCs, and motivating them to continuously share knowledge is critical to the eventual success of OHCs (29). This study has sought to fill this research gap by developing a theoretical framework to explore physicians' motivation to continue sharing knowledge in OHCs and to further examine whether physician motivation is related to their online seniority status. The next section presents a review of the literature on motivation theory and physicians' online seniority status.

Motivation theory

Motivation is an essential topic of research because it shapes individual behaviors and can be used to understand the types of activities an individual will engage in. Motivation defines the energization and direction of humans to conduct a certain behavior and prompts people to behave in a specific manner (30). In the literature, motivation has usually been divided into extrinsic motivation and intrinsic motivation (31). The former focuses on goal orientation and sees the individual participating in the activity to obtain valuable results, while the latter focuses on the activity itself and portrays the individual as participating in the activity to feel happy and satisfied (32).

Previous research has shown that extrinsic motivation (practical benefits) and intrinsic motivation (psychological rewards) play an essential role in knowledge-sharing. Specifically, practical benefits, a classic extrinsic motivation, reflects the financial or non-financial profits paid to individuals for their effort (18, 33). Psychological rewards, to some degree as intrinsic motivation, pertain to the joy and enjoyment that individuals experience when contributing knowledge to others (34). Similarly, Chang et al. found that reputation can motivate people to participate in knowledge-sharing activities (35). Knowledge contributors who enjoy helping others are more inclined to share knowledge because of the enjoyment and satisfaction they obtain from such behaviors (36). However, some scholars propose a new dimension to explain motivation of knowledge-sharing that is individuals' knowledge-sharing to the community are driven by their concern for the community rather than for self-interest (37). In other words, when members have a strong perceived connectedness to the community, they develop a sense of belonging to the community (38). Previous studies have confirmed that when people have established a sense of belonging to their community, they will take action to avoid losing it (39, 40). When people consider themselves part of the community, they will choose to stay and try to contribute to the community even when unsatisfied with the quality or price of community services. However, in the existing literature, we found little knowledge regarding the motivational effect of physicians' perceived connectedness on their continuous knowledge-sharing behaviors in the context of OHCs.

Based on the above discussion, to provide a holistic view of the motivations behind physicians' continuous knowledge-sharing behaviors, we explored the combined effect of the practical benefits [e.g., financial incentives (12) and online reputation (41)], the psychological rewards [e.g., enjoyment in helping others (14) and psychological satisfaction (13, 17)], and the perceived connectedness with the OHC [e.g., a sense of belonging (19)] in motivating physicians' continuous knowledge-sharing behaviors.

Physicians' online seniority status in OHCs

The online seniority status of physicians in OHCs refers primarily to the honorary designation that physicians receive in OHCs (22), which reflects the quality of information, timeliness of sharing, and attitude in the process of knowledge-sharing between physicians and patients (42). Physicians with high recognition tend to be those who are more competent, provide better service, and are more popular, and they tend to attract more patients (43) and, consequently, receive more rewards (22). The online seniority status of physicians can also reflect measures of the physicians' expertise and popularity on the platform, especially the level of service and patient satisfaction (44, 45). Hence, a high rating or award for good doctors online is thought to provide a good indicator. Several studies have evaluated the impact of a physician's online reputation on patient choice in the past (42). In examining the moderators of the relationship between motivational factors and physicians' knowledge-sharing behaviors, some past research has mainly focused on the moderating role of the professional status (offline seniority status) of physicians (13). The moderating role of physicians' online seniority status on physicians' continuous knowledge-sharing behaviors still remain largely unknown.

Research model and hypotheses

To address the issues raised in the above discussion, we developed a theoretical model for explaining continuous knowledge-sharing in OHCs based on the motivation theory (Figure 1). We use physicians' continuous knowledge-sharing behaviors as the dependent variable and practical benefits, psychological rewards, and perceived connectedness as the independent variables. Practical benefits are primarily the financial rewards and reputation that physicians receive from OHCs. Meanwhile, we introduced physicians' online seniority status as a moderating variable in the model.

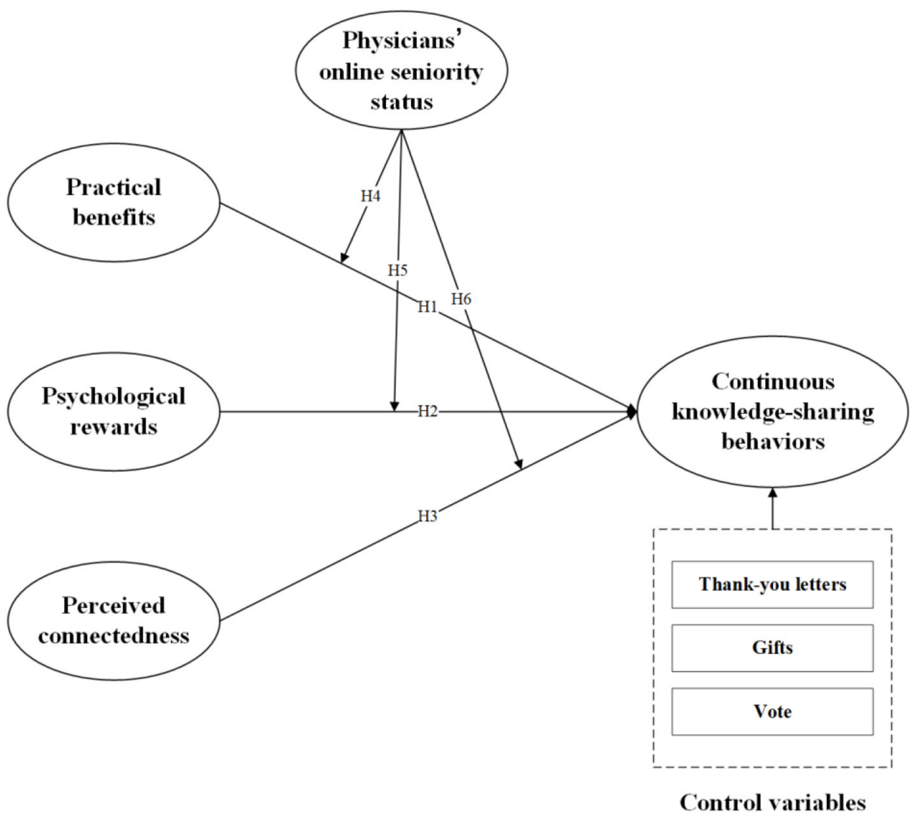

FIGURE 1
Research model.

The effect of practical benefits on physicians' continuous knowledge-sharing behaviors

Physicians' continuous knowledge-sharing refers to the continuous sharing of knowledge by physicians with their patients (46). Numerous factors have been shown to influence physicians' continuous knowledge-sharing behaviors in OHCs, among which extrinsic motivation relates to the activity as a means to obtain practical benefits (31). Specifically, physicians can obtain monetary rewards through paid counseling services and digital gifts purchased by patients (5). These monetary rewards can provide compensation for physicians' time, effort, and costs in the process of contributing knowledge to OHCs (13). This finding means that physicians who are willing to devote more time and energy to contributing knowledge online will end up earning more online revenue (47). In addition to monetary rewards, reputation, one of practical benefits, has been found to have a positive impact on the knowledge-sharing behaviors of community members (15, 31, 48). In particular, for physicians, reputation is an essential incentive for knowledge-sharing behaviors (16, 21). Therefore, we propose that obtaining more practical benefits in OHCs could incentivize physicians' continuous knowledge-sharing behaviors. Hence, we hypothesized that:

> H1: Practical benefits are positively associated with physicians' continuous knowledge-sharing behaviors.

The effect of psychological rewards on physicians' continuous knowledge-sharing behaviors

Factors that influence physicians' continuous knowledge-sharing behaviors in OHCs also include intrinsic motivation, which generally refers to the psychological rewards that arise from participating in an activity (32, 36). Individuals can gain inner happiness from helping others, which can significantly affect their attitude toward knowledge-sharing (36). In this light, Kankanhalli et al. reported that altruism essentially encourages members to contribute knowledge to the community (31). Accordingly, physicians who are pursuing psychological rewards will actively share their knowledge with patients through providing medical knowledge, treatment experience, and personal advices. By doing so, physicians can gain a sense of being needed, realize their value, and experience feelings of satisfaction regarding their contribution to the online community (36, 49). In this context, physicians can be motivated to continuously sharing knowledge in OHCs by their anticipation and experience of psychological rewards. Therefore, we proposed that psychological rewards could increase physicians' willingness to continue sharing knowledge. Hence, we propose the following hypothesis:

> H2: Psychological rewards are positively associated with physicians' continuous knowledge-sharing behaviors.

The effect of perceived connectedness on physicians' continuous knowledge-sharing behaviors

Perceived connectedness to OHCs refers to the social relationships established with community members; specifically, this connectedness can be described as a sense of belonging and an emotional connection to other members (50). In the context of virtual communities, demand satisfaction is the precursor of virtual community awareness, and emotional connection is highly related to the members (51). Belonging, in this context, is drawn from the need-to-belong theory, which highlights that individuals have a strong desire to establish and maintain close, lasting relationships with others (52, 53). According to the need attribution theory, the motivation to maintain a sense of belonging tends to affect people's engagement (54). This idea suggests that physicians' increased perceived connectedness to OHCs also motivates them to sustain their knowledge-sharing behaviors. In other words, physicians who feel a strong sense of belonging to OHCs gain emotional meaning and self-worth and are therefore more likely to contribute to OHCs (55). Based on the previous discussion, we proposed that physicians' perceived connectedness would have a positive impact on their continued knowledge-sharing behaviors. Based on these arguments, we hypothesized that:

> H3: Perceived connectedness is positively associated with physicians' continuous knowledge-sharing behaviors.

The moderating effects of physicians' online seniority status

A physician's online seniority status in OHCs, according to the status characteristics theory (56), reflects the degree of physician's expertise and contribution to the platform (22). Furthermore, physicians with higher online seniority status possess more economic and social returns compared to those with low online seniority status (18, 57), thus their motivations of contribution in OHCs will be various. Yang et al. demonstrated that when physicians are with higher professional status, their motivations to contributing to OHCs are strengthened by reputation but weakened by monetary rewards (13). According to Maslow's hierarchy of needs theory (58), lower-level needs are generally associated with material factors that are generally reflected in financial status (59). However, when lower-level needs are met, individuals will seek to satisfy higher-level needs that are emotionally or spiritually related, such as love, belonging, and respect (15).

Accordingly, in the context of our study, since physicians with a lower online seniority status in OHCs receive fewer financial incentives from those platforms, practical benefits (e.g., monetary rewards) have a stronger positive effect on physicians who have a low online seniority status than on those with high online seniority status (60). In other words, senior physicians' contribution behaviors in OHCs are prone to be voluntary rather than be motivated by practical benefits. Therefore, we proposed that the positive relationship between practical benefits and physicians' continuous knowledge-sharing behaviors would be weakened when physicians' online seniority status is higher. Based on the above statement, we propose the following hypothesis:

> H4: Physicians' online seniority status has a negative moderating effect on the relationship between the practical benefits and physicians' continuous knowledge-sharing behaviors.

Different from practical benefits which focus on economic and social returns, psychological rewards and perceived connectedness are tightly associated with physicians' social acceptance and recognition that satisfy the their emotional or spiritual needs (35). On the one hand, in the condition of higher level of online seniority status, physicians are more concerned about their reputation and patients' positive reviews when they continue sharing knowledge in OHCs (13). Therefore, the positive effect of psychological rewards on physicians' continuous knowledge-sharing behaviors will be improved when physicians are of higher seniority status. On the other hand, physicians with higher online seniority status may perceive a higher responsibility for patients and OHCs, thus motivating them continuing contributing knowledge to OHCs with the aim of maintain or increasing their status. The role of sense of belongingness on physicians' engagement in OHCs can be magnified when they enjoy a higher level of seniority status. Therefore, we proposed that physicians' higher online seniority status will strengthen the effects of psychological rewards and perceived connectedness on physicians' continuous knowledge-sharing behaviors. We accordingly propose the following hypotheses:

> H5: The physician's online seniority status has a positive moderating effect on the relationship between psychological rewards and the physician's continuous knowledge-sharing behaviors.

> H6: The physician's online seniority status has a positive moderating effect on the relationship between perceived connectedness and the physician's continuous knowledge-sharing behaviors.

Methodology

Data and variables

We drew from the "Good Doctor Online" website (www.haodf.com), a leading OHC website in China, as the background of our study. Currently, this website features 891,609 doctors from 10,148 regular hospitals in China. The platform provides an ideal environment for exploring online knowledge-sharing between physicians and patients for the following reasons. First, it enables physicians to share knowledge both publicly (without compensation) and privately (with compensation). Second, it attracts many patients visits and inquiries, which can motivate physicians to share knowledge on the platform. Third, as a leading online health platform, it has a large number of participants, which can provide rich data about physicians' homepages and physician-patient interactions.

Through this platform, patients can submit inquiries to specific physicians to obtain health and medical information about their conditions. Physicians can provide links to their home page, which provides basic information (e.g., hospital, professional title, online contributions, area of expertise, and personal website data statistics) as well as a section in which they can share free health education articles. By doing so, patients can obtain the information they need to learn more about their disease by accessing articles shared by their doctors. If an article matches their preference, they can choose a paid consultation to receive personalized treatment.

We collected data of physicians from haodf.com using a Java-based crawler. We collected data of article publishing and home page information for approximately 80,000 physicians over 6 months (February 2017–July 2017). After removing some samples with incomplete data, we obtained a total number of 308,481 observations. Data were organized in the panel at the monthly level. Table 1 provides descriptive statistics of the study variables. In this study, the dependent variable is physicians' continuous knowledge-sharing behaviors in OHCs, which is measured by the number of new health papers that physicians shared, following the procedures reported in studies by Kuang et al. (61) and Zhang et al. (17). This choice was made because new publications by physicians are seen as a form of continued input into OHCs, and most of these papers are free and open to the public (42, 62, 63). While some studies have used the number of free answers to questions posed by patients to measure physicians' knowledge-sharing behaviors (61), these answers were not directed to the public but to specific groups of patients. For example, a patient with thyroid disease might

TABLE 1 Overview of variables.

Variables	Description	Mean	SD	Min	Max
Newpapers	Number of new papers	6.592432	200.6461	0	53255
Newvisitors	Number of new visitors	212920.2	1210312	3	9.02e+07
Newpatient	Number of new patients	262.1878	1070.949	0	66825
Patientrevisit	Number of patient revisit	15.55301	39.74921	0	1179
Title	Honorary titles for physicians	2.751197	0.976704	1	4
Thank-you	Number of thank-you letters from patients	3.477274	13.75543	0	468
Gift	Number of Online gifts from patients	12.38782	69.23484	0	3060
Vote	Number of votes received by the physician	11.51708	34.85173	0	1179

ask her physician for advice on how to adjust her medication. The doctor subsequently shares answers that can be seen by other visitors; however, the shared information is not specific to these other patients due to their different conditions. In contrast, the free health articles shared by the doctor comprise open access patient education articles, such as descriptions of effective and practical dietary treatments for thyroid disease, which are scientifically accessible to the general reader. Therefore, the number of new responses to questions by physicians was not appropriate in this study for measuring continuous knowledge-sharing behaviors.

In our research model, the independent variables were the practical benefits received by the physician, the psychological rewards, and the physician's perceived connectedness. In this OHC, physicians are primarily paid in monetary form for their online services (18). Monetary incentives can be provided to physicians based on one-on-one paid consultations; specifically, physicians receive financial compensation on the platform featured in this investigation for patient consultations. The number of patients highlights the competence of the physician while boosting the physician's reputation at the same time. Therefore, we used the number of new patients as a measure of the practical benefits that physicians receive in OHCs (17). We also took the number of new visitors as an indicator of the psychological rewards that physicians receive to capture their intrinsic motivation. This choice was made because, in addition to practical benefits, physicians have their own intrinsic goals, such as influencing more patients and gaining a high level of patient recognition (64, 65). Patients frequently visit the physicians' home pages indicating that patients are seeking medical knowledge and help from the articles shared by the physicians (66). Although some studies have also used the number of thank-you letters to measure the psychological rewards received by physicians (13, 67) thank-you letters can often only be sent by the physician's patients. However, regular visitors are not able to express their appreciation to the physician through thank-you letters. Therefore, we chose the number of new visitors as a more appropriate measure of psychological reward than the other variables. Meanwhile, the perceived connection of physicians was measured by the number of patient revisits. More such visits would indicate that the physician has a stronger connection to the community and a greater sense of belonging to the community (35). In addition, the number of patient return visits can also reflect the level of doctor–patient interaction (13).

Lastly, the moderating variable in our study model was the online seniority status of the physicians, which was mainly reflected by the physicians' online prestige, in line with the findings of previous studies that the online honorary titles earned by physicians could reflect their prestige (13, 44). Therefore, we used the honorary title earned by the physician in the OHC as a proxy for the physician's online seniority status. Specifically, a physician's honorary title signifies the extent of the patient's recognition of that medical professional in the context of an OHC as a proxy for the physician's expertise, experience, and quality of service. Therefore, the ranking of a physician's honorary title can effectively reflect the physician's online seniority status. We ranked physicians' honorary designations and assigned points to each from highest to lowest.

To ensure the model had a high level of precision, this paper included control variables as follows. Seniority was measured by the professional title of the physician. The gift was measured by the number of online gifts from patients. Thank-you was measured by the number of online thank-you letters from patients. The vote was measured by the number of votes received by the physician.

Model estimation

To verify the hypothesis that the number of patient revisits, the number of new patients and the number of new visitors would affect the number of new papers published by physicians, and physicians who had higher-level professional titles had a regulatory effect on these factors, this paper developed the following empirical model:

$$\begin{aligned} newpaper = & \beta_0 + \beta_1 \, newvisit + \beta_2 \, newpatient \\ & + \beta_3 \, patientrevisit + \beta_4 \, newvisit^{*} title \\ & + \beta_5 \, newpatient^{*} title + \beta_6 \, patientrevisit^{*} title \\ & + \beta' Z \end{aligned}$$

where β is the coefficient, and Z is the variable that controls new visitors, new patients, and patient revisits. The model tested the moderating effect of physicians with higher professional titles on the relationship between the number of patients who visited again, the number of new patients, the number of new visitors of patients, and the number of new papers published by the physicians.

The model was tested hierarchically using fixed-effects models. Model, without the moderator variable, was tested to verify the effect of the number of new patients, the number of new visitors, and the number of patient return visits on the number of new papers published by physicians. In Stage 2, Model interaction terms were tested to verify their moderating effects. We used a fixed-effects model to control potential unobserved physician-level heterogeneities.

TABLE 2 Hierarchical regression results.

	Stage 1	Stage 2
	Newpaper	Newpaper
Patientrevisit	−0.00468***	−0.0589***
	(−12.59)	(−31.13)
Newpatient	0.00315***	−0.0268***
	(12.11)	(−34.75)
Newvisitor	1.00e-05***	0.000204***
	(53.40)	(114.4)
Title	0.00114	0.0208
	(0.0708)	(1.268)
Newvisitor*title		−4.98e-05***
		(−109.4)
Newpatient*title		0.00767***
		(29.57)
Patientrevisit*title		0.0139***
		(26.63)
Constant	0.0872*	−9.40e-05
	(1.767)	(−0.00185)
Observations	131,849	131,849
R-squared	0.024	0.106
Adjusted R^2	0.106	0.106
F-test	0	0

Standard errors are in parentheses.
$^{***}p < 0.01$, $^{*}p < 0.1$. All levels of significance are higher than $p < 0.1$.

Results

For this paper, a fixed effect model was used to test the model. In the first stage, the model was tested without adjusting variables to verify the impact of the number of patients who visited again, the number of new patients, and the number of new visitors of patients on the number of new papers published by physicians. The second stage involved testing the model with interactive items to verify its adjustment effect. In addition, this paper used a fixed effect model to control the potential unobserved heterogeneity at the physician level. Table 2 displays the results.

Hypothesis 1 proposed that practical benefits are positively associated with physicians' continuous knowledge-sharing behaviors. According to the data in the first column of Table 2, this hypothesis was supported because the coefficient of new patients ($\beta = 0.00315$, $t = 12.11$, $p < 0.01$) was positive and statistically significant.

Hypothesis 2 proposed that psychological rewards would be positively associated with physicians' continuous knowledge-sharing behaviors. The data in the first column of Table 2 reveal that this hypothesis was supported because the coefficient of the new visitors ($\beta = 1.00\text{e-}05$, $t = 53.40$, $p < 0.01$) was positive and statistically significant.

