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EDITED AND REVIEWED BY
Federico Giove,
Centro Fermi–Museo storico della fisica e Centro studi e ricerche Enrico Fermi, Italy

*CORRESPONDENCE
T. Beyer,
thomas.beyer@meduniwien.ac.at

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Editorial: Editor's challenge in medical physics and imaging: quantitative medical imaging

T. Beyer[1]* and E. V. Moser[2]

[1]QIMP Team, Center for Medical Physics and Biomedical Engineering, Medical University of Vienna, Vienna, Austria, [2]Center for Medical Physics and Biomedical Engineering, Medical University of Vienna, Vienna, Austria

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Editorial on the Research Topic
Editor's challenge in medical physics and imaging: quantitative medical imaging

In the realm of modern healthcare, the importance of timely and accurate diagnosis cannot be overstated. The advent of various diagnostic modalities has revolutionized patient management, particularly through the use of non-invasive, medical imaging. While effective for straightforward diagnostic tasks, such as identifying fractures or lesions, these methods faced also limitations with the increasing complexity of imaging modalities and the breadth of diagnostic information they provide. The integration of quantitative parameters has significantly enhanced the precision and reliability of medical imaging [1]. Quantitative imaging encompasses measurements of size, density, metabolic and functional parameters, among others, which contribute to more robust and standardized diagnostic assessments.

With the launch of this Editor's Challenge in late summer of 2022, we sought to provide a forum for imaging researchers to present fundamental concepts of quantification within their chosen imaging modalities. We did encourage explorations of the inherent limitations of quantification, such as spatial resolution, contrast, sensitivity, and robustness, in both clinical and research applications. In addition, we sought discussions on strategies to enhance counting statistics, improve signal-to-noise ratios, and develop methodological and algorithmic advancements that yield more reliable quantitative data. The topics of interest included: 1) Fundamentals of quantitative imaging, 2) Algorithmic updates and corrections for deriving quantitative data, 3) Quantitative capabilities across various imaging modalities, 4) Emerging trends to advance the limits of quantification, 5) Utilization of quantitative data in diagnostic and therapeutic contexts, and 6) Incorporation of validated artificial intelligence into quantitative diagnostics.

As always, when soliciting contributions to special issues in journals, initial interest is high while actual contributions come in lower quantities (sic). As it was the case with this challenge. Over the course of 18 months, we received 20 indications of full submissions, of which 16 panned out. All submissions went to peer-review and ultimately, 10 manuscripts have been accepted for inclusion in this Research Topic on Quantitative Medical Imaging. Despite the relatively small number of submissions, it is encouraging to see that the breadth of the papers did cover the range of topics laid out as part of this initiative, and we like to thank all authors for their valuable contributions.

Kumar et al. evaluate the feasibility of using a benchtop X-ray fluorescence (XRF) imaging system for high-resolution, quantitative imaging of tumour models. The study employs a 3D breast cancer model and investigates the use of metallic contrast agents. Results demonstrate the system's capability for detailed spatiotemporal localization of nanoparticles, offering potential for pre-clinical studies and enhanced understanding of cancer pathophysiology.

Hagberg et al. present a study on the use of iron-filled hydrogel clusters as phantoms for quantitative susceptibility mapping (QSM) in MRI. They validate the magnetic properties of these clusters, demonstrating their suitability as model systems for QSM. The phantoms mimic tissue properties and provide a reproducible means for calibrating MRI scanners, potentially improving the accuracy of susceptibility measurements in clinical settings.

Berg and Börner describe the design and development of a resolution phantom using Deep X-ray Lithography (DXRL) for high-resolution MRI and microscopy. Their proposed phantom features grids with varying spatial periods and orientation to assess and improve spatial resolution in the micrometer range. The phantom design aims to enhance quality control and performance in ultra-high-field MRI scanners, contributing to advancements in microimaging techniques. Furthermore, such phantoms might be used also in micro-CT and Optical Coherence Tomography.

Bibiano et al. introduces a novel model-based fitting approach for T_1 mapping in MRI, eliminating the need for waiting times between inversion pulses. The method combines inversion-prepared and unprepared measurements, enabling faster and more accurate T_1 mapping. Validation with phantom and volunteer data demonstrate that the new approach yields T_1 values closely matching reference methods, making it a promising technique for efficient and robust tissue characterization in clinical MRI.

Guidi et al. discuss the advancements in MRI-derived cerebrovascular reactivity (CVR) mapping for assessing vascular dysfunction in brain diseases. The study advocates for high-resolution imaging to better characterize microvascular alterations. By using novel MRI sequences and mild hypercapnic challenges, they were able to improve the spatial specificity of hemodynamic and metabolic measurements, providing deeper insights into neurovascular impairments associated with conditions, such as hypertension and Alzheimer's disease.

Moving on to Computed Tomography (CT), Chung et al. review the principles and clinical applications of CT perfusion (CTP) imaging, focusing on kinetic modelling and diagnostic interpretation. Their paper details the technical considerations for accurate quantitative imaging and discusses the use of CTP in stroke, cancer, and cardiovascular disease. The authors emphasize future research directions, including dose reduction strategies and advancements in CT hardware, to enhance the diagnostic utility of CTP.

Exploring dynamic and parametric imaging in the context of molecular imaging, Khamwan et al. assess 18F-FDG-PET imaging to localize seizure onset zones in drug-resistant epilepsy (DRE) patients. Their findings suggest that parametric approaches may offer superior sensitivity compared to traditional methods, aiding in the accurate localization of seizure origins for effective surgical intervention.

Wanek et al. investigate the distribution of the radiotracer [18F] THK-5317 in preclinical mouse models with tau pathology. Their study highlights sex, age, and strain-related differences in radiotracer uptake across various organs. The authors underscore the significance of incorporating the 3Rs principles (Replacement, Reduction, and Refinement) in preclinical imaging, and suggest that organ-to-blood concentration ratios can serve as effective quantitative parameters for radiotracer studies.

Staying in the field of PET, but moving from pre-clinical to clinical studies, Ferrara et al. examine the potential of low-dose (LD) [18F] FDG-PET/CT imaging protocols in reducing radiation exposure while maintaining diagnostic image quality. Their research involved 19 healthy controls and seven lung cancer patients, comparing LD and standard-dose (STD) imaging. Results indicated that mean standardized uptake values (SUVBW) were similar between LD and STD conditions, except in the heart. Although LD imaging showed increased noise, especially in cancer lesions, the study supports the feasibility of LD-PET/CT for studying multi-organ metabolic patterns in non-oncological contexts.

A major obstacle to PET-based quantification is involuntary patient motion. Tumpa et al. explore the application of deep learning for head motion correction in PET imaging. The proposed neural network effectively registers image volumes, reducing motion artifacts and improving quantification accuracy. The study highlights the potential of deep learning to enhance PET image quality and facilitate more accurate diagnostic assessments in clinical practice.

In conclusion, quantitative imaging represents a transformative advancement in the field of medical diagnostics. This is attested by the selected manuscripts in response to our challenge. By providing objective and reproducible measurements, quantification enhances the accuracy and consistency of diagnostic interpretations, supporting more informed clinical decision-making potentially leading to novel biomarkers. As medical imaging technologies continue to evolve, the integration of quantitative parameters will further refine diagnostic capabilities, enabling early detection and precise monitoring of various diseases. The ongoing research and innovations in this domain underscore the critical role of quantification in achieving better patient outcomes and advancing the frontiers of medical science.

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