Hypothesis 3 proposed that the perceived connectedness would be positively associated with the physicians' continuous knowledge-sharing behaviors. However, the data in the first column of Table 2 indicate that this hypothesis was not supported because the coefficient of the patient revisits ($\beta = 1.00\text{e-}05$, $t = 53.40$, $p < 0.01$) was negative and statistically significant.

In the second stage, the moderating effect of the physician's online seniority status was tested, and we found evidence to support Hypothesis 6. According to the data in the second column of Table 2, the coefficient of the interaction term patientrevisit*title ($\beta = 0.0139$, $t = 26.63$, $p < 0.01$) was positive and significant. However, Hypotheses 4 and 5 were not supported because the coefficient of the interaction term newpatient*title ($\beta = 0.00767$, $t = 29.57$, $p < 0.01$) was positive and statistically significant, while the coefficient of the interaction term newvisitor*title ($\beta = -4.98\text{e-}05$, $t = -109.4$, $p < 0.01$) was negative and significant.

Robustness check

To test the robustness of our model, following the suggestion of previous studies (13), we extracted a subsample of the total sample and ran the model again. First, to ensure that the findings of our empirical analysis are not influenced by a specific population, the subsample selected for this paper is doctors who have been registered with the "Good Doctor Online" website for a long time and have been online recently. Then, we extracted data from these doctors and selected a total of 5,136 data. Finally, we reran the model with this set of data to test our hypothesis. The results of the robustness test revealed that the coefficients of new patients ($\beta = 0.0765$, $t = 6.85$, $p < 0.01$) and new visitors ($\beta = 3.95\text{e-}06$, $t = 2.72$, $p < 0.01$) were still positive and significant, while the coefficients of patient return visits ($\beta = -0.0041$, t -3.81, $p < 0.01$) were negative and significant. In the second stage of the test, the coefficients of interaction terms newpatient*title ($\beta = 0.00016$, $t = 2.96$, $p < 0.01$) and patientrevisit*title ($\beta = 0.00073$, $t = 2.55$, $p < 0.05$) were still positive and significant, and the coefficients of interaction term newvisitor*title ($\beta = -9.79\text{e-}07$, $t = -2.68$, $p < 0.01$) were negative and significant. This result was consistent with the previous results. Therefore, we could be more confident that the results of our analysis were solid and robust.

Discussion and implications

Discussion

This paper explored the motivational factors that influence physicians' continuous knowledge-sharing in the OHC and the moderating role of physicians' online honorary titles. We hypothesized that in the context of an OHC, the practical benefits, the psychological rewards, and the perceived connectedness with the community would have an influential role on physicians' continuous knowledge-sharing behaviors on the platform. In addition, we hypothesized that physicians' online honors would have a moderating effect on these influences. Several key findings emerged in this investigation.

First, the practical benefits of an OHC were positively associated with physicians' continuous knowledge-sharing behaviors in OHCs. This result is consistent with previous findings in other contexts (12, 15, 68) that reputation as well as monetary rewards can motivate physicians to contribute to OHCs. Thus, based on motivation theory our results again validate the motivating effect of extrinsic motivation on physicians' continuous knowledge-sharing behaviors.

Second, our study found that psychological rewards were positively associated with physicians' continuous knowledge-sharing behaviors in the OHC and that psychological rewards received by physicians significantly influenced their continuous knowledge-sharing behaviors. Consistent with previous findings (12, 15), psychological rewards can motivate physicians' continuous knowledge-sharing behaviors in an OHC. The knowledge shared by physicians helps more people, and physicians can gain more psychological satisfaction, which in turn motivates them to continue to share knowledge. New visitors can also serve as potential patients for the physician, affording the possibility of giving the physician extrinsic rewards in the future by paying him/her for consultations.

Third, we found that the perceived connectedness with the OHC negatively influenced physicians' continuous knowledge-sharing in the OHC, which differed from the results of previous studies (13). A possible explanation for this unsupported hypothesis is that the analysis of the physician–community connection in this research was primarily between physicians and past patients who were often cured after treatment by physicians. Physicians have limited energy, and to help more patients, they tend to focus more on existing patients and will spend less time and effort on past patients. On the other hand, physicians attract more patients by publishing free articles online, and patients often go from online to offline, visiting the doctor's hospital, and establishing an offline connection with the physician so that there are no more late revisits (5). Moreover, patient return visits do not bring financial rewards to physicians, and physicians are not compensated for the cost of their time, thus negatively impacting physicians' knowledge-sharing behaviors.

Fourth, we found that the online seniority status plays an essential moderating role in the relationship between motivational factors and sustained knowledge-sharing among physicians. Although both practical benefits and psychological rewards can have a positive effect on physicians' continuous knowledge-sharing behaviors, the two motivational factors have different strengths for physicians with different online seniority statuses. The higher the online seniority status of physicians in OHCs, the stronger the role of practical benefits and the weaker the role of psychological rewards. And previous research on the moderating effect of physicians' offline professional titles found that the higher the physician's offline title, the lower the incentive for practical benefits (13). The reason for this different result is that many physicians who do not have high offline professional titles may have achieved high titles through their efforts in the OHC. The main source of income for physicians is their salaries from offline work, suggesting that although many physicians have high online seniority status, their actual economic reward is still limited. Many physicians with low offline professional titles actively contribute to the OHC, and these physicians often hope to gain more reputation in the OHC to increase their influence and gain more economic rewards to improve their economic situation. Physicians with higher online seniority status, are more likely to attract several patients for paid consultations. Their existing patient base is much larger than that of physicians with lower online credential status. Since physicians have limited energy, those with higher online status tend to focus more on existing patients rather than new visitors. In addition, we found that physicians' online seniority status weakened the negative relationship between perceived connectedness and physicians' continuous knowledge-sharing behaviors. Physicians with high online seniority status cared more about community affiliation than physicians with low online seniority status. A possible explanation for this result is that physicians with higher online seniority status tend to work harder to maintain their connection with patients in the community to maintain their already honored titles. The results of this study reveal the moderating mechanism of physicians' online seniority status in the relationship between motivational factors and physicians' continuous knowledge-sharing behaviors.

Theoretical implications

Our research contributes to the literature on knowledge-sharing and OHCs from several perspectives. First, this study is one of the first to investigate physicians' continuous knowledge-sharing behaviors from the sustainable development perspective of OHCs by exploring how practical benefits, psychological rewards, and perceived connectedness jointly influence continuous knowledge-sharing behaviors. Although previous research has explored physicians' motivations for knowledge contribution in OHCs, most were limited to exploring the motivations for physicians' knowledge-sharing behaviors (12, 21, 28), and lack of understanding of the motivations for physicians' continuous knowledge-sharing behaviors in the long run. Accordingly, this study addressed this research gap in knowledge-sharing in OHCs by revealing motivational factors of physicians' continuous knowledge-sharing behaviors.

Second, this study complements motivation theory in the context of knowledge-sharing in OHCs by specifically incorporating physicians' perceived connectedness into the motivational model to predict physicians' continuous knowledge-sharing behaviors. Previous research has extended the understanding the role of extrinsic and intrinsic motivation on knowledge-sharing behaviors in OHCs. However, most studies lack of considering the social attributes of OHCs (37, 38), therefore may fail to provide a comprehensive view regarding the motivation of physicians' continuous knowledge-sharing behaviors in OHCs. To fill this research gap, this study represents the first attempt to examine the combined effects of practical benefits, psychological rewards, and perceived connectedness on physicians' continuous knowledge-sharing behaviors.

Finally, in contrast to prior studies concerning OHCs focusing solely on the role of physicians' offline seniority status (13, 69), this study tested the moderating role of physicians' online seniority status (honorary title in OHCs) on their continuous knowledge-sharing behaviors. The findings shed the light on the role of online seniority status which is as important as offline seniority status in motivating physicians' knowledge-sharing behaviors in OHCs.

Practical implications

Our study provides several important implications for practitioners of OHCs. First, our findings indicate that both practical benefits and psychological rewards positively influence physicians' continuous knowledge-sharing behaviors. In other words, physicians can continuously benefit from their knowledge-sharing in OHCs, such as tangible benefits and psychological rewards. Therefore, to address the problem of physicians' inadequate contributions and sustainable development of OHCs, the platform managers should emphasize the practical benefits and psychological rewards of continuous knowledge-sharing for physicians with various levels of online seniority, thus better motivating physicians to share knowledge in OHCs. Specifically, the platform should increase practical benefits for physicians with low online seniority and strengthen psychological rewards for physicians with high online seniority, respectively, to motivate all physicians' continuous knowledge-sharing behaviors.

Second, inconsistent with our hypothesis, perceived connectedness is negatively associated with physicians' continuous knowledge-sharing behaviors. In other words, a large number of patients revisiting physicians' homepages (more potential patients) will lower physicians' motivation to continue sharing knowledge in OHCs. To weaken the negative effect of perceived connectedness on physicians' continuous knowledge-sharing behaviors, some measures should be taken such as lowering the threshold of interaction, optimizing the product design, simplifying the operation of patient–physician interaction, or making the act of interaction more interesting. In addition, managers of OHCs can provide physicians extra monetary rewards when the number of visitors (new visitors and returning visitors) to their homepages reaches a certain level to cover the cost of physician engagement.

Limitations and future research

This study has some limitations. First, although we examined the moderating effect of physicians' online seniority status on the relationship between incentives and physician behavior, the strength of the moderating effect could be influenced by other characteristics of physicians. For example, physicians' demographic characteristics and medical specialties may influence the moderating effect of online rank. In future research, we intend to explore the role of physician characteristics in our research model with multiple considerations.

Second, our study focused on the effect of online incentives on physicians' knowledge-sharing behaviors in OHCs. However, physicians' online behavior can be influenced by offline behavior. Usually, physicians use their time outside of work to provide services on an OHC; moreover, the rules and regulations of the hospitals where physicians work also have an impact on physicians' online behavior. That said, obtaining data on physicians' offline behaviors to study the influence of offline factors on physicians' knowledge-sharing behaviors in OHC entails various difficulties. In future studies, offline motivational factors should be included in the research model.

Finally, in this paper, only physicians' data from the "Good Doctor Online" website was collected. It is necessary to collect more extensive data from other platforms simultaneously to further validate our hypothesis. Therefore, data from several more OHCs should be collected in future research endeavors to explore any gaps that may exist between different platforms.

Conclusion

Physicians' continuous knowledge-sharing behaviors are crucial for the sustainable development of OHCs as well as patient education. Therefore, how to motivate physicians to continuously share their knowledge in OHCs has drawn the attention of related scholars. Based on motivation theory, this study constructed an integrated motivational model to explore the motivational factors on physicians' continuous knowledge-sharing behaviors as well as the moderating role of physicians' online seniority status. The research model and relevant hypotheses were tested using real data from the "Good Doctor Online" website. The results indicate that practical benefits and psychological rewards positively influence physicians' knowledge-sharing behaviors. Inconsistent with our hypothesis, perceived connectedness is found to have a negative effect on physicians' continuous knowledge-sharing behaviors. In addition, physicians' online seniority status moderated the relationships between motivational factors (practical benefits, psychological rewards, and perceived connectedness) and continuous knowledge-sharing behaviors. This study makes a vital contribution to the existing literature regarding motivation theory, knowledge-sharing, and OHCs. In practice, our findings provide crucial insights and strategies for designers and practitioners of OHCs to manage and motivate physicians' sustainable contributions.

Data availability statement

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

Author contributions

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

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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.

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Are social networks effective in promoting healthy behaviors? A systematic review of evaluations of public health campaigns broadcast on Twitter

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Introduction: While public health campaigns disseminated through Twitter have multiple theoretical advantages over other strategies (e.g., a high potential reach and low economic cost), the effectiveness of social networks as facilitators of attitudinal and behavioral changes in the population seems to remain weakly supported. Therefore, this systematic review was aimed to analyze the degree of impact of healthy behavior-related campaigns as documented in scientific literature.

Methods: Strictly following the PRISMA methodology, a total of 109 indexed articles were obtained, of which only 18 articles met the inclusion criteria. In addition to accessing the literature available on WOS, Scopus, BVS, Medline, Cochrane Library and PubMed, the quality of the existing studies was assessed through the Critical Appraisal Skills Programme (CASP) protocol.

Results: The results of this systematic review revealed a small number of evaluations of the effectiveness of social campaigns disseminated on Twitter, although the quality of these studies was considerably good. Most of the research used statistics and metrics for evaluation, with residual use of other measurement methodologies. However, their effectiveness and impact on public health-related behaviors remain arguable, in view of the existence of marked tendencies to: (i) not evaluate these campaigns; (ii) evaluate them through excessively brief, ambiguous, or potentially biased indicators; and (iii) not carry out systematic follow-ups over time.

Discussion: Although there is no strong evidence of the suitability of Twitter as a suitable medium for raising public health awareness on behavioral health affairs, the actual limitations identified in this review would help to optimize this paradigm and enhance the quality, reach, and effectiveness of such communication strategies.

KEYWORDS

public health, communication campaigns, social marketing, evaluation, Twitter, social media

Introduction

Typically, social marketing strategies tend to use very generic marketing practices (i.e., those used for advertising a variety of goods) in the attempt to raise public awareness of a wide range of issues (1), partly as a result of the assumption that behavioral changes might uniformly act at different levels, and for several purposes (2, 3). Indeed, recent macro-social critical events such as the COVID-19 pandemic have facilitated that, given their high accessibility and coverage, social networks have been systematically used to divulgate campaigns, programs or interventions on public health under approaches compatible with the basic principles of social marketing (4, 5). Social networks are dedicated websites or applications that allow users to communicate with each other by facilitating the exchange of information through the posting of messages, comments and images. In these cases, campaigns are usually aimed at preventing negative behaviorally-influenced outcomes affecting public health, such as road crashes, air pollution or viral contagions (6–8). Complementarily, there are also campaigns specifically aimed at people who present a certain health problem, and their families, with the purpose of creating support groups or promoting tools that might enhance their quality of life (9).

Like any other publicity campaign, cost-effectiveness becomes a critical factor in determining the effectiveness of campaigns in raising awareness among the audience (10). In this regard, scientific evidence is somewhat inconsistent. For instance, while several studies suggest that broadcasting advertising campaigns on television remains something effective to achieve behavioral change in citizens, others remark what they call "a clear advantage" of digital channels nowadays (11, 12). Indeed, a comparative study performed by Allom et al. (13) shows that campaign broadcast solely through digital media was significantly more cost-effective than the same campaign broadcast on television, taking into account not only the economic factors but also the impact on individual behavior. This finding is consistent with other research indicating that online broadcasting of campaigns to reduce tobacco consumption was more beneficial than the joint presentation of the spot in digital media, press and radio (14).

In the same line, some other applied researches have shown that, while product advertising usually achieves the expected effectiveness, social campaigns through traditional media fail to modify behaviors in favor of healthier behaviors and lifestyle habits (15). However, and especially as the current coverage of social media remains low in some age and income segments, it seems unlikely that traditional media, and particularly television, would cease to be the main broadcast channels for social advertising (16). This phenomenon is due to the fact that they continue to be an important source of entertainment and information for many people, with a high degree of reach spanning all social classes (17).

Twitter as a communication channel with the public

The good results obtained by digital media in many terms have contributed to "open the door" to a new line (technical term) for developing public health campaigns. During recent years, social networks have been a way to raise awareness of different issues (18). In particular, Twitter is a low-cost channel with a potentially high reach and impact, something in fact evidenced by its high revenue, currently estimated in over 5 billion dollars. Moreover, it presents a mostly young audience, which prefers to be informed on social networks rather than traditional media (19). Therefore, developing awareness campaigns on Twitter either as the sole broadcast medium -or as a potential complement to campaigns launched by other media-could be particularly beneficial for reaching key audiences in public health terms, such as young people, at-risk minorities and other individuals of interest in terms of public health (20).

The latest official data indicate that worldwide 500 million tweets are posted every day (21). These figures offer the possibility that millions of people can receive a campaign message without geographical restriction. However, at the same time, the large amount of content makes it difficult for the message to stand out from the rest, and for the audience to reflect on the issue addressed (22). Therefore, assessing the impact of communication campaigns transmitted by Twitter would add important insights to further analyze (e.g.) which factors capture the attention of users, and which ones influence recall and attitude change.

Objectives of the study

The core aim of this systematic review was to analyze the reported impact and effectiveness of behaviorally-based public health campaigns broadcast on Twitter. Additionally, we applied assessment tools commonly used for this type of campaign, in order to detect the possible methodological limitations of the methodologies used to assess such issues on communication campaigns.

Methods

Overall, systematic literature reviews consist of a comprehensive mapping of scientific evidence based on a protocol and a transparent and systematic methodology to find and explain in detail a research question (23). The present review was conducted according to the quality standards and protocol established by PRISMA, last updated in 2020 (24), and following the recommendations of the Cochrane Review Group (25). All the four authors of the article acted as independent reviewers, each performing the selection, evaluation and data extraction of the studies. Discrepancies that arose were resolved through consensus decisions.

Five steps were followed in the development of the systematic review:

(1) Identifying the research question.
(2) Finding relevant studies.
(3) Selecting the studies.
(4) Charting and collating the data.
(5) Summarizing, analyzing and reporting the results.

Step 1: Identifying the research question

The aim of this systematic review was to determine the degree to which healthy behavior-targeted campaigns broadcast on Twitter are reported as effective in their evaluation studies. Consequently, this study seeks to identify the number and category of scientific studies that have evaluated the efficacy of a health campaign carried out through this social network.

In this sense, articles that analyze the opinion of Twitter users regarding social or health issues were discarded. Neither there were be taken into account those investigations that collect reactions to campaigns issued through other media or any other type of study in which the objectives are not to evaluate the effectiveness or impact of a campaign published using Twitter. No comparisons were made between the studies. The results include a summary and a thematic analysis of all the selected articles.

Step 2: Finding relevant studies

The present investigation was conducted following the PRISMA 2020 guidelines for reporting systematic reviews (24). In the first instance, a scoping review (a standard literature search, as performed in the case of empirical papers) of the literature was performed to preliminarily assess the potential and scope of the research objectives. In addition, it served to identify key terms that would be applied in the searches for the next phase of the systematic review process.

Subsequently, six databases were used for the preliminary literature search, which were selected because of their recognition as reliable quality indicators valued by the scientific community. The selected databases were Web of Science, Scopus, Virtual Health Library, Medline, Cochrane Library and PubMed. We also reviewed other reference lists of different primary research scoping reviews, potentially eligible and not captured by our search strategies.

The search was conducted in the first week of August 2022. It did not have exclusion criteria related to the year of publication. Therefore, all literature published from the beginning of the database until the search date was taken into account for the present review.

The search strategy was carried out taking into account that the review covered research published in both English and Spanish. Therefore, the same Boolean search operator "(evaluation OR evaluación) AND twitter AND (health OR salud) AND (campaign OR campaña)" was used in all databases. The terms selected and the search operator were agreed upon by the authors following the information acquired during the scoping review.

Step 3: Selecting the studies

During this step, articles that did not address our research objective (i.e., focusing on healthy behaviors and also having been broadcast on Twitter) were excluded. Given their substantial differences in terms of targets, dynamics and population quotas, no other potential social networks were considered as suitable channels for the campaigns analyzed. Therefore, all studies assessing campaigns broadcast on e.g., Instagram, Facebook and TikTok, or overlapping Twitter with other platforms were automatically excluded. Although it clearly reduces the scope of the review, it also prevents the data analysis to get affected by many biases and virtually uncontrollable effects. All authors initially, and independently, evaluated a subset of titles and abstracts and then met to discuss and resolve any discrepancies.

Only scientific articles were included, avoiding the inclusion of gray literature. Therefore, we did not select publications in the form of letters, doctoral dissertations, conferences/abstracts, editorials, case reports, protocols, or case series. We also restricted our eligibility criteria to articles published in English and Spanish to which we could obtain access to the full paper, either because they were available due to their open access status, or because they could be requested through the library system used.

Step 4: Charting and collating the data

The data sources (papers) meeting the inclusion criteria were critically reported and analyzed using the Arksey and O'Malley's (26) descriptive-analytic method, which provides a suitable and considerably standardized set of sections to be included in the data extraction form, contained in Table 1. For each eligible paper included, the following data were extracted and recorded: author(s), year of publication, country of study, topic, brief description of the campaign, evaluation method, results (main outcomes) and key limitations.

TABLE 1 Summary of the general characteristics of the selected studies.

References	Country	Topic	Campaign	Method of evaluation	Results (main outcomes)	Key limitations
Schlichthorst et al. (27)	Australia	Suicide	"Man Up" campaign, which links masculinity and suicide (hashtags #MANUP, #ABCMANUP, #LISTENUP and #SPEAKUP)	Twitter statistics (followers, likes, retweets and impressions metrics)	Hashtags grew substantially during the campaign broadcast. The most frequent content was related to help-seeking, masculinity and expression of emotions. Very effective in disseminating information and promoting real-time conversations	Metrics Tweet screening Biased sample
Harding et al. (28)	Ghana	Breastfeeding	Breastfeed4Ghana Campaign	Online cross-sectional survey ($n = 451$)	Acceptability was high but 61% of the audience did not remember the purpose of the campaign. Exposure was not associated with increased breastfeeding awareness	Metrics Survey limitations
Castillo et al. (29)	Canada	Dementia	Dissemination of digital content on pain in dementia, with the hashtag ##SeePainMoreClearly	Twitter statistics (metrics and impressions)	Hashtag received more than 5,000,000 impressions and was used in 31 countries. There was a greater number of posts on the topic during the campaign broadcast period	Metrics Lack of post-test
Grantham et al. (30)	Canada	Nutrition	Campaign of a dietician for 16 weeks, with the hashtag #eatwellcovid19	Twitter statistics (metrics and follower testimonials)	Two types of followers: those who appreciated listening to stories submitted by followers, and those who appreciated evidence-based information	Metrics Campaign design
Moukarzel et al. (31)	World	Breastfeeding	World Breastfeeding Week 2020 (WBW) Campaign	Social network analysis (users and topics of conversation)	Increased conversation during the campaign. Formation of identifiable communities based on geolocation, interests and profession. Identification of influencers as a "bridge" between the public and the scientific community	Lack of behavioral assessment
Viguria et al. (32)	Spain	Eating disorders	Eating Disorder Awareness Week and Wake Up Weight Watchers campaigns, through #wakeupweightwatchers, #eatingdisorderawarenessweek, #eatingdisorderawareness, and #EDAW	Twitter statistics (impressions of collected and sorted tweets)	During the campaign there were more tweets about the topic, comparing the official hashtags with the control hashtag, which is used throughout the year (#eatingdisorder). Medical and awareness content was low. A large percentage of tweets did not promote preventive or help-seeking behaviors	Biased sample Lack of behavioral assessment
Sundstrom et al. (33)	United States	Vaccination	Campaign aimed at parents, to raise awareness about the human papillomavirus (HPV) vaccine	Twitter statistics (metrics and impressions)	More than 370,000 total impressions were reached, with pro- and anti-vaccine comments using personal experiences. Comments with misinformation were responded to and corrected by the users themselves	Not generalizable
Lenoir et al. (34)	United Kingdom	Cancer	Campaign #SmearForSmear to encourage women to take a selfie showing their lipstick going over the edge and post it, to raise awareness of cervical cancer	Twitter statistics, coding of tweets by topic and analysis of the content of the messages	More than half of the users posted the required photo, and almost a third of the tweets were awareness-raising. The awareness messages were linked to the factors "female gender", "women who experienced an abnormal smear test" and "UK inhabitants"	Data biases Lack of behavioral assessment

(Continued)

TABLE 1 (Continued)

References	Country	Topic	Campaign	Method of evaluation	Results (main outcomes)	Key limitations
Lee et al. (35)	Korea	Cancer	Korean Society of Coloproctology colon cancer campaign	Twitter statistics for the keywords "colorectal cancer," "colorectal cancer awareness campaign," "gold ribbon," and/or "love handle"	The majority of the content of the tweets analyzed was spam, with only 12.6% of the messages sharing information. The impact of the campaign among Twitter users was questionable	Small sample size Data biases
Booth et al. (36)	Canada	Mental Health	Bell Let's Talk campaign on mental health awareness and utilization of available preventive services	Record of monthly mental health visits in Ontario outpatient clinics	Twitter inclusion in the campaign was associated with increased utilization of mental health and psychiatric services. Especially significant was the increase in adolescents aged 10–17 years	Data limitations
Wittmeier et al. (37)	Canada	Hirschsprung's Disease	Shit Happens campaign to engage family members affected by the disease	Twitter statistics (metrics and reach)	Assessment of responsiveness showed that within 2 h of posting, a question could receive 143 views and 20 responses, increasing to 30 responses after 5 h	Biased sample Not representative
Harding et al. (38)	Ghana	Breastfeeding	Campaign to promote safe breastfeeding	Twitter statistics (metrics and impressions)	At the start of the campaign, the materials received an average exposure of 60 users. Reach on Twitter was not significant, while it was on Facebook.	Data limitations Small sample size
Gough et al. (39)	United Kingdom	Cancer	Dissemination of messages on the effects of sunlight and the prevention of skin cancer	Pre- and post-intervention household survey; Twitter statistics (metrics and reach), and coding of tweets by topic	There were a total of 417,678 tweet impressions. Shocking messages generated the most impressions, while humorous messages generated the most engagement. The survey revealed an increase in skin cancer awareness, and a change in attitudes about UV rays and tanning	Not representative Survey limitations
Ayers et al. (40)	United States	Tobacco	Great American Smokeout campaign to encourage smoking cessation	Twitter statistics (metrics and impressions) using a quasi-experimental design	There was a 28% increase in tweets related to the topic compared to the rest of the year	Metrics
Jawad et al. (41)	United States	Tobacco	ShishAware campaign warning of the dangers of pipe smoking	Twitter statistics (metrics and impressions)	Twitter enabled the most organization-based contact, but Facebook was the most interactive medium. There is no data on the effects on awareness, knowledge and attitude of users	Data limitations Lack of behavioral assessment
Friedman et al. (42)	United States	STDs	GYT: Get Yourself Tested campaign to reduce stigma and promote communication and testing for sexually transmitted diseases (STDs)	Twitter statistics and affiliate data for Planned Parenthood and infertility prevention clinics	It is estimated that the campaign reached over 52,000 youth. Subsequent years saw a 71% increase in STD testing, although cases of positivity remained stable	Data limitations
Fung et al. (43)	China	Hand washing	Global Handwashing Day Campaign	Qualitative content analysis of messages	Social networks serve as amplifiers of content provided by traditional media	Data limitations
Chung (44)	United States	Tobacco	Tips From Former Smokers is a smoking cessation campaign from the Centers for Disease Control and Prevention (CDC)	Twitter statistics (metrics and impressions)	The role of non-profit entities in disseminating the message launched by government authorities is noted. Two-way interactions with users were minimal	Data limitations Lack of behavioral assessment

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Step 5: Summarizing, analyzing and reporting the results

The data extraction is recorded in tabular form, in order to help readers to identify the key sections, features and contents of these sources. Once their relevant features and main findings were summarized, the quality of the papers included in the systematic review process were assessed through the Critical Appraisal Skills Programme (CASP) tool, whose core utility is performing a quality assessment of the studies analyzed, in order to ensure that the results are not significantly altered or biased by potential technical shortcomings present in these sources.

Results

Search results

By means of the search strategy, a total of 109 possible articles were obtained for analysis, after discarding all duplicate documents. After reading the title and abstract and being preliminarily assessed by reviewers, 79 articles were discarded because they did not respond to the objectives of the review. Subsequently, a new manual screening was performed after reading the full text of the remaining articles. After this process, 18 eligible articles were obtained and included in the study. Figure 1 shows the process of searching and selecting data sources.

Characteristics of eligible research articles

Although the search was conducted for articles published in both Spanish and English, the 18 eligible articles were all published in English. The selected papers were published between 2014 and 2021, which is in accordance with the recentness and novelty of the subject matter of the study. In addition, the studies were conducted in geographically different countries (Figure 2). In this sense, there is representation from 8 countries located in five continents: United States ($n = 5$), Canada ($n = 4$), Ghana ($n = 2$), United Kingdom ($n = 2$), Australia ($n = 1$), Spain ($n = 1$), Korea ($n = 1$) and China ($n = 1$). In addition, one of the studies was conducted worldwide without restricting the data geographically.

Table 1 details the main characteristics and findings of the selected scientific articles.

The evaluated health campaigns broadcast on Twitter cover a wide range of issues. Figure 3 shows the distribution of the topics of the campaigns. The data show that more physical health campaigns are evaluated ($n = 14$) than mental health campaigns ($n = 4$). Specifically, the issues that have been most emphasized

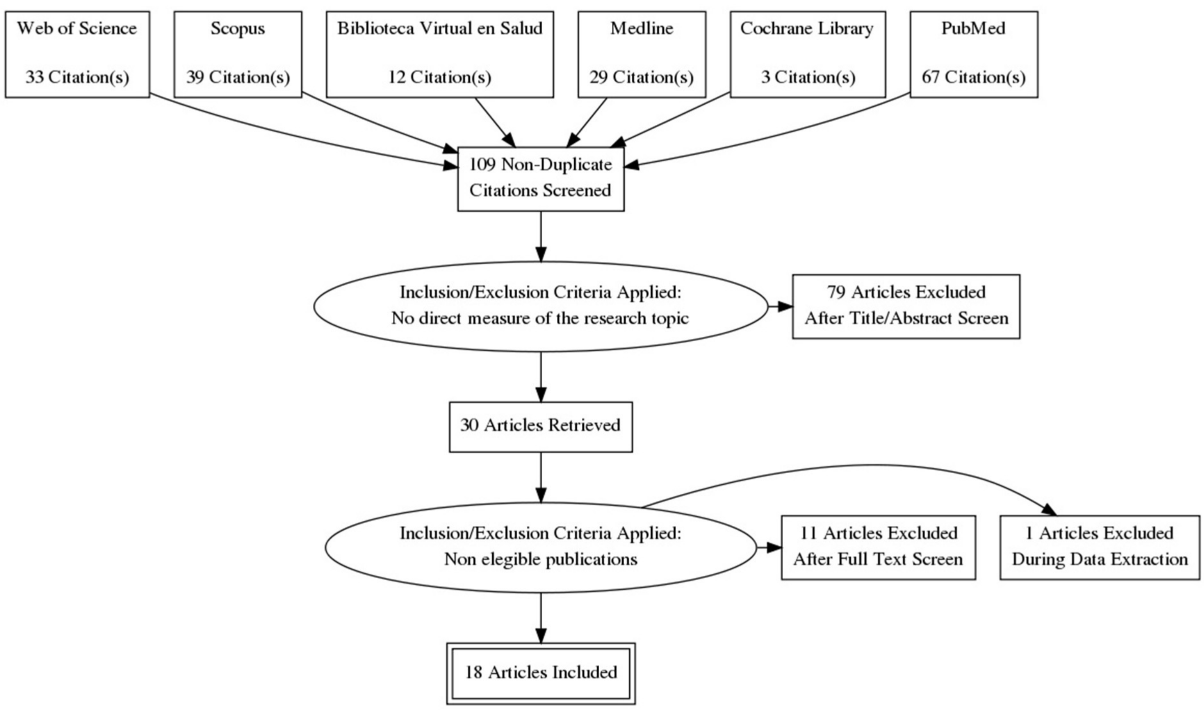

FIGURE 1
PRISMA diagram for this systematic review.

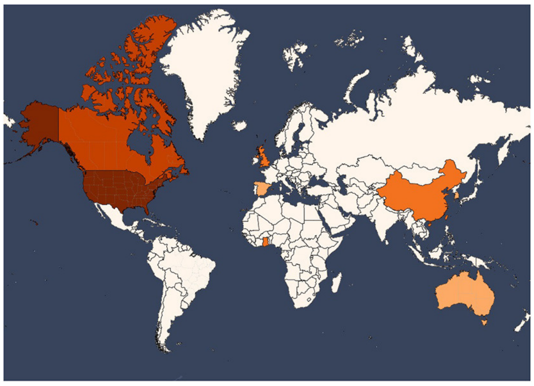

FIGURE 2
Geographical distribution (country of origin) of the selected studies.

are cancer prevention ($n = 3$), each of which deals with a different type of cancer, reduction of tobacco consumption ($n = 3$) and breastfeeding recommendations ($n = 3$). On the other hand, most of the health campaigns are of a preventive nature ($n = 16$), with very few referring to the treatment of diseases that are already present or manifest ($n = 2$). This is the case of the campaign on dementia and on Hirsch-Sprung's Disease, in which its broadcast *via* Twitter was not only aimed at information and awareness of the disease, but also intended to facilitate contact between people or families who were living the same situation for the formation of support groups in the distance.

The record of findings on the effectiveness evidenced by the campaigns indicates that the conversation on Twitter about the issue addressed increased substantially during their broadcast period (27, 29–31, 40, 43). In this regard, in most cases, the evaluation tools were Twitter's own statistics on metrics, impressions and reach, all measured by the numbers of followers, likes, retweets, interactions and conversations generated with the official hashtag ($n = 16$; 88.9%). Therefore, these articles generally conclude that the campaign was useful in raising user awareness.

However, it should be noted that some research uses category analysis or additional qualitative analysis that provides further information ($n = 6$; 33.3%). In some of these cases, the results of this qualitative analysis evidence that part of the users' messages was not linked to the promotion of healthy behaviors or attitudes (32, 35). Thus, it is evident that the information transmitted through Twitter fails to raise awareness among the audience. Furthermore, in the two articles comparing the impact on various social networks, Facebook is the channel that generates the most interactions, while Twitter has a residual impact (38, 41).

Few studies have conducted evaluations beyond the analysis of metrics and the social network users' own messages. Only three studies employ other instruments, and these provide somewhat contradictory data. On the one hand, Harding et al. (28) conducted a survey after the broadcast of the breastfeeding campaign in Ghana. The data collected stated that respondents remembered the campaign itself, but not its message or purpose. In contrast, the survey conducted by Gough et al. (39) revealed an increase in skin cancer awareness, and even a change in attitudes related to the intention to engage in preventive behaviors regarding this issue. Likewise, research by Booth et al. (36) and Friedman et al. (42) relied on records from clinics and outpatient centers, which evidenced a substantial increase in young people attending for treatment or prevention of the problems that the campaigns raised awareness about.

The discrepancies observed in the results of the studies may be due to limitations in the recording of information or the instruments used for evaluation (40). In this sense, a large portion of the articles in which Twitter tools were used to analyze campaign metrics and impressions specify that errors or limitations may have occurred in the data that distort the results ($n = 11$; 61.1%). In addition, an important limitation is that, except in two of the investigations, no post-campaign follow-up was performed, so we only have data from the time of broadcast (29, 35). Likewise, the tools used, except in a few cases, have not allowed us to assess the degree of real impact on audience attitudes and behaviors (32, 34, 41, 44).

Evaluation of the quality of the selected studies

To ensure that no selected study could interfere with or distort the conclusions of this systematic review, the Critical Appraisal Skills Programme (CASP) quality assessment tool was applied. This instrument makes it possible to assess the level of rigor, credibility and relevance of a study by means of ten questions (45). The results obtained from the evaluation of the selected articles are shown in Figure 4. All of them have a low risk of bias, so they have been included in the review. In this process, no article chosen in the selection process has been eliminated.

Discussion

The core aim of this systematic review was to explore and analyze existing scientific studies evaluating the effectiveness of behavioral-based public health communication campaigns broadcast on Twitter. Social networks offer multiple advantages for the promotion of awareness campaigns (46). However, it is important to conduct periodic evaluations of these campaigns' actual impact on the population. This process will provide valuable information to make appropriate adjustments in future communication campaigns' design, approach or message.

However, evaluations of the impact of this type of awareness campaigns are not usually carried out. Only 18 articles were

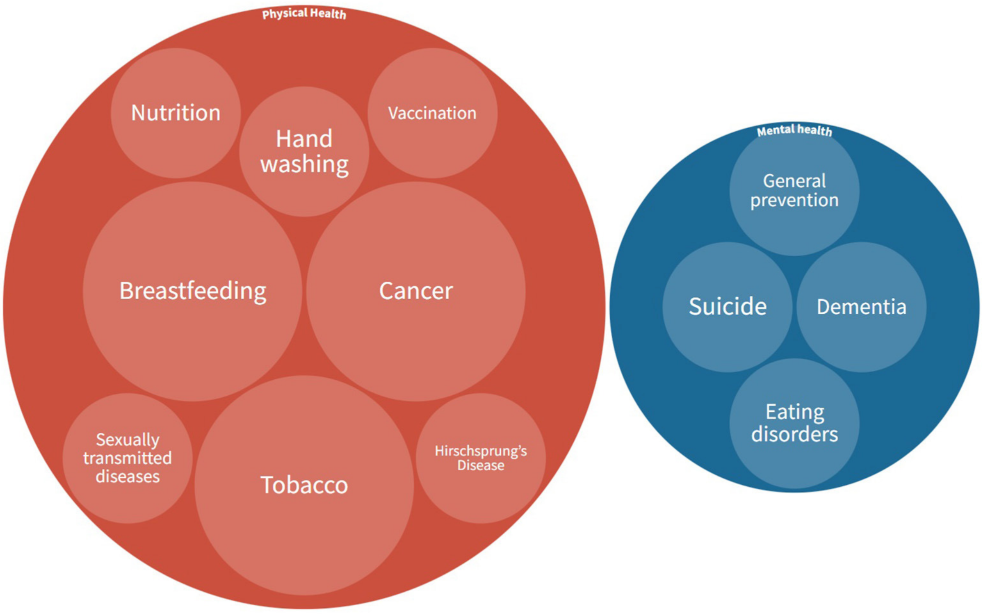

FIGURE 3
Distribution of the themes addressed by the health campaigns evaluated in the selected articles.

found that met the inclusion criteria. Thus, given the large number of campaigns that are based on Twitter sharing, or that use this social network as a complement to other broadcasting channels, it is surprising that there is so little research aimed at evaluating the impact of these campaigns (47). Despite this, the fact that studies of this type have been carried out in countries with very different sociocultural characteristics indicates that, in recent years, there is some interest in knowing the degree of effectiveness of these strategies.

Why are public health campaigns broadcast on social networks not evaluated?

The scarcity of analysis of the impact of campaigns is a common problem in social marketing, regardless of the subject matter and the media used to disseminate them (48). Cost-effectiveness might be one of the reasons explaining this scarcity (49). In practice, many social campaigns are awarded to a particular agency or company because of the economic advantage of their proposal compared to the ones submitted by other candidates. As a result of such a managerial process, all resources tend to be allocated to the design and implementation of the campaign rather than effectiveness evaluations. This entails a pitfall because large amounts of material and economic resources may be allocated to campaigns that are not effective (50). Worse still, erroneous awareness strategies may be perpetuated in future campaigns because their ineffectiveness has not been detected.

There are other factors that may be influencing this situation. For example, the scientific literature evidences certain limitations in measuring the effectiveness of social campaigns (51). The main shortcoming in this regard is that the evaluation instruments adopted for this purpose evaluate perceived effectiveness by the users, assuming it is a direct antecedent of real effectiveness. This is a problematic assumption, though. Therefore, a better and more accurate alternative would be to use cognitive neuroscience tools that allow direct assessment of actual efficacy (52). However, these measurement tools usually entail unaffordable economic costs and therefore, difficult to be adopted.

These limitations are exacerbated in campaigns broadcast through social networks (53). Our review points out the methodological limitations and in the access to information existing in digital impact assessment tools (27, 29). Therefore, those responsible for the development and implementation of this type of campaigns might need to be more cautious when measuring their effectiveness, because the validity and reliability of the current tools are questionable.

Effectiveness of Twitter campaigns: Current limitations and evaluation proposals

Added to the aforementioned, one of the main problems in resolving the issue is to identify variables to be considered to evaluate the effectiveness of a public health campaign (54). From a product marketing perspective, there is no

	Schlichthorst et al. (2018)	Harding et al. (2020)	Castillo et al. (2021)	Grantham at al. (2021)	Moukarzel et al. (2021)	Viguria et al. (2020)	Sundstrom et al. (2021)	Lenoir et al. (2017)	Lee et al. (2016)	Booth et al. (2018)	Wittmeier et al. (2014)	Harding et al. (2019)	Gough et al. (2017)	Ayers et al. (2016)	Jawad et al. (2015)	Friedman et al. (2014)	Fung et al. (2015)	Chung (2016)
Were the objectives clearly defined?	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Is the methodology consistent?	+	+	+	+	+	+	?	+	?	+	+	+	+	?	+	+	+	+
Is the research method adequate?	?	+	?	?	+	+	?	+	+	+	+	?	+	+	?	+	?	?
Is the sample selection adequate?	+	+	+	+	+	+	+	+	?	+	+	+	+	?	+	+	+	+
Are the data collection techniques adequate?	+	+	+	+	+	+	+	+	+	?	?	+	+	+	+	+	+	+
Is the relationship researcher - object of research adequate?	?	?	?	+	+	?	+	+	+	+	+	?	+	+	+	+	?	?
Have ethical aspects been taken into account?	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Was the analysis rigorous?	+	+	+	+	+	+	+	?	?	+	-	-	+	+	+	?	+	+
Is the presentation of the results clear?	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Are the results applicable?	+	+	-	?	+	+	+	+	+	+	?	+	+	+	?	+	?	+

FIGURE 4
Evaluation of the quality of the selected articles using the "Critical Appraisal Skills Programme" tool.

unanimous agreement on what factors measure the impact of advertising campaigns in social networks. In this regard, Raudeliuniene et al. (55) identified 39 primary factors in the literature, including digital marketing analytics (website traffic, impressions or content relevance), sales, customer attraction, audience retention, and consumer engagement, among others.

However, the factors are inevitably different for the evaluation of social advertising (56). Thus, in the first instance, Twitter statistics could be evaluated, in the form of metrics, impressions, reach, geographic areas where most interaction occurs, and user profile. However, this information is not sufficient for two reasons. First, these are immediate results that do not take into account the subsequent evolution of the degree of effectiveness of the campaign (29, 34). Therefore, at least, it would be possible to analyze the statistics of this social network in time periods subsequent to the moment of the campaign's broadcast. This would allow a follow-up of its impact on networks, and thus better assess whether the campaign has proved effective (34). Even so, the systematic review carried out points out limitations in the access to users' information and in the recording of their messages (32, 41). For this reason, these data should be complemented with other tools that assess behavioral change.

Second, most of the research reviewed assesses impact solely using Twitter metrics (27, 30, 31, 40). Therefore, one should be restrained in the interpretation of their results because a campaign with a high digital impact, is not always synonymous with a high level of effectiveness (28). In this sense, we could go a step further and analyze the content of the interactions with the tweets and hashtags of the campaign. In this way, it would be possible to know the main topics derived from it and analyze the sentiment aroused in the audience (28–57). In this regard, Sentiment Analysis tools specially designed for social network interactions (58, 59) have proved to be a promising area worthy of further attention (60).

Additionally, from a social advertising perspective, a campaign is considered effective when it manages to raise awareness among the audience about a certain issue, promoting a change in their attitudes and behaviors. Therefore, qualitative evaluation tools could be applied, such as semi-structured interviews, focus groups or anonymous mass surveys, which would allow knowing the real change achieved through communication strategies (61, 62). These instruments should identify the degree of recall, impact, attitudes, and healthy or prevention behaviors acquired after the campaign broadcast (63, 64).

The current evidence is insufficient to support the effectiveness of Twitter as a broadcasting platform for public health campaigns in general. However, some advantages make it worthy of consideration and further studies, especially having in mind its cost-effectiveness and the broad audience they can reach, especially if compared with traditional programs or interventions based on "aged" communication sources, such as TV, radio and paper-based media (15, 18). The apparent economic benefit such platforms offer can justify them, at least, as a perfect complement for multimedia campaigns, especially to reinforce the message for younger audiences (43).

Limitations of this systematic review and future lines of research

This systematic review was carried out following the PRISMA procedure to avoid possible biases in the selection and/or recording of data. In addition, the inclusion/exclusion criterion was that the eligible articles should form part of relevant indexes and databases worldwide to guarantee, as far as possible, the quality of the research.

Despite all this, the present systematic review is not exempt from the limitations characteristic of this type of study. Thus, the review may present publication bias. This bias occurs when research with negative" or non-significant results is either published in journals of lower impact or not published at all. Therefore, they may not have been included in the review (65).

Moreover, the final low number of original research papers that met the eligibility criteria makes it remarkable the high number of technical shortcomings and potential quality flaws found in these papers. This indeed is one of the conclusions of the conducted review, i.e., that the scientific literature on the evaluation of health campaigns issued through Twitter is really scarce. However, this circumstance could limit the breadth and scope of the research findings. Furthermore, it is possible that the non-indexed literature could have provided more interesting information on this subject (although it could have methodological limitations or limitations in the quality of the results). Also, it is worth mentioning that none of the sources found corresponded to longitudinal or time-based research, something that might be of great use to measure the successfulness and stability of the effects produced by these actions/program over time (66).

The present study has provided some guidelines for the improvement of public health campaigns. However, future studies could try to address this aspect and develop a standard and accessible tool to evaluate the impact of social communication campaigns carried out through Twitter. In this way, it could be easier to measure the effectiveness of awareness campaigns, and data of interest for the development of future communication strategies could be obtained.

Conclusions

Contrary to what was initially hypothesized on the basis of the study background, the results of the studies analyzed in this systematic review do not provide clear evidence on the suitability of Twitter as an effective communication channel for the promotion of healthy behaviors.

On the other hand, it is noteworthy that the evaluation of the quality of the studies analyzed gave considerably positive results endorsing their key features and scientific rigor in many terms, but the adequacy of both research methods and researcher-object relationship represent frequent constraints among these scientific studies.

In addition, the scarcity of research that performs post-campaign follow-up, as well as the lack of measurement on the degree of awareness and behavioral change, are manifested. These factors limit the findings of the studies, since they do not take into account the real effectiveness of the campaign, but only its digital impact.

The usefulness of this review is fundamentally practical since it offers information of interest for the development of communication strategies on Twitter. Thus, the limitations of current evaluation tools are discussed, and more complete evaluation methodologies are proposed to measure the impact of public health campaigns on social networks.

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/s.

Author contributions

MF and FA conceived and designed the research and contributed with reagents, materials, and analysis tools. MF, SU, and AJ analyzed the data and wrote and revised the paper. All authors contributed to the article and approved the submitted version.

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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.

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A process evaluation of an on-line fall prevention and management program for individuals who use wheelchairs or scooters living with multiple sclerosis

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Background: Falls and resulting injury are a significant concern for individuals living with multiple sclerosis (MS) that use a wheelchair and/or scooter to support mobility. Effective fall prevention efforts are vital to support the health, wellbeing, and participation for these individuals.

Aims: This study reports the findings from the process evaluation conducted in association with a pilot study evaluating the efficacy of Individualized Reduction of FaLLs-Online (iROLL-O), an online, group fall prevention, and management program specifically designed for community-based people living with multiple sclerosis (pwMS) who are full-time wheelchair or scooter users.

Methods: A mixed-methods process evaluation was conducted, with specific attention to the impact of online delivery on intervention implementation, participant satisfaction, and mechanisms of change (MOC). Multiple data sources were utilized, including post-session and post-intervention participant and trainer feedback forms and participant qualitative interview data. Descriptive analysis was conducted using Microsoft Excel. Close-ended questions were analyzed by examining five-point Likert scale responses. Qualitative interview data was explored using thematic analysis.

Results: Twelve participants and three trainers (one occupational therapist and two physical therapists) contributed to the study. Online delivery did not compromise session fidelity, which averaged 95%. No significant adaptations to the intervention were made during delivery. Participant satisfaction was high at 4.6/5.0. *Post-course Trainer Feedback Forms* indicate trainer satisfaction with the group dynamic, ability to address unique group needs, and program content. Reach improved with online delivery as transportation barriers were removed and recruitment from a broader geographic area was enabled. Three themes reflecting key MOC emerged from the analysis: group context, motivation for participant engagement, and the multifaceted nature of the program. The COVID-19 pandemic was identified as a contextual factor impacting community participation. Both participants and trainers identified the group dynamic as a strength. The trainers valued the program's flexibility in allowing them to address individual and/or group-specific fall prevention needs.

Conclusion: Feedback from key stakeholders was essential to a meaningful process evaluation. Online delivery supported program implementation, including reach, and resulted in high levels of satisfaction among participants and trainers. Future iterations should aim to uphold the positive group context, recruit, and train skilled interventionists who are licensed as occupational or physical therapists and continue to provide the program's diverse approach to fall prevention and management.

KEYWORDS

fall management, multiple sclerosis, wheelchair users, scooter users, telerehabilitation, complex intervention evaluation, mechanisms of change, implementation

Introduction

Fall prevention is a recognized public health priority and falls pose a significant threat to the health and wellbeing of people living with multiple sclerosis (pwMS). Emerging evidence points to the high prevalence of falls and fear of falling among the 250,000 pwMS who use wheelchairs and scooters as their primary means of mobility and highlights the unique fall prevention needs of this population (1). Among wheelchair and scooter users living with multiple sclerosis (MS), between 50 and 75% report falling at least one time in a period of 6 months (2, 3) and multiple falls and fall-related injuries are common (2). Rice et al. (2) found that 76.7% of wheelchair and scooters users with MS reported concerns about falling and 65.9% limited their activities due to these concerns. Activity limitation associated with fear of falling may lead to deconditioning and ultimately a greater risk for falls (4). Activity limitation also has the potential to compromise quality of life and community participation (4, 5). Understanding the etiology and circumstances of falls among full-time wheelchair and scooter users is essential to informing intervention priorities. Studies involving non-ambulatory pwMS, i.e., pwMS who are unable to perform a timed walk test (6), indicate that falls in this population frequently occur during unavoidable routine activities, such as transferring and walking short distances (7). In addition to risk factors stemming from MS (e.g., compromised balance, weakness), pwMS experience behavioral, environmental, and psychological risk factors (e.g., fear of falling) that increase their risk of falling (8). Simply put, theses diverse and interacting influences lead to a high risk of falls and an imperative need for fall prevention and management programming.

In recent years important advances in evidence-based fall prevention and management programs designed for pwMS who use wheelchairs and scooters as their primary form of mobility have been made. Specifically, a single session, 45-min intervention created by Rice et al. (9) resulted in improvements in transfer quality, postural control, and reduction in fall frequency. Building upon that success, Rice et al. (10) created the Individualized Reduction of FaLLs-In Person (iROLL-IP) program. Individualized Reduction of FaLLs-In Person is a six-session, community-based intervention for full-time wheelchair and scooter users. It is delivered in-person to small groups of participants of approximately two to five people. The primary aim of iROLL-IP is to reduce fall incidence among full-time wheelchair and scooter users with MS. Secondary aims of the intervention are to improve functional mobility skills associated with fall risk (e.g., transfer and wheelchair/scooter skills, balance), increase knowledge of fall risk factors, decrease fear of falling, and enhance quality of life and community participation (10). Descriptions of the study undertaken to evaluate the feasibility and efficacy of iROLL-IP and the intervention itself, along with the complete iROLL-IP study protocol and participant manual, is described elsewhere (10). Briefly, the intervention is delivered by licensed physical and occupational therapists (herein referred to as "trainers") and applies the health belief model (11), as well as Bandura's social cognitive theory (12) and features content to build participants' self-management of chronic fall risk. Development of the self-management content was informed by Lorig and Holman's operationalization of self-management, which includes six specific self-management skills: problem solving, decision making, resource utilization, the formation of patient–provider partnership, action planning, and self-tailoring (13).

Individualized Reduction of FaLLs (iROLL) program content is evidence-based (10). Specifically, the developers of the intervention drew extensively from their research to identify and address circumstances of falls among individuals who use a wheelchair or scooter (e.g., MS symptoms, environmental hazards, activity curtailment associated with fear of falling) (2, 7, 9, 14). Individualized Reduction of FaLLs-In Person includes concise didactic instruction on these topics, as well as exercises to improve sitting balance and core strength, and content designed to build wheelchair/scooter and transfer skills. Post-fall recovery and use of assistive technologies is highlighted in the intervention (15). Individualized Reduction of FaLLs trainers use a variety of educational strategies to actively engage participants ranging from group discussions, physical demonstrations, and practice opportunities. A number of resources support program implementation and receipt, including a program manual, videos, and pictures.

Skills built through the intervention range from developing transfer and wheelchair/scooter skills, building postural control and developing exercise habits to managing environmental hazards, completing wheelchair maintenance checks, and developing post-fall recovery plans (10). Participants are offered structured opportunities to incorporate their self-management skills into their lifestyle (10). These self-management skills take on many forms for participants depending on their individual needs. Some examples include navigating relationships with healthcare providers, and action planning.

Findings from the multi-site clinical trial undertaken to evaluate the efficacy of the iROLL-IP intervention demonstrated that 3 months after completion of the intervention, iROLL-IP participants demonstrated significant improvements in knowledge of fall prevention strategies ($p = 0.01$), knowledge of fall management strategies ($p = 0.01$), community participation in activities important to the participant ($p \leq 0.01$), and transfer quality ($p = 0.002$). No significant differences were seen related to fall frequency, quality of life, seated postural control, or wheelchair skills (15). Process evaluation findings indicated iROLL-IP was implemented with high fidelity and that participants were highly satisfied with the intervention. Key mechanisms of change (MOC) ascertained through qualitative analysis of data yielded through trainer interviews included the group context, a strong program informed by evidence and interprofessional perspectives, and skilled interventionists (16). Online delivery was identified as a potential strategy to improve recruitment, which was identified as the most significant challenge associated with the iROLL-IP intervention.

These informative process evaluation findings, combined with the social distancing measures associated with COVID-19 infection control, led the research team to translate iROLL-IP to an online course: Individualized Reduction of FaLLs-Online (iROLL-O). Individualized Reduction of FaLLs-Online mirrors iROLL-IP in content, processes, and outcomes sought. Highlighted changes include adding asynchronous learning activities, trainer discussion guides, and the use of synchronous group videoconferencing. Like iROLL-IP, iROLL-O is a complex, group-based intervention with multiple potentially active elements that support change and/or impact key study outcomes.

This study reports the findings from the process evaluation (17, 18) conducted in association with the pilot study evaluating the efficacy of iROLL-O (19). The primary questions for this evaluation were: (1) How does online delivery impact intervention implementation (i.e., fidelity, dose, adaptations, and reach)? (2) Are participants and trainers satisfied with iROLL-O? (3) What are the key MOC associated with iROLL-O? Additionally, the process evaluation was intended to identify strengths and limitations of iROLL-O to inform the improvement of future delivery of the intervention.

Methods

Translation of iROLL-IP for online delivery

In April 2020, iROLL-IP was translated to iROLL-O. Individualized Reduction of FaLLs-Online offered the same content as iROLL-IP and was created with the same desired outcomes in mind. Any adaptations made to translate iROLL-IP for online delivery were made with the intent of keeping key MOC identified through the iROLL-IP process evaluation intact. Specifically, the team sought to preserve the group dynamic, comprehensive nature of the program, strong program development, role of a skilled interventionist, and motivated participants (16). The logic model for iROLL-O and the present process evaluation is provided in Figure 1.

A series of adaptations were made to allow for remote delivery of the intervention. To begin, participants were required to have access to the Internet. The most substantial change was an increase in the use of asynchronous content. Specifically, in addition to the homework activities that were included in iROLL-IP (e.g., goal setting, journaling, exercise program, action planning) each week of iROLL-O, participants were asked to watch brief, pre-recorded videos in advance to the synchronous group time. During iROLL-IP, the trainers provided the program to study participants in six weekly, 2-h long, in-person, synchronous sessions. Between the weekly group sessions, participants were asked to set goals, write journal entries, and practice skills learned during the session. For iROLL-O, the weekly content was delivered online using asynchronous and synchronous learning strategies. A table describing key synchronous and asynchronous activities in each iROLL-O session is provided in Table 1. In line with recommended best practices for teaching online (20), the didactic presentations included in iROLL-O were brief (i.e., 5–7 min) each, adding up

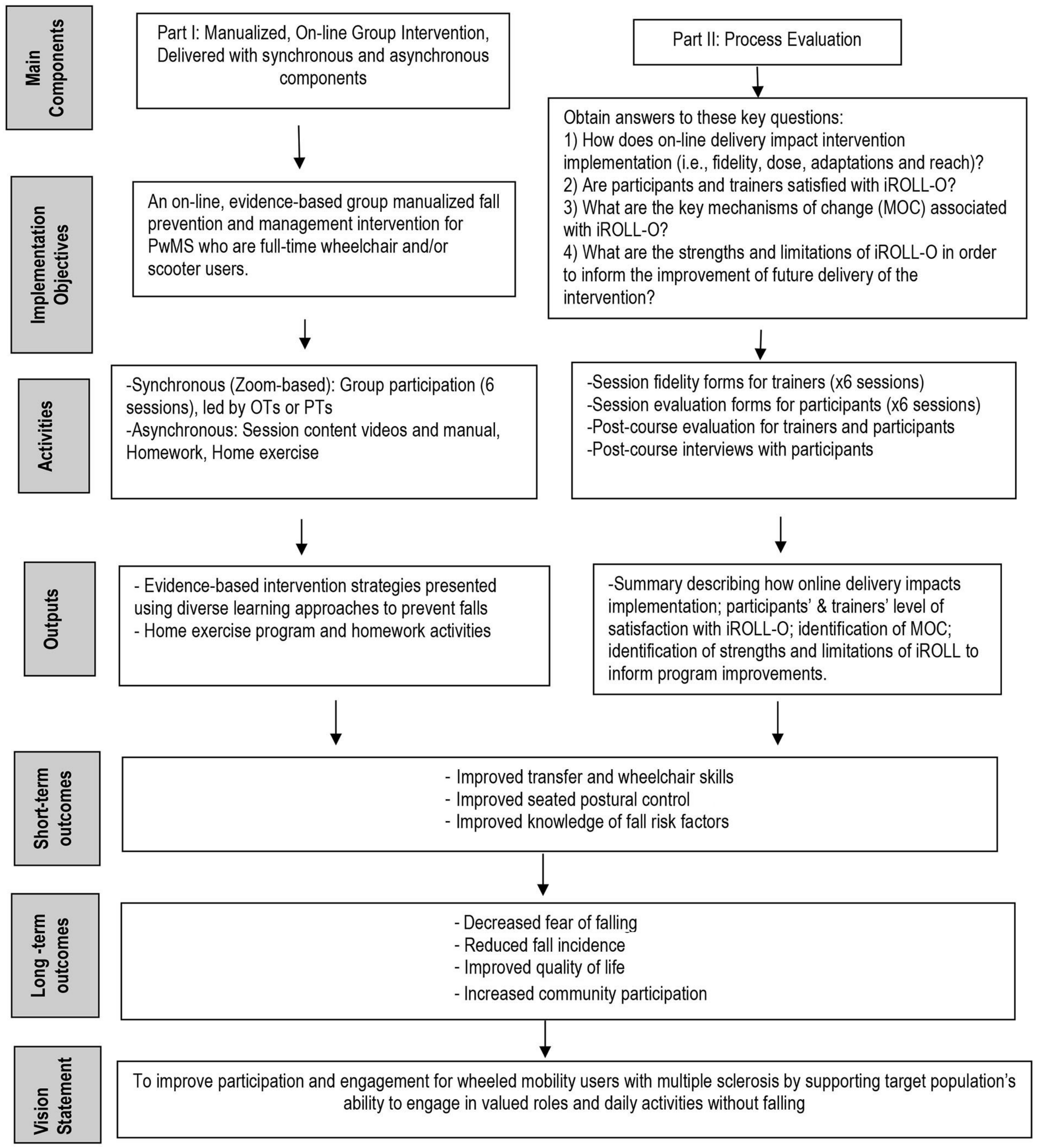

FIGURE 1
The iROLL-O intervention and process evaluation logic model.

to approximately 60 min of content. Individualized Reduction of FaLLs-Online participants were also asked to set goals, write journal entries, and practice skills learned during the session. The planned dose of each synchronous session was 60 min per session. Compared to iROLL-IP, iROLL-O involved less time to practice functional mobility skills however detailed discussions about functional mobility technique and safety were retained.

Significant changes were also made to the trainer responsibilities and materials due to the reduced synchronous time. During iROLL-IP, the trainers presented didactic lectures, led discussions related to program material, and provided

TABLE 1 Synchronous and asynchronous session components for iROLL-O.

Description of iROLL-O components		
Session no.	**Asynchronous session components completed by iROLL-O participants in advance of synchronous session**	**Synchronous session components completed by iROLL-O trainers**
Optional Session 0	• Download Zoom	• Conduct Zoom session to ensure access to program technologies
Session 1	**Watch short video containing content that addresses the following objectives:** • Introduce participants to the problem of falls and fall risk factors specific to wheelchair and scooter users with MS, including fear of falling. • Highlight the multifactorial nature of most falls and the importance of a multifactorial approach to managing fall risk. • Justify the importance of developing fall prevention strategies that (a) meet unique needs; (b) address risk factors operating within, and outside the individual; and (c) support participation in valued home and community-based activities. • Introduce the concept of journaling to reflect on new knowledge learned and goal setting for continued improvement. • Introduce therapeutic exercise program focused on enhancement of postural control and practice exercises. • **Complete:** fear of falling reflection, journal activity related to reducing fall risk, goal setting related to exercise, exercise program participation.	• Introduce participants to the program with an emphasis on program goals and the importance of group members sharing expertise/supporting each other during the six sessions. • Highlight that the program builds upon participants' strengths and expertise. The program activities were developed with the understanding that participants have experience with transfers, wheelchair management, etc., and the activities are designed to help the refine those skills to improve safety, save energy, and use the body in a way that is efficient and prevents overuse injuries. • Discuss regarding "ground rules," such as maintaining confidentiality and being respectful to co-participants. • Identify participants' motivation for joining iROLL and key outcomes sought. • Answer questions regarding the therapeutic exercise program and help participants make adjustments based on their specific needs.
Session 2	**Watch short video containing content that addresses the following objectives:** • Participants will be provided tips to help them perform transfers in a manner that reduces the potential for falls and conserves energy. • Participants will be provided tips to improve performance of basic wheelchair skills to enhance safety. • Participants will learn about common environmental hazards in the community and how they can be avoided. • Direct participants how to practice the therapeutic exercise program, transfer, and wheelchair skills with a care partner. • **Complete:** transfer and wheelchair skills reflection, home safety check list, action planning related to environmental modification needs, goal setting related to wheelchair and/or transfer skills, exercise program participation.	• Discuss the therapeutic exercise program and help participants problem solve through challenges faced related to the exercise program. • Draw from participants' experiences to review common environmental hazards in the home and community. • Problem solve management of common environmental hazards. • Discuss transfer and wheelchair/scooter skill practice and discuss challenges faced.
Session 3	**Watch short video containing content that addresses the following objectives:** • Introduce post-fall management skills. • Instruct participants in the development or refinement of individualized fall management plans. • Continued education on refinement of wheelchair/scooter skills necessary for active community engagement. • Continued instruction on how to practice the therapeutic exercise program, transfer, and wheelchair skills with a care partner. • **Complete:** fall experience reflection, fall management plan worksheet, goal setting related to wheelchair and/or transfer skills practice, exercise program participation.	• Discuss importance of post-fall management. • Discuss development of individualized fall management plan and provide feedback on plan development. • Discuss challenges participants face in the community related to wheelchair skills.

(Continued)

TABLE 1 (Continued)

Description of iROLL-O components		
Session no.	**Asynchronous session components completed by iROLL-O participants in advance of synchronous session**	**Synchronous session components completed by iROLL-O trainers**
Session 4	**Watch short video containing content that addresses the following objectives:** • Provide instruction on refinement of advanced wheelchair/scooter skills. • Provide instruction on refinement of complex transfer for active community engagement. • Instruct participants on key strategies to manage common MS symptoms than can increase fall risk: Example: fatigue management. • Direct participants to continue practicing the therapeutic exercise program, transfer, and wheelchair skills with a care partner. • **Complete:** symptom related fall risk reflection, complex transfer reflection, and journal entry, participation-based goal setting activity, including an action plan, exercise program participation.	• Provide an opportunity for participants to ask questions about MS related symptoms. • Discuss the impact of skills learned through the iROLL program on confidence, quality of life, and community participation, and set realistic individualized goals for safe participation in home or community-based activities. • Discuss challenges participants face in the community related to wheelchair/scooter and complex transfer skills.
Session 5	**Watch short containing content that addresses the following objectives:** • Educate users on different types of assistive technology to manage fall risk and how to access and maintain equipment. • Provide practice opportunities to perform and receive feedback on transfer and wheelchair skill techniques and the therapeutic exercise program. • **Complete:** fall reflection activity on wheelchair and scooter set-up, including action planning to minimize fall risk related to wheelchair or scooter set-up, journaling wheelchair and/or scooter related problems, wheelchair/scooter maintenance plan development, identify a wheelchair/scooter maintenance professional, exercise program participation.	• Discuss current assistive technology use and plans for obtainment of future technology. • Revisit impact of skills learned through the iROLL program on confidence, quality of life, and community participation. • Evaluate progress on goals for individualized activity.
Session 6	**Watch short video containing content that addresses the following objectives:** • Educate users on methods to maintain skills and retain knowledge learned during the iROLL program. • Provide practice opportunities to perform and self-evaluate transfer and wheelchair skill techniques, exercise skills, and future needs. • **Complete:** iROLL skills learned activity, goal setting on iROLL skills maintenance, homework/practice activities, including goal setting, action planning, exercise participation.	• Provide a final opportunity for participants to ask clarifying questions about newly developed skills. • Compare strategies participants plan to use to sustain transfer, wheelchair, and exercise skills in order to prevent future falls.

supervision as iROLL-IP participants practiced exercise, transfers, and wheelchair skills. During iROLL-O, the didactic content was presented during the asynchronous portion of the program. As a result, the trainers focused primarily on fostering discussion during the synchronous sessions. A detailed discussion guide was developed for the trainers to assure consistent discussion across each implementation of the program. Additional practice opportunities were offered. Participants were given the option of sending a video recording of a transfer and/or wheelchair/scooter skills and obtaining trainer feedback. Like the iROLL-IP training (16), the supplementary iROLL-O training was delivered by the project's Principal Investigator (LR) to all returning iROLL trainers.

Study participants

As described by Rice et al. (10), the North American Research Committee on Multiple Sclerosis (NARCOMS) research registry was the primary vehicle used to recruit iROLL-O participants. All iROLL participants were ≥18 years old with a self-reported diagnosis of MS whose main form of mobility is a wheelchair or scooter. All reported the ability to perform transfers independently or required minimal to moderate assistance to perform transfers. All participants had experienced at least one fall in past 12 months.

Trainers

All iROLL-O trainers were recruited by invitation only. All had experience delivering at least one cycle of iROLL-IP, were licensed as an occupational or physical therapist, had at least 2 years of clinical experience including at least 1 year of experience providing care to individuals with neurological impairments utilizing wheeled mobility devices, and had experience providing education to patients/clients in a group setting. As iROLL-IP trainers, iROLL-O trainers had previously participated in an iROLL-IP training workshop, which featured a thorough review of the facilitators' and participants' manuals. Strategies to maintain fidelity associated with both program content and delivery was described in detail. Individualized Reduction of FaLLs-In Person trainers also participated in ongoing meetings with the principal investigator to ensure questions were answered during the implementation of the intervention (16). Individualized Reduction of FaLLs-Online trainers received additional training to learn about iROLL-O processes, with an emphasis on program modifications associated with online delivery (e.g., use of the discussion guide instead of a trainer manual, revisions to the length of synchronous group time, inclusion of asynchronous content).

Study protocol

Participants prospectively tracked fall frequency using a fall diary 12 weeks before and 24 weeks after the intervention. Outcomes were assessed pre, immediately post and 12-weeks post intervention regarding fear of falling, knowledge of fall prevention, mobility skills, quality of life, and community participation. Once assigned to a group and prior to each synchronous iROLL-O session, participants were asked to independently watch pre-recorded videos in specific content areas related to fall prevention and management. In addition to viewing asynchronous videos, iROLL-O participants were asked to complete an exercise program, goal setting, journaling, and action planning activities between sessions as homework. During the consent process the participants were informed that they were required to have assistance when engaging in any of the physical skills. In addition, during the synchronous sessions, the trainers reminded iROLL-O participants to practice physical skills with the help of another person. Trainers invited participants to report upon homework activities during synchronous group session. During the synchronous session, trainers facilitated discussions, highlighted key content-related messages for the week, and reviewed the exercise program. Participants were instructed to attend all six synchronous group sessions. Information describing key synchronous and asynchronous activities for each iROLL-O session is provided in Table 1. Participants received a $100 Amazon Gift Card for completing the study. The study protocol associated with the process evaluation is described below.

Process evaluation data collection tools

Each iROLL-O participant was asked to complete a *Participant Post-Session Evaluation* after each iROLL-O synchronous session and a *Participant Final Course Evaluation Form* immediately following the sixth and final synchronous iROLL-O session. The forms included a mix of Likert scale satisfaction questions and open-ended feedback to ascertain perspectives on the program. Individualized Reduction of FaLLs-Online participants were also invited to participate in a one-on-one interview (audio only) led by a trained research assistant. Participant interviews were recorded and transcribed for data analysis purposes.

Each trainer was asked to complete a *Trainer Fidelity Form* after each iROLL-O synchronous session, and a *Post-Course Trainer Feedback Form* at the end of each course. These forms included a mix of Likert scale questions, Yes/No completion responses to specific fidelity items, and open-ended feedback on program strengths, limitations, and improvement opportunities.

Data collection strategies are delineated in Table 2. All forms used to collect iROLL-O process evaluation data were developed by the research team and were slightly modified versions of the forms used in process evaluation of iROLL-IP (16). The process evaluation forms used in iROLL-IP were adapted from work by Finlayson et al. (21). Individualized Reduction of FaLLs-In Person process evaluation used a Post-Course Trainer Interview guide and associated transcripts to inform MOC, which the iROLL-O process evaluation did not utilize. The only other modification to data collection tools between iROLL-IP and iROLL-O's process evaluations were slight wording revisions to accommodate the change to an online environment.

Intervention implementation data collection

Trainers completed a *Trainer Fidelity Form* to assess **fidelity** at the end of each synchronous session. At the end of the course, Trainers completed the *Post-Course Trainer Feedback*

TABLE 2 iROLL-O process evaluation data collection strategies.

Data source	Key measurement area	Completed by	When completed
Trainer Fidelity Form	Implementation: fidelity, synchronous dose; trainer satisfaction	Trainer	Post-session
Adaptation Log	Implementation: adaptations	Principal investigator	Received post-intervention
Research Staff Log	Implementation: reach	Research staff	Completed on an ongoing basis during the study period
Post-*Course Trainer Feedback Form*	Implementation: fidelity; trainer satisfaction; mechanism of change; environmental elements	Trainer	Post-course
Post-course Participant Interview Transcripts	Mechanism of change; environmental elements	iROLL participant	Post-course
Participant Post-Session Evaluations	Participant satisfaction; mechanism of change; environmental elements	iROLL participant	Post-session
Participant Final Course Evaluations Forms	Mechanism of change; environmental elements	iROLL participant	Post-course

Revised from Van Denend et al. (16).

Form to assess perceptions of implementation strengths and weaknesses. **Synchronous dosage** was determined by calculating the duration of each iROLL session based on start and end times documented by trainers on *Trainer Fidelity Forms*. **Asynchronous dosage**, including practice activity completion was not tracked for this study. **Adaptations** were identified via documentation and communication (i.e., *Adaptation Log*) with the PI (LR) of the study. **Reach** was tracked by a research staff member, who monitored interest calls, eligibility, and attendance (i.e., *Research Staff Log*). The staff member also monitored attrition of study participants by completing telephone calls with those missing sessions and maintaining findings on an internal tracking log.

Participant and trainer satisfaction data collection

Participant satisfaction data was collected using the *Participant Post-Session Evaluations* following each session. Trainers used the *Trainer Fidelity Form* after each session and the *Post-Course Trainer Feedback Forms* at the end of each course to rate their perspective on program features and satisfaction. Data was collected confidentially via REDcap and participants were e-mailed a link from the study coordinator to complete the assessments independently online. The trainers were not involved in the data collection process of the feedback forms.

MOC data collection

To examine MOC, relevant data were extracted from the *Participant Post-Session Evaluations, Post-course Participant Interview Transcripts, Participant Final Course Evaluations*, and the *Post-Course Trainer Feedback Forms*.

Process evaluation data analysis

Descriptive analysis was conducted using Microsoft Excel (Redmond, WA). As with iROLL-IP process evaluation (16), close-ended questions were analyzed by examining five-point Likert scale responses. Open-ended survey response data was reviewed, categorized, and discussed by the investigative team. Qualitative interview data was explored using thematic analysis (22). Using a shared code book, two team members conducted independent open coding. The code book was later refined to address coding discrepancies and newly emerging codes. Initially, all four coders ensured intercoder reliability until consensus was reached for definitions of codes. After consensus was established, coding was performed in pairs for the remaining interview. To develop the code book, codes were grouped into themes, definitions developed and refined, and key representative participant quotes were identified for each code.

Using triangulation to support internal validity of findings, a member of the investigative team (TV) compared the findings that emerged from the transcripts of the telephone interviews conducted with iROLL-IP participants, to the *Participant Post-Session Evaluations*, *Participant Final Course Evaluations*, and the *Post-Course Trainer Feedback Forms*.

Ethics

The study was approved by the Human Research Protection Offices at the three collaborating sites: the University of Illinois at Chicago (UIC), the University of Illinois Urbana-Champaign (UIUC), and the Shepherd Center (SC) in Atlanta, GA. All study participants provided informed consent prior to engaging in any research activities.

Results

Results from three trainers and all available process evaluation data are presented herein, including participants who dropped out of the program at various points. Seven cycles of iROLL-O were delivered between June 2020 and May 2021. Trainers ran between one and four iROLL-O groups. When assigned a group, a trainer conducted each of the six sessions. Process evaluation data was collected between June 2020 and May 2021.

Description of iROLL-O participants and trainers

Key characteristics of the 12 iROLL-O participants that completed follow up testing after the intervention can be found in Table 3. Of the 12 participants that completed all iROLL-O follow-up testing, six attended all six synchronous group sessions, five attended five sessions, and one attended four sessions. The majority of participants were women (92%), with an average age of 62 (SD ± 12) years and reported time with MS averaging 27 (SD ± 13) years. Participants reported using a wheelchair for an average of 11 (SD ± 4) years. The participants lived in nine different states; eleven lived in urban areas and one lived in a rural area. The three trainers involved in the present study had an average of 16 years in practice (SD ± 2 years) and included one occupational therapist and two physical therapists.

TABLE 3 Characteristics of the iROLL participants*.

Variable	Participants*
Age: years, [mean], (range)	62.33, [12.15], (38–76)
Gender [*n* (%)]	Female 11 (92%)
	Male 1 (8%)
Types of MS [*n* (%)]	Secondary progressive 6 (50%)
	Relapse-remitting 3 (25%)
	Primary progressive 2 (17%)
	Progressive relapsing 1 (8%)
Time with MS: years, [mean], (range)	26.58, [12.63], (4–50)
Years of current wheelchair use: years, [mean], (range)	10.91, [4.42], (3–16)
Primary mobility device use: hours per week, [mean], (range)	82.45, [46.38], (18–185)
Type of wheeled mobility device [*n* (%)]	Power W/C: 6 (50%)
	Manual W/C: 3 (25%)
	Scooter: 3 (25%)
Participant location	9 different states
	11 from Urban areas**
	1 from a Rural area
Number of falls in the past 6 months: *N*, [Median], (range)	2.75, [2.67], (1–10)
Experience with Zoom or telehealth (Yes/No) (%)	7 Yes (58%)
	4 No (33%)
	(1 missing)

*People living with MS who are full-time wheelchair or scooter users who completed all iROLL-O follow up testing.
**As identified by areas >5,000 by the Department of Commerce (23).

Intervention implementation findings

Fidelity findings indicated that the intervention was delivered with 94.9% fidelity, on average. The lowest fidelity score was associated with Session 6 (89.3%) and the highest fidelity score was associated with Session 3 (97.4%). The items on the fidelity forms that primarily related to logistics (e.g., starting on time, providing a reminder about completing course evaluations) were scored the lowest by trainers. Content-related items (e.g., "I provided an overview of MS symptoms impact on fall risk") were rated high by trainers, with the exception of one item ranked slightly lower than the others (i.e., Session 1 SMART goals at 71.4%).

Regarding **dose findings,** each iROLL-O session was designed to have 60 min of synchronous session activities. Session 3 was rated the longest, averaging 78 min and Session 5 was the shortest at 58 min. The average synchronous time for iROLL-O was 65 min, per reports from session trainers. No significant **adaptations** were made during the course of the intervention.

Reach findings indicated 18 individuals were deemed eligible and planned to participate in iROLL-O. Three withdrew prior to the intervention: one individual was deemed ineligible, one was lost to follow up, and another reported the intervention did not fit their needs. Three additional individuals dropped out after their iROLL-O cycle began: one was hospitalized, one reported an injured spouse who required care, and a third was lost to follow-up. Twelve individuals completed the program. The number of iROLL-O participants in each group ranged from two to three individuals. Table 4 summarizes fidelity scores, dose, and attendance; Table 5 summarizes iROLL-O's reach.

How online delivery impacted implementation and participant experience

Many participants appreciated the accessibility of the online program. In fact, participation in a face-to-face program clearly would not have been an option for some iROLL-O participants.

- *...if it was in person I don't know that I could have participated because I don't know that I would have been able to get there* (Age 67, Scooter User).

TABLE 4 Findings from iROLL-O fidelity forms.

Session	Fidelity	Synchronous dose
	(No. of completed fidelity items/Total no. of fidelity items)	(Length of session in min)
Session 1	95.24%	68
Session 2	94.81%	62
Session 3	97.40%	78
Session 4	96.10%	68
Session 5	96.43%	58
Session 6	89.29%	60
Average	**94.88%**	**65**

Bolded terms offset the average from each of the individual session scores.

TABLE 5 Summary of iROLL-O's reach.

	iROLL-O
Screened	32
Did not pass screening	12
Declined due to transportation/distance	0
Withdrew before visit 1	2
Enrolled iROLL participants	18
Withdrew prior to intervention (Ineligible = 1, Did not feel intervention fit needs = 1, Lost to follow up = 1)	3
Withdrew during the intervention or during follow up (Hospitalization due to MS = 1, Change living situation mid-intervention = 1; Lost to follow up = 1)	3
iROLL participants who completed all iROLL-O follow up testing	12

- *Well, I think it was probably a little more adaptable, you can do a little at a time and turn it off if you wanted to and go back to it. I kinda like that idea rather than having to spend 2 h at a time. Maybe, it was easier the way we did it* (Age 73, Power Wheelchair User).

Despite the benefits of online delivery of the program, there were also some drawbacks. Notable challenges included technical problems and limitations with transfer practice as a result of being virtual.

- *Personally, I was not able to join in on the meeting because the computer took so long to power up and I was late* (Age 74, Power Wheelchair User).
- *...One seemed to have signed in and then walked away—never responded to questions and we only saw her ceiling* (Trainer Feedback).

TABLE 6 Summary of iROLL-o's post-session participant satisfaction (on scale of 1–5: 1 = poor; 5 = excellent).

Session	Average
1	4.68
2	4.45
3	4.48
4	4.53
5	4.77
6	4.63
Average	4.59

- *Although virtual sessions are great and have some benefit they do limit the ability to practice or provide a lot of practical feedback on how people are able to transfer* (Trainer Feedback).
- *... it probably would have been better to learn in person. You know, instead of watching a video of someone getting up, actually being there and you know... showing me how to get up* (Age 38, Manual Wheelchair User).

Participant and trainer satisfaction findings

Participant satisfaction based on findings from data yielded by the *Participant Post-Session Evaluations* was high (4.6/5.0). The highest satisfaction scores were associated with Session 5 (4.8/5.0) and the lowest scores were associated with Session 2 (4.5/5.0). Across all sessions, participants reported the highest satisfaction with the following program features: Week 4—Follow up home exercise training 4.9/5.0; Week 5—Follow up home exercise training 4.9/5.0; and Week 5—Knowledge of assistive technology to manage fall risk 4.8/5.0. Likewise, participants rated the following program features the lowest across all sessions: Week 4—Practice opportunities to refine wheelchair safety skills 4.3/5.0, Week 3—Training on complex transfers 4.3/5.0, and Week 2—Wheelchair/Scooter safety skills training 4.3/5.0. Tables 6, 7 outline the participant satisfaction reporting.

Program features rated the highest by trainers, as indicated by the completed *Post-Course Trainer Feedback Forms,* were: participants were given enough time to engage in and benefit from social learning; the program supported participants' ability to manage several types of fall risk factors; and the program improved knowledge and management of fall risk factors (all 4.8/5.0). The three lowest rated program features were: the program improved community participation 3.6/5.0; the program improved participants' ability to manage wheelchair skills and transfers 4.2/5.0; and the quality of the manual with respect to its usefulness in supporting one's ability to facilitate

TABLE 7 Summary of iROLL-O's post-course participant satisfaction (on scale of 1–5: 1 = poor; 5 = excellent).

Item	Rating
Instructor's knowledge of the course content	5.00
Instructor's ability to present course material and to facilitate discussion	4.93
Physical environment of the course allowed you to see, hear, concentrate, and participate	4.71
Overall value of the course content to help you manage falls	4.64
Ability of course and instructor to motivate you to try new fall prevention strategies	4.57
Overall quality of homework review sessions at the beginning of each session	4.50
Overall quality of the manual	4.43
Overall quality of homework	4.36
Format of the course	4.36
Overall rating score	4.61

and deliver the iROLL intervention 4.2/5.0. The most essential program features as reported by trainers included: the videos, group discussion/context, transfer skills, and wheelchair skills and maintenance. The least essential program features included wheelchair or scooter higher-level skills (e.g., navigating curbs and ramps), and community participation discussions.

MOC findings

The *Post-course Participant Interview Transcripts* were the primary data source yielding insights into MOC, with data from *the Post-Course Trainer Feedback Forms*, *Participant Post-Session Evaluations,* and *Participant Final Course Evaluations* adding additional insights. Three major themes emerged: group context, motivation for participant engagement in iROLL-O, and the multifaceted nature of the program.

Theme 1: The group context

Participants highlighted the value of the group context, which allowed them to encourage each other and share problems, ideas, experiences, and information. The trainer was often mentioned as a positive influence on the group discussion.

- *"It's nice to have a small group of people that you'll get to know and will share your problems"* (Age 60, Power Wheelchair User).
- *"In my group we share learned experiences, along with encouraging suggestions with each other. Our facilitator is great, she allows for open discussion without compromising the module info for the week"* (Age 74, Power Wheelchair User).

Theme 2: Motivation for participant engagement in iROLL-O

The participants described their intrinsic motivation to participate in iROLL-O. Participants' reasons for joining the iROLL-O program ranged from recognizing a history of falls and a desire to learn skills to prevent or manage falls to contributing to research, receiving financial compensation, and accessing social support:

- *I have lots of falls in my history because no one actually gave me a license to use this [wheelchair], you know... I just made a terrible mess and no one gave me a license so that explains it* (Age 73, Power Wheelchair User).
- *I wanted to learn how not to fall and different ways to use my wheelchair because I was never taught and I was just subscribed hey I think you need to be in a wheelchair since I didn't go to any therapy or anything. You know I didn't learn how to get up from a fall or what to do when you go over a bump or anything like that so I was really interested in what the program could offer* (Age 38, Manual Wheelchair User).

Theme 3: Multifaceted nature of the program

Trainers and participants alike spoke to the benefit of the wide range of topics covered in iROLL-O and the diverse learning approaches used. The intervention's ability to support both current and future fall prevention needs and its attention to fall management was specifically highlighted, as was the value of the content on fear of falling, fall management, self-management, self-awareness, environment-related safety considerations, and transfer training. Both trainers and participants described the usefulness of the resource materials, exercise, and the videos.

- *... I have become more aware, like if you're rushing ... I can't be rushing* (Age 73, Power Wheelchair User).
- *... I know that when I have to transfer from the wheelchair to a chair or from the wheelchair to the toilet or to the shower, I need to make sure that there's really a clear access path... the program was great and made me aware and made me start doing it* (Age 59, Manual Wheelchair).
- *I think it was a lot of help cause it gave me different views of doing different transfers and well it did as we said it opened my eyes to how I could be my own worst enemy when it comes to falls. Well I was just like going through life thinking that I can do this no problem and being sorta nonchalant about things and falling* (Age 67, Scooter User).
- *This course was very informative. I feel like my core has gotten stronger from exercises. Transfers are still pretty*

difficult for me being in a scooter so this course has taught me that I need to investigate getting a power chair… (Age 62, Scooter User).

- *And It was helpful in a lot of ways and it gave me and idea of what to prepare myself for in the future because I am probably headed toward not being able to use a scooter anymore or having to put a lift in my van and stuff like that, where I haven't had to do that yet so far* (Age 64, Scooter User).

Contextual factors

The present study occurred during COVID-19 pandemic. Data from the *Post-course Participant Interview Transcripts*, *Participant Post-Session Evaluations*, *Participant Final Course Evaluations*, and the *Post-Course Trainer Feedback Forms* provided important insights into the influence of COVID-19 on the participants' experience of the intervention. Individualized Reduction of FaLLs participants described the negative impact of the pandemic on their activity levels:

- *…I haven't been doing anything* (Age 64, Scooter User).
- *Because I really missed being able to go to a gym and do any workout, so this helps me* (Age 76, Manual Wheelchair).
- *COVID-19 has put a halt to any attempts to get engaged in community activities* (Age 67, Power Wheelchair).

Likewise, trainers identified the pandemic as the probable reason that conversations about community participation and engagement were so challenging:

- *It was difficult to engage participants in discussion of community participation. Not sure if is due to COVID-19 restrictions or lack of participation in other parts of the program* (Trainer Feedback).
- *Participants did not have much to say about community engagement as they are not really accessing the community due to COVID. It made this topic of discussion somewhat difficult and irrelevant* (Trainer Feedback).

Winter weather was another contextual factor that negatively impacted participation in activities outside of the house. Participants who engaged in iROLL-O during the winter months clearly curtailed activity due to dangers posed by snow and ice. One participant stated, "*I am a 'victim' of snow and ice which makes me homebound*" and another, "*…Every time I have a plan [to buy new DME] the weather changes so I don't want to go out and experience the life of falling on the snow or ice…*" (Age 67, Power Wheelchair User).

The final contextual factor identified was living in areas where access to physical or occupational therapy was limited, which negatively impacted participants' ability to pursue recommended services upon the conclusion of iROLL-O. One participant stated, "*…the suggestion is to find a PT or OT that can show how to do the technique being demonstrated. I do not live in an area with those services easily accessed…*" (Age 59, Manual Wheelchair User).

Key strengths, limitations, and recommendations to improve iROLL-O

Findings from the *Trainer Fidelity Forms* highlighted many program strengths/facilitators and challenges/barriers (See Table 8). Trainers emphasized the value of the positive group dynamic, the quality videos and content, and the motivated participants as key strengths/facilitators for iROLL-O. They also valued the program's flexibility in allowing them to address individual and/or group-specific fall prevention needs. With respect to challenges or barriers, trainers noted that the "relatability" of some of the videos or manual content could be improved, especially for scooter users. The trainers offered suggestions to improve the exercises, and to more effectively manage session time and technological issues. Suggestions on supporting community participation during the COVID-19 pandemic were also noted.

Participants and trainers also highlighted specific areas for program improvements. For example, one participant stated, "*The manual could use a bit of visual break between sections … the sections visually run together. A header or banner could be added to identify Sections. Maybe a few asterisks at the edge of a section page would help break up the run-on appearance of the content*" (Age 65, Scooter User). Trainers also requested a hard copy of the participant manual.

Some participants found the selected images, models, information, and transfer samples unrelatable to their experience.

- *I think the real challenge, besides the type of wheelchair that I had that some of the things I wasn't able to do, also seeing like the demonstrations, they weren't necessarily for me. It was like maybe if they had someone that had more difficulty being able to get up. Maybe having someone with my type of MS instead of just saying "hey just put your leg up here" and doing it like its nothing because its not nothing* (Age 38, Manual Wheelchair User).

Participants provided suggestions to specific aspects of the program, including improving the wheelchair maintenance and exercise portions of the program. One participant reported, "*Well, maybe I would say that the only part that I didn't think was wonderful was the maintenance and the back and forth of how we were supposed to do such and such every month or every 6 months and back to something that was once a year and you know*

TABLE 8 Summary of iROLL-O's *Trainer Fidelity Form* open ended coding.

Facilitators/Positives (N = number of responses for category)	
Positive group dynamic (Participant resource sharing)	10
Ability to "individualize" or increase focus on group selected material/topics (GB, backward falls, bathroom transfers, fall alert device, w/c fittings) Note: includes flexible trainer decision making/addressing group individualization needs	7
Quality videos or content (promoting safety awareness/helpful with early access pre-session)	4
Motivated participants	3
Barriers/Challenges (N = number of responses for category)	
Relatability of or additional videos and images in manual (notes related to scooters; directing CGs, outdoor curb navigation)	13
Time issues: late start/late end/extra time needed (more time needed on proper body positioning and biomechanics, late start d/t tech challenge, late joiner to group)	8
Exercise issues (Declining to practice exercises, difficulty with scooting exercise, exercise tracking, complicated professional jargon used)	8
Technology challenges	4
Community participation challenges due to COVID-19	4
Long-term maintenance concerns/Follow-up requested	3
Availability of resources	2
Unengaged participant	1
Only one attending group	1
None or general "went well"	23

it was sort of erratic..." (Age 73, Power Wheelchair User). Others had suggestions to improve the exercise portion of the program, such as simpler exercise naming, adding more leg exercises, and the potential of a separate, optional exercise meeting.

Finally, trainers and participants agreed on the need for more practice opportunities, especially to hone, wheelchair and transfer skills, as well as a preliminary session occurring before Session 1 to acquaint the group with the technology associated with the mode of delivery.

- *I think the online version is great—it expands the program to many more people and decreases demands on transportation. But I think more can be done to incorporate "doing" into the sessions—planning to "do" a transfer during the session by creating a plan to have a caregiver present or planning to "do" w/c skills by signing in on your phone that day...* (Trainer Feedback).

Table 9 provides a full summary of strengths, limitations, and associated recommendations of iROLL-O.

Discussion

The COVID-19 pandemic, combined with reach-related challenges identified in the process evaluation of iROLL-IP (16) created an imperative for this process evaluation conducted in association with a pilot study evaluating the efficacy of iROLL-O, an online fall prevention and management program for individuals living with MS who are full-time wheelchair or scooter users. The diverse data collection strategies utilized yielded answers to the key questions intended to be addressed through the process evaluation. Among these strategies was the plan to collect both quantitative and qualitative data from of two groups of stakeholders: end users and interventionists.

Findings demonstrated that online delivery resulted in high levels of satisfaction among participants and trainers. Participants were especially satisfied with the home exercise program and training on use of assistive technology to manage fall risk. Findings also demonstrated that online delivery supported program implementation, including program reach. It is evident that online delivery facilitated increased access to iROLL. In iROLL-IP, 32% of screened individuals declined to participate either due to transportation related issues or time/scheduling issues (16). Such barriers were not reported in iROLL-O. This study supports the findings of Banbury et al. (24) who reported that videoconference delivery may improve program accessibility, especially for those with limited mobility. Our findings also build the growing body of evidence demonstrating the value of online delivery formats to support healthy lifestyle behaviors for wheelchair users. For example, Hoevenaars et al. (25) studied wheelchair users with spinal cord injury or lower limb amputation and found that supporting physical activity, diet, sleep, and relaxation using a developed mobile application was feasible and led to high levels of participant satisfaction. Building upon the success of the online delivery, use of mobile application technology could be a consideration for future iterations of iROLL-O to support interactions among program participants, interactions among

TABLE 9 Summary of iROLL-O's strengths, limitations, and recommendation.

Key strengths	Source (s)	Recommendations
Description of strength		
Online experience	*Participant Final Course Evaluation, Trainer Final Course Feedback Form Participant Post-Session Feedback Form, Post-course Participant Interview Transcripts*	Outside of a few technical challenges, the online forum was a satisfactory and feasible means to deliver the synchronous portion of the course. Recommend ongoing utilization of online delivery.
Implementation: Quality trainer training (Rated 5.0/5.0 by Trainers)	*Post-Course Trainer Feedback Form*	Maintain the current training approach.
Implementation: Delivered with high fidelity (Rated at 94.88%)	*Trainer Fidelity Form*	Adequate training and manualized material appear to be supporting fidelity. Maintain these efforts.
Implementation: Asynchronous video utilization	*Trainer Final Course Feedback Form, Participant Post-Session Feedback Form*	Using videos prior to the session appeared satisfactory to participants and trainers, although minor revisions are suggested to the content in the MOC recommendations.
MOC: The group context	*Trainer Final Course Feedback Form, Trainer Fidelity Form, Participant Post-Session Feedback Form, Participant Final Course Evaluation, Post-course Participant Interview Transcripts*	Continue to ensure the utilization of a group and skilled trainers in future iterations.
MOC: Motivated participants	*Trainer Fidelity Form, Participant Post-Session Feedback Form, Participant Final Course Evaluation, Post-course Participant Interview Transcripts*	Recruitment efforts and program topic area are of interest to participants. Continue to consider expansion of recruitment to include integration of key participant motivators for future recruitment efforts.
MOC: Multifaceted nature of the program	*Trainer Final Course Feedback Form, Trainer Fidelity Form, Participant Post-Session Feedback Form, Participant Final Course Evaluation, Post-course Participant Interview Transcripts*	Participant and trainers alike are satisfied with the scope of fall prevention and management areas covered in the program. Continue to offer these diverse areas, including the utilization of varied learning approaches (didactic teaching, group discussion, manuals, asynchronous videos, and practice activities).
Key limitations		
Description of limitation		
Implementation: Manual formatting (availability of hard copies, general formatting, Trainer manual revisions)	*Trainer Final Course Feedback Form, Participant Post-Session Feedback Form, Participant Final Course Evaluation*	Consider enhancements to the iROLL-O trainer material, making hard copies of the participant manuals available for trainers and consider investing in enhancements of the formatting (increase visual appeal, adding tabs) to participant manual.
Implementation: Recruitment	*Study Coordinator log*	Recruitment was slow. Using online delivery, consider expanding to additional states/areas. Will need to explore cross-state licensure for occupational and physical therapists to deliver an intervention across state lines. Alternatively, have cohorts arranged by state with licensed therapists in each state to deliver the intervention.
Implementation: Technical challenges (logging onto/fully accessing Zoom)	*Participant Post-Session Feedback Form*	As mentioned in the trainer feedback, consider a "Group 0," where the only thing addressed is ensuring participants are both confident and able to access necessary technology. Training and a technical support team to on-board both trainers and participants to field necessary technology is recommended. Consider availability of loaned hot spots in poor internet serviced areas.
Implementation: Starting on-time	*Trainer Fidelity Form*	A "Group 0," adequate onboarding and technical support will help with the issue of starting on time.

(Continued)

TABLE 9 (Continued)

Description of limitation	Source (s)	Recommendations
Environmental element: Challenging to impact community participation (due to COVID)	*Trainer Final Course Feedback Form, Trainer Fidelity Form, Participant Post-Session Feedback Form, Post-course Participant Interview Transcripts*	Consider additional training and material to support trainers in addressing participation challenges. COVID-19 mitigation efforts are lessening, but participation recovery may need additional support for various reasons (e.g., deconditioning, decrease social connectedness, fear).
Improvement Recommendation: Exercise issues (declining to practice, difficulty with scooting exercise, exercise tracking, complicated professional jargon, wanting additional time exercising)	*Trainer Fidelity Form, Participant Post-Session Feedback Form*	Regarding those declining to practice, one participant suggestion was to offer an additional (potentially optional) session that is geared toward exercise (form, accountability to engage in, etc.). Recommend further exploration of the lower extremity exercise included, as well as the scooting exercise as participants expressed suggestions in these areas. Recommend simplifying the exercise tracker and consider renaming exercises, using lay language.
Improvement Recommendation: Relatability of program material, content, or videos to each participant's current skill or functional level	*Trainer Final Course Feedback Form, Trainer Fidelity Form, Participant Post-Session Feedback Form, Participant Final Course Evaluation, Post-course Participant Interview Transcripts*	Some participants expressed interest in additional scooter related images, examples and content, in addition to video examples of what to do in more challenging transfer scenarios. Recommend consider expanding the representation of various disability levels and devices used in videos, images, examples, etc. As possible, use more natural environmental settings over more clinic-based settings.
Improvement Recommendation: Long-term maintenance	*Trainer Fidelity Form, Participant Post-Session Feedback Form*	Recommend engaging care partners in certain program sections (e.g., exercise and transfer training especially) to support long-term maintenance. Could consider a semi-regular group check-in built in monthly post-course to support long-term maintenance.
Improvement Recommendation: Declining to engage in practice activities or compromised practice opportunities d/t being online	*Participant Post-Session Feedback Form, Trainer Final Course Feedback Form*	One trainer suggested sending sample videos of participant transfers to provide feedback. Increasing care partner engagement in the practice portions of program may also increase practice opportunities.

the program participants and the trainer, and long-term self-management of fall risk.

Positive group dynamics, the multifaceted nature of the program and the motivated participants were identified as key MOC supporting attainment of program outcomes. These MOC provided evidence that social learning theory and self-management strategies were effectively applied in iROLL-O. Trainers were notably satisfied with the group format, the social learning that occurred, and the program's ability to improve participants' self-management of diverse fall risk factors. Similar to the experience reported by Banbury et al. (24), effective group processes were maintained through online delivery. Our process evaluation findings clearly pointed to the value of involving licensed occupational and physical therapists as trainers. The iROLL-O trainers drew from knowledge and skills gained through their extensive work experience (16 years, on average) to facilitate the iROLL-O group process and individualize program content while maintaining program fidelity. The trainers' feedback regarding their high level of satisfaction with the training they received in advance of delivering iROLL-O was important given that administering healthcare services using telehealth requires adequate training to ensure competent delivery of quality services (26).

As intended, the process evaluation led to identification of several opportunities to improve iROLL-O. Participants and trainers alike supported the revision of program material to increase relatability to more diverse functional levels and devices utilized. For example, more images portraying scooter users were recommended. Importantly, the need for more opportunities for participants to practice wheelchair skills and transfers was identified through several sources. The challenges associated with teaching wheelchair skills via telehealth are not unique to iROLL-O. In an intervention aimed at evaluating an mHealth wheelchair skills program for older adults using manual wheelchairs, Giesbrecht and Miller (27) reported challenges improving wheelchair skills capacity but found positive results improving safety. Bell et al. (28) discovered the value of evaluating wheelchair skills and accessibility in a client's natural environment using telehealth but emphasized the value of telehealth services in partnership with traditional in-person services to support functional outcomes. Future iterations of iROLL-O could consider a hybrid approach that compliments online learning with in-person activities. A one-on-one in-home visit that provides participants with the opportunity to practice wheelchair and transfer skills in their natural home environment under the supervision of the iROLL-O trainer could be utilized. Alternatively, a group of iROLL-O participants could meet with the iROLL-O trainer together, in-person, to refine skills. Meeting as a group to work toward skill mastery would allow for peer modeling and may increase the potential for enhanced falls self-efficacy (29).

Additional areas for improvement identified through the process evaluation pertain to addressing challenges associated with online delivery. Future iterations of iROLL-O can utilize an iterative process to onboard participants and trainers, and develop a protocol for technical support. An optional pre-intervention session was offered to support/check technology and orient participants to the program, but few chose to attend. Rather than making this pre-intervention session optional, an iROLL-O "Session Zero" designed to orient participants to the online platform and support services available can integrated into the iROLL-O program to mitigate technology-related issues noted by participants and trainers. Finally, while expansion of delivery of the iROLL program using the online form is warranted, professional state laws and regulations related to telehealth need to be considered, especially when delivering services across state lines (30).

Understanding the context in which iROLL-O was delivered goes beyond consideration of online delivery. The iROLL-O cycles took place between June 2020 and May 2021, a period when social distancing was heavily utilized to mitigate risk of infection. The pandemic had a significant psychological impact on pwMS, including a "higher burden of depressive symptoms, a worse sleep quality and perceived an increase in fatigue level" compared to the general population (31). The pandemic also prompted a decrease in community participation for many, especially for those with mobility limitations (32). Thus, the process evaluation findings yielding insights into the COVID-19 pandemic's impact on the participants' experience of the iROLL-O intervention and outcomes sought are noteworthy. Two key COVID-19-related findings were identified through the process evaluation. First, compared to iROLL-IP trainers, iROLL-O trainers were less likely to report that community participation increased among the people living with MS who were participating in the study they were a part of. Second, in light of reduced opportunities for socialization, access to an online community was welcomed by many iROLL-O participants. For example, one participant stated, "*... things that you couldn't participate before because you couldn't get out, now everything is being held online, like church and meetings, like my MS meetings they're all zoom now and they got a MS zoom dance class they can be done in a chair, so yeah so zoom has been awesome really. I really like that and I really liked that part of the study*" (Age 62, Scooter User). Overall, the process evaluation findings provide an important reminder that study results related to community participation must consider contextual influences on the outcome.

Limitations

There are several limitations associated with this study that require consideration. To enhance learning, trainers reviewed and highlighted key points of the asynchronous session content during the synchronous group sessions. However, asynchronous dosage received by the participants was not tracked. The research team cannot confirm if participants watched assigned videos, completed practice activities, and/or if quantity of participation in asynchronous activities had an impact on study outcomes. As emphasized by Lichstein et al. (33), delivery receipt is an independent treatment component that must be assessed to determine if a valid clinical trial has been conducted. Therefore, future iROLL process evaluations must capture participants' receipt of synchronous, as well as asynchronous, content. Considering the usage of application technology to monitor dose received could be a viable option. The process evaluation strategies utilized in the future can also be strengthened by applying best practices in survey research. Specifically, double or multi-barreled questions (e.g., on the iROLL-O's *Trainer Fidelity Form*) must be avoided. In addition, although the study utilized feedback from both interventionists and end users, the numbers of people in both stakeholder groups were small. Feedback from larger samples of stakeholder groups would yield more robust data to inform evaluation design and intervention development. Future studies involving larger numbers of participants from a variety of geographic regions are needed to improve generalizability of the findings. Fidelity was also measured by trainer self-report. An external rater of fidelity would increase the validity of the session fidelity findings. Finally, given that findings suggested that participants' community participation, a long-term goal of the iROLL-O intervention, was negatively impacted by the COVID-19 pandemic, enhancing process evaluation strategies to better understand contextual influences on intervention participation and outcomes is warranted.

Conclusion

Feedback from key stakeholders was essential to an informative process evaluation. Online delivery supported program implementation, including reach, and resulted in high levels of satisfaction among participants and trainers. Individualized Reduction of FaLLs content and processes that apply social learning theory and application of self-management strategies were closely tied to MOC and were supported by online program delivery by skilled occupational and physical therapy interventionists. Future iterations should aim to uphold the positive group context, recruit, and train licensed occupational or physical therapists as interventionists, and continue to provide the program's diverse approach to fall prevention and management. Revisions to enhance participants' technical capabilities and relatability of program materials are indicated.

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 the study was approved by the Human Research Protection Offices at the three collaborating sites: the University of Illinois Chicago (UIC), the University of Illinois Urbana-Champaign (UIUC), and the Shepherd Center (SC) in Atlanta, GA. The patients/participants provided their written informed consent to participate in this study.

Author contributions

TV: conceptualization and design, data analysis and interpretation, methodology, manuscript drafting, and revision. EP and LR: conceptualization and design, data analysis and interpretation, methodology, manuscript drafting and revision, funding acquisition, and supervision. AM, RY, SS, JK, and AS: data analysis and interpretation, methodology, manuscript review, and revision. All authors contributed to the article and approved the submitted version.

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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.

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Effectiveness of a mHealth intervention on hypertension control in a low-resource rural setting: A randomized clinical trial

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Background: Despite the increasing popularity of mHealth, little evidence indicates that they can improve health outcomes. Mobile health interventions (mHealth) have been shown as an attractive approach for health-care systems with limited resources. To determine whether mHealth would reduce blood pressure, promote weight loss, and improve hypertension compliance, self-efficacy and life quality in individuals with hypertension living in low-resource rural settings in Hubei, China.

Methods: In this parallel-group, randomized controlled trial, we recruited individuals from health-care centers, home visits, and community centers in low-resource rural settings in Hubei, China. Of 200 participants who were screened, 148 completed consent, met inclusion criteria, and were randomly assigned in a ratio of 1:1 to control or intervention. Intervention group participants were instructed to use the Monitoring Wearable Device and download a Smartphone Application, which includes reminder alerts, adherence reports, medical instruction and optional family support. Changes in the index of Cardiovascular health risk factors from baseline to end of follow-up. Secondary outcomes were change in hypertension compliance, self-efficacy and life quality at 12 weeks.

Results: Participants ($n = 134$; 66 in the intervention group and 68 controls) had a mean age of 61.73 years, 61.94% were male. After 12 weeks, the mean (SD) systolic blood pressure decreased by 8.52 (19.73) mm Hg in the intervention group and by 1.25 (12.47) mm Hg in the control group (between-group difference, −7.265 mm Hg; 95% CI, −12.89 to −1.64 mm Hg; $P = 0.012$), While, there was no difference in the change in diastolic blood pressure between the two groups (between-group difference, −0.41 mm Hg; 95% CI, −3.56 to 2.74 mm Hg; $P = 0.797$). After 12 weeks of follow-up, the mean (SD) hypertension compliance increased by 7.35 (7.31) in the intervention group and by 3.01 (4.92) in the control group (between-group difference, 4.334; 95% CI, 2.21 to −6.46; $P < 0.01$), the mean (SD) hypertension compliance increased by 12.89 (11.95) in the intervention group and by 5.43 (10.54) in the control group (between-group difference, 7.47; 95% CI, 3.62 to 11.31; $P < 0.01$), the mean (SD) physical health increased by 12.21 (10.77) in the intervention group and by 1.54 (7.18) in the control group (between-group difference, 10.66; 95% CI, 7.54–13.78; $P < 0.01$), the mean (SD) mental health increased by 13.17 (9.25) in the intervention group and by 2.55 (5.99) in the control group (between-group difference, 10.93; 95% CI, 7.74 to 14.12; $P < 0.01$).

Conclusions: Among participants with uncontrolled hypertension, individuals randomized to use a monitoring wearable device with a smartphone application had a significant improvement in self-reported hypertension compliance, self-efficacy, life quality, weight loss and diastolic blood pressure, but no change in systolic blood pressure compared with controls.

KEYWORDS

mHealth, hypertension, low-resource rural settings, randomized clinical trial, behavior intervention

Introduction

Hypertension is the most common chronic condition for cardiovascular and cerebrovascular events worldwide, affecting 32.6% of US adults, and has an estimated annual medical expenses exceeding $50 billion (1, 2). Worldwide, 422.7 million people diagnosis with cardiovascular disease (3), and causes 16.7 million deaths each year, 80% of which occur in low-income and middle-income countries (4). According to a recent investigation, in rural China, the control and control under-treatment rate of hypertension were only 8.6 and 19.8%, respectively (5). Decades of research have shown that even the modest reductions in blood pressure (BP) would reduce the premature mortality and the risk of associated morbidity (6). However, despite the widespread availability of well-tolerated, effective, and inexpensive drugs, approximately half of treated patients do not have well-controlled BP (7). Lack of patient engagement, poor medication adherence, and therapeutic inertia are major contributors to patients not reaching their recommended BP levels (8).

Many types of intervention methods have been conducted to improve therapeutic targets and BP control. Systematic reviews summarizing more than 3 decades of research advocate for specific lifestyle modifications in populations with high risk of cardiovascular disease (9, 10). In addition, improvement of patients' self-management, nurses and pharmacists have also been proved to be effective in hypertension control in team-based care (11, 12). However, in favor of lifestyle modifications for the reduction of cardiovascular disease risk is mostly restricted to trials done in high-income countries (13). Few trials have been done in low-income and middle-income countries, despite robust evidence supporting their effectiveness (14).

With the rapid rise and popularity in mobile phone use, mobile health (mHealth) could become a potential way to address several health-care system constraints in low and middle income countries, such as limited medical resources, overburdened health-care workforce, and an increasing prevalence of chronic diseases (4). In view of all these constraints, it is very challenging to extend the health care to difficult-to-reach populations. Strategies that depend on offering education, providing reminders for medication taking and refilling, or facilitating social interactions have been shown to increase physical activity, promote weight loss, encourage behavior change and improve patient-provider communication (15–17). In a systematic review, use of mobile apps and SMS messaging was found to improve physical health and reduce stress, anxiety, and depression, and the review showed using mobile apps and SMS text messaging as promising mHealth interventions (18). However, a systematic review (19) showed that m-health interventions had a positive effect on chronic diseases and also highlighted the need for more rigorous research in developing countries. Since, only 9 trials from low and middle-income countries were included in the analysis, and only 1 of them conducted in China.

In our research, we aimed to investigate whether mHealth including wearable monitoring device support home-based self-monitoring weekly counseling phone calls and advice for lifestyle modification could reduce BP, promote weight loss, and improve hypertension Compliance, self-efficacy and quality of life in adults with hypertension living in low-resource rural settings in China.

Methods

Study design

The Self-Monitoring Intervention Programme for Hypertension Control was a randomized trial conducted among 6 primary care centers within a remote mountainous districts of Hubei province, China. Details of the Program's study design and organizations have been published elsewhere (20).

All the selected primary care centers were located in a poor rural area and provided free medication and health care to hypertensive patients. Three centers were assigned to the mobile health intervention and the other 3 centers to usual health care. All participants were included consecutively to avoid selection bias. Given the nature of the behavioral intervention, no action was taken to balance the recruitment for individuals that refused consent.

Conceptual framework

We adopted an integrating of constructs adapted from the following conceptual models: the Task-Technology Fit (21), the Theory of Planned Behavior (22) and the Process Virtualization Theory (23). A generic schema of various factors are comprised in this conceptual framework. It includes 6 primary constructs (X_1-X_6): user friendly, high user benefit, remote monitoring, emergency contacts, unique identifiers And data security, timey feedback and 3 moderating constructs (Y_1-Y_3): representation, reach and security and privacy. The primary constructs have negative influence on Fit, while the 3 moderating constructs can moderate the potential negative effect of the 6 primary constructs (Figure 1).

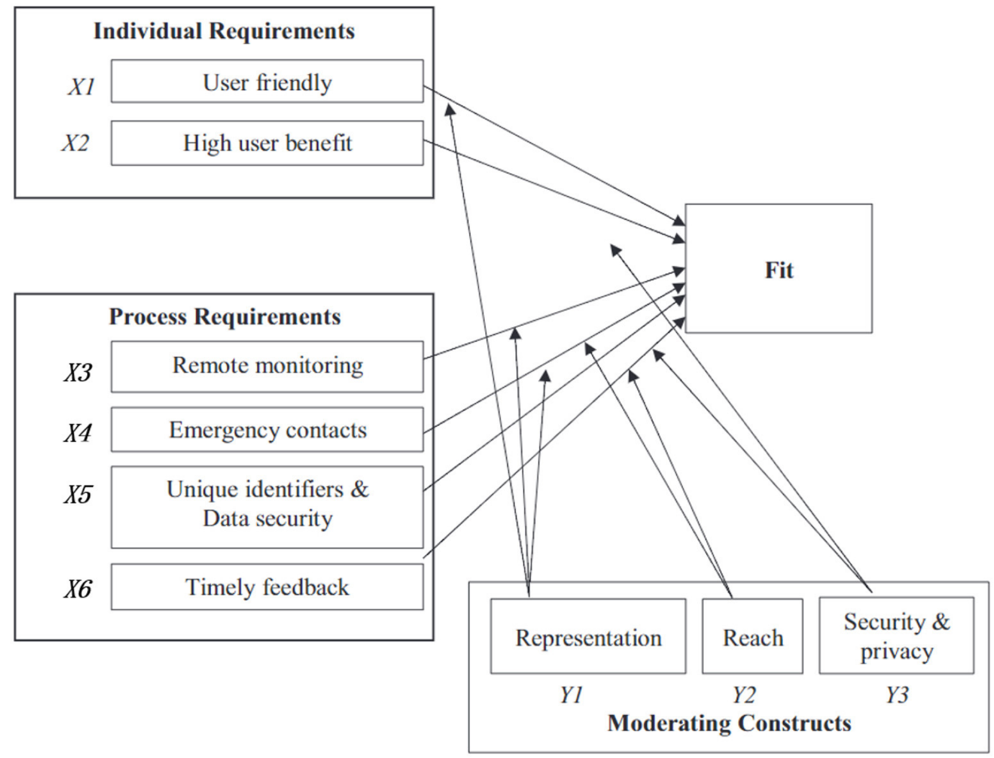

FIGURE 1
Conceptual framework for designing mHealth solutions.

Study population

Eligibility criteria were an age of more than forty, definite diagnosis of hypertension: Systolic blood pressure (SBP) ≥140 mmHg and/or Diastolic blood pressure (DBP) ≥90 mmHg or being treated with antihypertensive medication, no cognitive deficit and able to possess communication proficiency to carry out study tasks. Participants were excluded if they had cognitive dysfunction, developed serious health conditions that led to hospitalization or death, or had no smart phones to perform the mobile healthcare. Moreover, written informed consent was obtained from all participants during screening.

Study data were collected at baseline and at 12 weeks. The mHealth intervention program included education of healthcare providers, adherence to drug treatment, home-based lifestyle modification, and a mobile health intervention.

Patient recruitment and randomization

Participants were recruited though the cooperation of local Health and Family Planning Committee (HFPC), which composed of a diverse group of community leaders, township health centers personnel. These cooperative relationships were maintained with regular health advocacy meetings, face-to-face contact, and HFPC events, as described elsewhere (24). Potential participants were directed to local healthcare clinical centers to assess eligibility and to provide informed consent. Eligible participants completed a baseline measurements including BP, waist and hip circumference, height and weight, and a survey consisting of demographics, the Compliance of Hypertensive Patients' Scale (CHPS), self-efficacy, and quality of life. The CHPS is widely used tool for self-reported hypertension compliance scale that was found to be reliable (Cronbach's $\alpha = 0.80$) (25, 26). This study used the Hypertension Self-efficacy Scale original designed by Han (27) to evaluate the self-efficacy of patients. The test-retest reliability and content validity of the revised version were 0.87 and 0.92, respectively (28). Health-related quality of life was assessed using SF-12 which was a short alternative to the SF-36 (29). The SF-12 has been validated among hypertensive patients and the Cronbach's alpha was 0.801 in our study (30).

Upon receipt of the Bluetooth-enabled BP monitor, potentially eligible individuals were provided with a written instruction manual on how to set up the monitor and properly take a BP measuring. The BP monitor has been approved by BP associations for its accuracy in home use, as described elsewhere (31). Participants were recruited and randomized in a ratio of 1:1 to the control or intervention or using a random number generator. The study staff interacting with patients were not blinded to group assignment, while all the study investigators and data analysts remained blinded until the primary analytic strategies were finalized and all follow-up data were obtained.

Intervention

The mobile health intervention was the key element, with a complementary text messaging, BP warning, and home-visited intervention. The research team members, who were part of the staff of the local primary care centers, were trained in interactive intervention techniques, performing wearable device, measuring BP, providing life-style modification skills based on the Change Model Stages (32). The motivational training was conducted in a 1-day session, followed with onsite field testing. The research team members visited participants weekly in the first month and every other week thereafter. The mobile health system was developed and formulated though a consensus team including electronics technicians, health care physicians, pharmacists, and patient's family. It included monitoring wearable wristband, mHealth app and website.

All participants were given written information about hypertension and health promotion, and continued to receive routine hypertension management from local clinical centers. Each intervention group participants received a home-based BP monitor wearable wristband that stored and uploaded BP data to a secure website *via* Bluetooth, and then were instructed to transmit at least 1 BP measurements daily. During the first 1 week of the intervention, patients and medical staff of local health centers met everyday *via* telephone until BP measurements data was uploaded and sustained for the whole week, and then the frequency was reduced to weekly.

Using the model to develop a mHealth intervention

We conducted the mHealth intervention programmes under the guidance of the conceptual framework. Also, we adopted the same conceptual framework to design the intervention strategies which were similar in the constructs but different in detailed content of care needs for the two groups of patients. Table 1 presents examples how we delivered intervention strategies for hypertensive patients based on the conceptual model.

Follow-up assessment

Follow-up assessments were performed at baseline and 12 weeks after enrollment based on intention-to-treat principles for participants. Each assessment included BP measurement using the provided wearable BP monitor, measurement of waist and hip circumference, height and weight, and questionnaire survey.

Outcomes

The primary outcomes were change in SBP and DBP, and the co-primary outcomes were change in waist and hip circumference, height and weight. The second outcomes were change in self-reported CHPS, self-efficacy, and quality of life.

Ethical consideration

The study protocol was approved by the ethics committee of School of Health Sciences, Wuhan University in China (Ethical approval number: 2019YF2054). At the process of recruitment, clear explanations about the study objection were provided to all the participants and written informed consent was obtained.

Statistical analysis

According to the results of our protocol, after the mobile platform management, the BP compliance rate of patients was more than 70%. According to the epidemiological survey conducted by Lin (33) in 125 hospitals in 31 cities in China, the blood pressure compliance rate of outpatients with hypertension was 33.68%, with a conservative estimate of 40%. The parameters and calculation formula of sample size required for the comparison of two sample rates are as follows:

$$n = \left(\frac{\mu_\alpha + \mu_\beta}{\delta}\right) [\pi_1 (1 - \pi_1) + \pi_2 (1 - \pi_2)]$$

We sought to recruit at least 134 patients to have 90% power to detect a 5-mm Hg difference in SBP between treatment arms, with an α of 0.05.

We conducted our analyses according to intention-to-treat principles. Means and frequencies of baseline characteristics were calculated between two group differences despite randomization. The primary outcomes and the secondary outcomes were analyzed using univariate linear regression models. We defined statistical significance as $P < 0.05$ and did not adjust our *P-value* threshold for our outcomes, which we assumed would be correlated. In sensitivity analyses, we repeated our analyses for whom the whole complete outcome data were available. Also, we evaluated changes in BP measurements at baseline and the subsequent follow-up assessment using generalized estimating equations with autoregressive errors and an identity link function.

In subgroup analyses, we evaluated differential effects of the intervention on the outcomes with respect to gender, age, number of concomitant diseases, years of hypertension, baseline BMI, baseline hypertension compliance, baseline self-efficacy, and baseline SBP based on the statistical significance of the interaction term for the subgroup of interest in the multivariable model.

All data analyses were conducted using SAS software (version 9.4).

Results

Participants

From Nov 2017 to Jul 2018, we screened 200 participants, of whom 148 met eligibility criteria and randomly divided into two equal groups. Eight participants from the intervention group and 6 participants from the control group were lost to follow-up because they could not attend the scheduled meetings despite being contacted by research personnel. Therefore, 66 patients in the intervention group and 68 in the control group completed the final assessment at 12 weeks and were included in the intention-to-treat analysis.

TABLE 1 Use of the conceptual framework to design the mHealth intervention for participants.

Model element	Strategies included in intervention
Individual requirements	
User friendly (*X1*)	We kept the user interface as simple as possible with self-explaining navigation icons. Considering the remoteness of some villages where the internet is unavailable or weak, we made the app operate even without the internet.
High user benefit (*X2*)	The app can send reminder alerts for high BP and due medication to patients. The chat platform in the mHealth app can provide timely support or response from medical staff when patients report any alert signs. These interactive app functions can promote the initiative for app use.
Process requirements	
Remote monitoring (*X3*)	Considering the sensory requirements are costly and difficult to virtualize in remote mountains areas, we developed a separate chat platform where multimedia messaging is available.
Emergency contacts (*X4*)	Interaction between health care providers and patients is crucial for health concerns. Virtualization of face-to-face communication *via* video over Internet technology was not feasible in app settings due to high data consumption and limited bandwidth. For any situation that requires emergency medical care, we provided the phone numbers of contracted doctor.
Unique identifiers and Data security (*X5*)	Identification of patients, caregivers and medical care providers is crucial. The patients' mobile phones are the unique identifiers. Health care providers who registered in our mHealth app system have access to all the registered patients. All identifiers and patients' health demographics data security were protected through an encrypted mechanism.
Timely feedback (*X6*)	The patients were provided with website to log health information and free BP monitors which give timely feedback and real-time graphical display about blood pressure fluctuation. Subsequently, health care providers worked with patients to identify health goals and help them link to further health readings available on the website (eg, patient forums, diet advice, videos, and exercise advice).
Moderating constructs	
Representation (*Y1*)	Representation refers to the capability of mHealth chat platform to allow communication between patients and medical staff, moderating the potential negative impact of user friendly, remote monitoring and emergency contacts.
Reach (*Y2*)	Reach refers to the capability of mHealth to minimize the medical load and ensure the availability of health care at the fingertips at any time. Consequently, this construct moderate the emergency contacts and timely feedback.
Security and Privacy (*Y3*)	Security and privacy features of mHealth app system can ensure patients' trust in the application. Hence, this construct moderate high user benefit and timely feedback.

Baseline characteristics

Demographic and socioeconomic characteristics, systolic blood pressure (SBP), diastolic blood pressure (DBP), BMI, waist circumference (WC), hip circumference (HC), hypertension compliance, self-efficacy, physical health and mental health in the intervention group were similar to those of the control group participants (Table 2).

Blood pressure

At baseline, the mean (SD) SBP was 152.59 (23.44) mmHg in the intervention group and 148.85 (20.70) mmHg among controls. After 12 weeks of follow-up, the mean (SD) SBP decreased by 8.52 (19.73) mmHg in the intervention group and by 1.25 (12.47) mmHg in the control group (between-group difference, −7.265 mm Hg; 95% CI, −12.89 to −1.64 mm Hg; $P = 0.012$) (Table 3). While, there was no difference in the change in DBP between the two groups (between-group difference, −0.41 mm Hg; 95% CI, −3.56 to 2.74 mm Hg; $P = 0.797$).

Subgroup analyses of the association of the intervention with SBP by gender, age, number of concomitant diseases, years of hypertension, baseline BMI, baseline hypertension compliance and baseline self-efficacy showed no significant between-group differences, while was significant by baseline SBP ($P < 0.001$) (Table 3).

Waist and hip circumference

At baseline, the mean (SD) WC was 91.42 (12.92) cm in the intervention group and 90.37 (9.45) cm in the control group. After 12 weeks of follow-up, the mean (SD) WC decreased by 2.14 (2.61) cm in the intervention group and by 0.25 (0.61) cm in the control group (between-group difference, −1.89 cm; 95% CI, −2.53 to −1.25 cm; $P < 0.01$) (Table 3). While, there was no difference in the change in HC between the two groups (between-group difference, −0.30 cm; 95% CI, −0.63 to 0.04 cm; $P = 0.079$).

Hypertension compliance

At baseline, the mean (SD) hypertension compliance was 46.70 (6.69) in the intervention group and 46.46 (6.89) among controls. After 12 weeks of follow-up, the mean (SD) hypertension compliance increased by 7.35 (7.31) in the intervention group and by 3.01 (4.92) in the control group (between-group difference, 4.334; 95% CI, 2.21 to −6.46; $P < 0.01$) (Table 3).

Subgroup analyses of the association of the intervention with hypertension compliance by gender, age, number of concomitant diseases, years of hypertension, baseline BMI, baseline self-efficacy and baseline SBP showed no significant between-group differences, while was significant by baseline hypertension compliance ($P = 0.003$) (Table 4).

TABLE 2 Sociodemographic characteristics of participants ($N = 134$).

Characteristics	Intervention ($n = 66$)	Control ($n = 68$)	χ^2/t	*P*
Gender, no. (%)			2.149	0.158
Male	45 (68.18)	38 (55.88)		
Female	21 (31.82)	30 (44.12)		
Age, mean (SD), y	61.37 (11.73)	62.09 (10.66)	0.136	0.713
Ethnic, no. (%)			3.170	0.205
Han	15 (22.73)	25 (36.76)		
Tujia	28 (42.42)	23 (33.83)		
Others	23 (34.85)	20 (29.41)		
Marital status, no. (%)			1.337	0.366
Married	62 (93.94)	60 (88.24)		
Single	4 (6.06)	8 (11.76)		
Years of schooling, *y*			2.080	0.556
≤6	17 (25.76)	25 (36.76)		
7–9	10 (15.15)	8 (11.76)		
10–12	15 (22.73)	15 (22.06)		
≥13	24 (36.36)	20 (29.42)		
Years of hypertension, *y*			2.231	0.693
<1	8 (12.12)	11 (16.18)		
1–3	14 (21.21)	13 (19.12)		
3–5	10 (15.15)	7 (10.29)		
5–10	18 (27.27)	15 (22.06)		
>10	16 (24.24)	22 (32.35)		
Number of concomitant diseases, No. (%)			5.294	0.151
0	25 (37.88)	19 (27.94)		
1	20 (30.30)	33 (48.53)		
2	9 (13.64)	9 (13.24)		
≥3	12 (18.18)	7 (10.29)		
SBP, mean (SD), mmHg	152.59 (23.44)	148.85 (20.70)	−0.979	0.329
DBP, mean (SD), mmHg	92.85 (14.93)	91.34 (15.31)	−0.578	0.564
BMI, mean (SD), kg/m^2	25.55 (2.95)	25.99 (4.20)	0.701	0.485
WC, mean (SD), cm	91.42 (12.92)	90.37 (9.45)	−0.541	0.589
HC, mean (SD), cm	96.74 (8.81)	98.01(6.66)	0.945	0.347
Hypertension compliance, mean (SD)	46.70 (6.69)	46.46 (6.89)	−0.205	0.838
Self-Efficacy, mean (SD)	59.21 (10.44)	57.84 (11.70)	−0.716	0.475
Physical health, mean (SD)	41.68 (9.39)	40.12 (10.30)	−0.912	0.363
Mental health, mean (SD)	48.62 (11.09)	48.72 (9.87)	0.056	0.955

Self-efficacy

At baseline, the mean (SD) self-efficacy was 59.21 (10.44) in the intervention group and 57.84 (11.71) among controls. After 12 weeks of follow-up, the mean (SD) hypertension compliance increased by 12.89 (11.95) in the intervention group and by 5.43 (10.54) in the control group (between-group difference, 7.47; 95% CI, 3.62 to 11.31; $P < 0.01$) (Table 3).

TABLE 3 Primary and secondary outcomes.

Variable	Intervention group			Control group			Unadjusted effect estimate		Adjusted effect estimate	
	Wk 0	Wk 12	Change	Wk 0	Wk 12	Change	Absolute Difference	*P-value*	Absolute Difference	*P-value*
SBP, mmHg, mean (SD)	152.59 (23.44)	144.08 (14.19)	−8.52 (19.73)	148.85 (20.70)	147.6 (17.27)	−1.25 (12.47)	−7.265 (-12.89 to −1.64)	0.012	−0.82 (−4.19 to 2.55)	0.631
DBP, mmHg, mean (SD)	92.85 (14.94)	92.42 (14.12)	−0.42 (10.91)	91.34 (15.31)	91.32 (13.13)	−0.01 (7.19)	−0.41 (-3.56 to 2.74)	0.797	−7.20 (-13.12 to −1.27)	0.018
WC, cm, mean (SD)	91.42 (12.92)	89.29 (12.74)	−2.14 (2.61)	90.37 (9.45)	90.12 (9.34)	−0.25 (0.61)	−1.89 (−2.53 to −1.25)	<0.01	−1.84 (−2.53 to −1.17)	<0.001
HC, cm, mean (SD)	96.74 (8.81)	96.44 (8.87)	−0.30 (1.38)	98.01 (6.66)	98.01 (6.65)	−0.01 (0.04)	−0.30 (−0.63 to 0.04)	0.079	−0.32 (−0.67 to 0.03)	0.075
Hypertension compliance, mean (SD)	46.7 (6.69)	54.05 (5.17)	7.35 (7.31)	46.46 (6.89)	49.47 (5.62)	3.01 (4.92)	4.334 (2.210 to 6.46)	<0.01	3.92 (1.68 to 6.16)	0.001
Self-Efficacy, mean (SD)	59.21 (10.44)	72.11 (4.14)	12.89 (11.95)	57.84 (11.71)	63.26 (9.73)	5.43 (10.54)	7.47 (3.62 to 11.31)	<0.01	7.89 (3.81 to 11.98)	<0.001
Physical health, mean (SD)	49.52 (10.10)	61.72 (6.64)	12.21 (10.77)	49.59 (9.11)	51.13 (7.48)	1.54 (7.18)	10.66 (7.54 to 13.78)	<0.01	10.47 (7.72 to 13.22)	<0.001
Mental health, mean (SD)	41.68 (9.39)	54.85 (2.04)	13.17 (9.25)	40.12 (10.30)	42.67 (9.19)	2.55 (5.99)	10.62 (7.97 to 13.28)	<0.01	10.93 (7.74 to 14.12)	<0.001

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TABLE 4 Subgroup analyses of the difference between intervention and control from baseline to 12 weeks.

Subgroup	SBP difference between intervention and control groups (95% CI)	Interaction *P*-value	Hypertension compliance difference between intervention and control groups (95% CI)	Interaction *P*-value	Self-Efficacy difference between intervention and control groups (95% CI)	Interaction *P*-value	Physical health difference between intervention and control groups (95% CI)	Interaction *P*-value	Mental health difference between intervention and control groups (95% CI)	Interaction *P*-value
Gender		0.743		0.645		0.478		0.038		0.248
Male	−7.20 (-12.78 to −1.63)		4.43 (2.33 to 6.53)		7.61 (3.80 to 11.42)		10.20 (7.62 to 12.78)		10.46 (7.38 to 13.54)	
Female	−7.53 (-13.81 to −1.24)		3.94 (1.57 to 6.31)		6.89 (2.59 to 11.19)		12.35 (9.45 to 15.26)		11.50 (8.02 to 14.97)	
Age		0.420		0.126		0.903		0.788		0.078
At or below median	−5.75 (-11.38 to −0.13)		4.99 (2.88 to 7.11)		7.84 (3.94 to 11.74)		10.26 (7.57 to 12.95)		11.13 (7.97 to 14.28)	
Above median	-9.44 (-15.25 to -3.63)		3.38 (1.20 to 5.57)		6.93 (2.90 to 10.97)		11.14 (8.36 to 13.92)		9.99(6.73 to 13.26)	
Number of concomitant diseases				0.068		0.097		0.353		
0		0.092								0.774
1	−8.56 (-14.51 to −2.81)		3.56 (1.39 to 5.74)		8.52 (4.53 to 12.51)		10.22 (7.44 to 12.99)		10.67 (7.41 to 13.94)	
2	−7.02 (-13.42 to −0.63)		3.64 (1.27 to 6.01)		7.71 (3.35 to 12.07)		10.65 (7.62 to 13.69)		11.15 (7.58 to 14.72)	
≥ 3	−5.68 (-11.67 to 0.31)		5.46 (3.24 to 7.68)		6.14 (2.06 to 8.68)		11.10 (8.26 to 13.94)		10.50 (7.16 to 13.85)	
Years of hypertension		0.111		0.636		0.921		0.867		0.092
<1	−1.06 (−8.22 to 6.10)		6.99 (4.30 to 9.67)		11.15 (6.23 to 16.06)		8.58 (5.16 to 12.01)		9.60 (5.55 to 13.66)	
1–3	−7.80 (-13.57 to −2.20)		3.99 (1.83 to 6.16)		6.47 (2.51 to 10.43)		10.73 (7.97 to 13.49)		10.35 (7.08 to 13.62)	
3–5	−7.82 (-13.50 to −2.10)		4.20 (2.07 to 6.33)		7.75 (3.84 to 11.65)		10.87 (8.15 to 13.59)		11.11 (7.89 to 14.33)	
5–10										
>10										
Baseline BMI		0.950		0.475		0.317		0.215		0.163

(Continued)

TABLE 4 (Continued)

Subgroup	SBP difference between intervention and control groups (95% CI)	Interaction *P*-value	Hypertension compliance difference between intervention and control groups (95% CI)	Interaction *P*-value	Self-Efficacy difference between intervention and control groups (95% CI)	Interaction *P*-value	Physical health difference between intervention and control groups (95% CI)	Interaction *P*-value	Mental health difference between intervention and control groups (95% CI)	Interaction *P*-value
<18.5	−15.48 (-47.84 to 16.87)		23.01 (10.93 to 35.08)		51.53 (30.16 to 72.90)		11.79 (-3.79 to 27.31)		22.24 (3.91 to 40.57)	
18.5–24.9	−8.11 (-13.82 to −2.39)		4.47 (2.34 to 6.60)		8.19 (4.41 to 11.96)		11.38 (8.64 to 14.12)		11.21 (7.97 to 14.44)	
≥ 25	−5.58 (-11.28 to 0.11)		4.95 (2.83 to 7.08)		8.41 (4.65 to 12.17)		9.79 (7.06 to 12.52)		10.43 (7.21 to 16.36)	
Baseline Hypertension compliance		0.583		0.003		0.445		0.514		0.905
At or below median	−5.31 (−11.42 to 0.81)		7.30 (5.27 to 9.33)		12.19 (8.38 to 16.00)		9.91 (7.01 to 12.81)		10.43 (7.01 to 13.85)	
Above median	−7.89 (−13.45 to −2.34)		3.38 (1.54 to 5.23)		5.95 (2.49 to 9.41)		10.85 (8.22 to 13.48)		10.74 (7.63 to 13.84)	
Baseline Self-Efficacy		0.328		0.060		<0.001		0.793		0.926
At or below median	−5.08 (−13.32 to 1.16)		6.84 (4.64 to 9.05)		14.58 (11.11 to 18.06)		10.27 (7.30 to 13.24)		10.81 (7.33 to 14.31)	
Above median	−7.80 (−13.33 to 7.62)		3.73 (1.77 to 5.68)		5.74 (2.66 to 8.83)		10.71 (8.08 to 13.34)		10.62(7.53 to 13.72)	0.416
Baseline SBP		<0.001		0.684		0.842		0.712		
≤ 160 mmHg	−2.72 (−7.04 to 1.61)		4.54 (2.41 to 6.67)		7.77 (3.91 to 11.63)		10.55 (7.88 to 13.22)		10.80 (7.66 to 13.94)	
>160 mmHg	−17.29 (-21.98 to −12.61)		3.89 (1.58 to 6.20)		6.81 (2.62 to 10.99)		10.79 (7.89 to 13.68)		10.36 (6.96 to 13.76)	

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Subgroup analyses of the association of the intervention with self-efficacy by gender, age, number of concomitant diseases, years of hypertension, baseline BMI, baseline hypertension compliance and baseline SBP showed no significant between-group differences, while was significant by baseline self-efficacy ($P < 0.001$) (Table 4).

Quality of life

At baseline, the mean (SD) physical health was 49.52 (10.10) in the intervention group and 49.59 (9.11) in the control group, and the mean (SD) mental health was 41.68 (9.39) in the intervention group and 40.12 (10.30) in the control group. After 12 weeks of follow-up, the mean (SD) physical health increased by 12.21 (10.77) in the intervention group and by 1.54 (7.18) in the control group (between-group difference, 10.66; 95% CI, 7.54 to 13.78; $P < 0.01$), the mean (SD) mental health increased by 13.17 (9.25) in the intervention group and by 2.55 (5.99) in the control group (between-group difference, 10.93; 95% CI, 7.74–14.12; $P < 0.01$) (Table 3).

Subgroup analyses of the association of the intervention with mental health by age, number of concomitant diseases, years of hypertension, baseline BMI, baseline hypertension compliance, baseline self-efficacy, and baseline SBP showed no significant between-group differences, while was significant by gender ($P = 0.038$) (Table 4). While, Subgroup analyses of the association of the intervention with mental health by all of them showed no significant between-group differences (Table 4).

Discussion

To our knowledge, this study is the first randomized controlled trial to assess mHealth intervention to improve cardiovascular factors and promote healthier lifestyle behaviors among individuals at high risk of cardiovascular disease in low-resource rural settings in China. This study aimed to evaluate the effects of mobile phone-based intervention on BP control, waist and hip circumference, self-reported hypertension compliance, self-efficacy, and quality of life. Our findings show that compared with local usual primary care, mHealth BP monitoring intervention resulted in significant improvements in SBP and other cardiovascular factors. Compared with usual community-based management of hypertension patients, mHealth intervention patients had greater controlled SBP, waist and hip circumference. Moreover, the intervention also improved some aspects of self-reported hypertension compliance and self-efficacy, and appeared to have an acceptable level of quality of life.

The results of this randomized control trial showed that the wearable BP wristband and app-based management could decreased SBP by 8.52 (19.73) mm Hg (95% CI, −12.89 to −1.64 mm Hg; $P = 0.012$), which showed similar treatment effects of medication treatment. A recent meta-analysis (34) that analyzed 14 RCTs showed that intensive BP-lowering medication treatment could decrease SBP by an additional 8.3 mmHg (95% CI: 2.1–14.1 mmHg), which could resulted in 14% reduction of cardiovascular disease (CVD) risk. In line with our findings, a RCT on 1,372 hypertension patients reported that mobile phone text messages could resulted in a small reduction in SBP compared with usual care after 12 months intervention (6). Also, it was reported that observations, including in-person visits, telephone support, and text messaging may have important implications when conducting internet-based interventions (35, 36). So we added mobile devices, including phone calls, short message service, face-to-face communication *via* video and in-person visits as our intervention methods. However, according to our literature review, there is no clear explanation for the different intervention results of the SBP and DBP.

Unique features of our study were the significant improvement in self-reported hypertension compliance and self-efficacy with corresponding reductions in SBP. In our study, readings from the home-based BP monitoring wearable devices were used to evaluate trial outcomes. A possible explanation might be that the reductions in BP from baseline to the 12 weeks of follow-up that we observed in both the control and intervention group were resulted from fluctuations in these home BP monitoring readings, and that the magnitude of these fluctuations was larger than the hypothesized effect from the smartphone application (37). Hence, all participants were engaged in some level of self-monitoring. In this respect, the home-based BP monitoring intervention have significant positive effects on BP control (38), hypertension compliance (6) and self-efficacy (39) and may have been particularly motivating for the patients in our trial.

It is interesting to note a net reduction in the waist circumference, while, no changes were seen in levels of hip circumference. It might be related to the amount of exposure to the intervention domains defined by the patients during motivational suggestion, following the autonomy support on the basis of principle. Thus, target behavior including reduction of high-sugar and high-fat foods intake was most commonly chosen during motivational home visit or counseling calls. In line with our findings, Partridge et al. (40) conducted a 12-week mHealth prevention program, with weekly goal setting to prevent weight gain and improve lifestyle behaviors among overweight young adults.

How could home-based BP monitoring wearable devices enhance the quality of life for patients with hypertension? While the wearable devices we tested has received high usability scores? It may be the reason that patients with hypertension in low-resource rural settings have needs that differ from those with other conditions (20, 24). Therefore, smart tools shown greater effects on clinical outcomes when they linked with additional support, especially though connection to health care professionals (41). Meanwhile, it seems the individuals would be highly adherent to their hypertension compliance to derive clinical benefits (42). If the highly adherent from the intervention could persist more than 12-week duration of our trial, it may be possible that we could have observe more significant life quality improvements with longer follow-up. Finally, quality of life was measured by self-report. Although, the SF-12 questionnaires has been validated and extensively used, self-reported tools are difficult to avoid social desirability bias and may overestimate true condition (43). As such, after exposure to a home-based BP monitoring device that very clearly encouraged adherence, intervention group participants may have been more likely to report higher level life quality without actually changing their physical or mental health condition.

Several limitations should be considered of this trial. The sample size was small and included only 6 primary care centers, and excluded those had no smartphones, which may contributed discrepancies in participant baseline characteristics and lack of power to detect differences of the secondary and subgroup analyses outcomes between two groups. Also, the hypertension compliance, self-efficacy and SF-12 questionnaires were all self-reported measurements, therefore we cannot conclude the findings to a broader population. In addition, the trial was not double-blinded, which may lead to an effect on the reporting bias such as recall error, social desirability or other subjective outcomes. However, BP recordings were measured by automated wearable devices with a standard protocol, which was unlikely to have been biased. Lack of information on long-term intervention effects, reimbursement mechanisms, and return on investment have been revealed as barriers to trail implementation (44). Future studies should be conducted to address these issues when a planned long-term follow-up study.

Conclusions

Despite the popularity of smartphone health-related apps has increased quickly, there has been a lack of rigorous studies which including a clinically important outcome (45, 46). Our trial, to our knowledge, is one of the first randomized clinical studies using a conceptual framework (47), reporting the effect of a stand-alone mHealth platform to improve DBP control and increase hypertension compliance, self-efficacy and life quality. We found mHealth platform was safe and effective for promoting hypertension compliance, self-efficacy, life quality and DBP control, but no difference in SBP between the control and intervention groups during 12 weeks. If these finding are found to be stable and cost-effective during an even longer intervention period, it should spur wider testing and dissemination of similar alternative platform to manage hypertension and other chronic conditions.

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 the Ethics Committee of the School of Public Health, Wuhan University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

ZY conceived the study and completed the original draft preparation. ZY and TX collected data. TX provided the recruitment resources. WQ reviewed, edited the final draft, and received the funding. All authors contributed to the article and approved the submitted version.

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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.

Publisher's note

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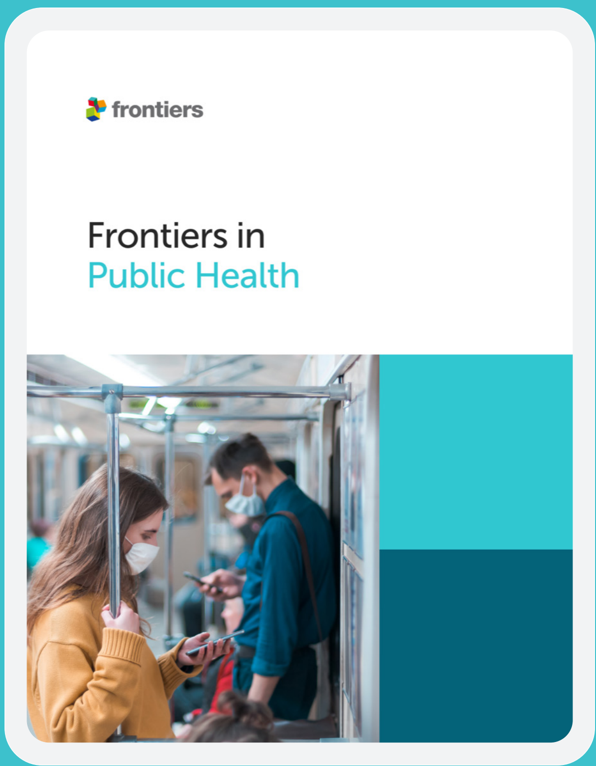

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