Rong and Liu *BMC Methods* (2024) 1:10
https://doi.org/10.1186/s44330-024-00010-7

BMC Methods

EDITORIAL

Open Access

Advances in medical imaging techniques

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Abstract

Medical imaging techniques play a crucial role in diagnosing major diseases such as cardiovascular diseases, cancers, and neurological disorders. The *BMC Methods* Collection "Advances in medical imaging techniques" will showcase the latest advancements in this field, including state-of-the-art imaging modalities, novel biomedical applications, progress in molecular probes and radiopharmaceuticals, and innovative methodologies for image analysis, data fusion, and visualization.

Main text

The discovery of X-rays by Wilhelm Conrad Röntgen in 1895 marked a turning point in medicine, providing the first glimpse into the inner workings of the human body [1]. Since then, medical imaging has evolved rapidly, with the development of diverse modalities like ultrasound, X-ray computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and single-photon emission computed tomography (SPECT). Today, medical imaging is indispensable in healthcare, enabling early disease detection, guiding treatment decisions, and monitoring patient progress.

Recent years have witnessed remarkable technological and methodological advancements in medical imaging, enhancing our ability to diagnose and monitor diseases with greater accuracy and efficiency. The *BMC Methods* Collection "Advances in medical imaging techniques" (https://www.biomedcentral.com/collections/amit), compiles original methodology and protocol articles on the latest developments in medical imaging, covering advances in imaging modalities, biomedical applications, molecular probes, radiopharmaceuticals, and data and image processing.

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Medical imaging techniques

Each medical imaging technique offers unique strengths and applications. X-ray computed tomography (CT) utilizes multiple X-ray images to create detailed three-dimensional images, albeit with higher radiation exposure [2]. Ultrasound imaging, considered safe and often used during pregnancy, excels in visualizing soft tissues [3]. Magnetic resonance imaging (MRI) provides high-resolution images of soft tissues without ionizing radiation, making it invaluable for diagnosing conditions in the brain, spinal cord, and musculoskeletal system [4]. Positron emission tomography (PET) and single-photon emission computed tomography (SPECT) are nuclear medicine techniques that employ radioisotope-labeled probes to visualize biological processes at the molecular level, playing a crucial role in cardiology, oncology, and neurology [5, 6].

Latest technological and methodological advances

Medical imaging continues to evolve rapidly, driven by technological and methodological innovations, revolutionizing diagnostic capabilities and patient care across the globe.

Technological innovations have led to the development of hybrid imaging modalities such as PET/CT, PET/MRI, and SPECT/CT, which integrate anatomical and functional data for more precise disease detection and treatment monitoring. For example, PET/CT is widely used in cancer imaging to simultaneously reveal metabolic activity and structural details, improving the accuracy of tumor detection and treatment monitoring [5].

The integration of artificial intelligence (AI) and machine learning (ML) in medical imaging has also revolutionized image analysis. AI algorithms enhance image quality, facilitate early diagnosis, and predict disease progression by analyzing vast amounts of data quickly and accurately. Explainable AI (XAI) in deep learning-based medical image analysis helps clinicians and researchers understand how AI systems arrive at their conclusions, ensuring transparency and reliability in clinical decision-making [7]. To address AI's rapid evolution in medical imaging, the Checklist for Artificial Intelligence in Medical Imaging (CLAIM) has also been updated in 2024, to promote consistent reporting of scientific advances of AI in medical imaging, build trust in published results and enable clinical translation [8].

Developments in molecular probes and radiopharmaceuticals have broadened the horizons of nuclear imaging techniques. Innovations in ^{11}C-, ^{18}F-, ^{13}N-, and ^{15}O-labeling reactions have led to more specific and sensitive PET radiopharmaceuticals, crucial for detecting and monitoring various diseases at the molecular level [9].

In the realm of MRI technology, continual advancements, including higher field strengths and functional imaging techniques, have improved the spatial and temporal resolution of images. Innovations in functional MRI (fMRI) and diffusion tensor imaging (DTI) provide insights into brain connectivity and function, aiding in the diagnosis and treatment of neurological disorders [4].

Lastly, the 3D printing of organs from MRI and CT scans allows for precise surgical planning and personalized treatment strategies [10].

Future challenges and perspectives

Despite these advancements, several challenges remain in the field of medical imaging.

One major challenge is the standardization and integration of various imaging modalities into a cohesive diagnostic workflow. Establishing uniform imaging protocols and improving interoperability among different imaging systems are essential for enhancing diagnostic accuracy and workflow efficiency across different healthcare settings. Additionally, the increasing volume and complexity of imaging data demands advancements in data management and analysis. The integration of AI technologies into clinical practice presents ongoing challenges, including ensuring robustness, reliability, and addressing ethical concerns in decision-making processes.

Enhancing the sensitivity and specificity of imaging modalities to detect diseases earlier and with reduced invasiveness remains a critical area for improvement. Advances in molecular imaging and the development of novel contrast agents hold promise in achieving this goal. Meanwhile, reducing radiation exposure, especially in pediatric imaging, is a continuous challenge. Ongoing research in low-dose imaging techniques and non-ionizing methods is essential to mitigate the risks associated to this imaging method [11].

Moreover, expanding the applications of medical imaging into new areas, such as imaging pathogenic proteins like α-synuclein in Parkinson's disease, is crucial for advancing disease diagnosis and treatment. Research efforts focused on developing specific molecular probes for new targets are expected to have a significant impact [12].

Conclusions

Collaborative efforts between researchers, clinicians, and industry partners will be crucial in overcoming these challenges and ultimately advancing healthcare delivery worldwide.

We encourage researchers to submit their work to our new collection, contributing to the ongoing advancement of medical imaging.

Abbreviations

CT	X-ray computed tomography
MRI	Magnetic resonance imaging
PET	Positron emission tomography
SPECT	Single-photon emission computed tomography
fMRI	Functional magnetic resonance imaging
DTI	Diffusion tensor imaging
3D	Three-dimensional
AI	Artificial intelligence
ML	Machine learning
XAI	Explainable artificial intelligence
CLAIM	Checklist for artificial intelligence in medical imaging

Acknowledgements

Not applicable.

Authors' contributions

JR and YL wrote the manuscript. All authors read and approved the final manuscript.

Authors' information

J. R. is a Research Scientist at Emory University. His research interests include the labeling of radioisotopes and the development of novel radiopharmaceuticals for positron emission tomography (PET). He earned his PhD in Organic Chemistry with Professor Jinbo Hu at the Shanghai Institute of Organic Chemistry (SIOC), Chinese Academy of Sciences (CAS) in 2017. His doctoral research focused on the synthesis of fluorinated compounds. Following that, he pursued his postdoctoral research in ^{18}F-labeling and neuroimaging with Professor Steven H. Liang at Massachusetts General Hospital (MGH) and Harvard Medical School (HMS). In 2022, he joined Emory University and continued his research in radioisotope labeling and radiopharmaceutical development for PET imaging and radiotherapy.

Y. L. is a Professor of Radiology at the University of Nebraska Medical Center. The goals of his research include developing noninvasive imaging biomarkers for the diagnosis, disease progression monitoring, and therapeutic assessment of neurodegenerative disorders, stroke, and brain tumors in small animals. His current projects include MRI measurements of pharmacokinetics and biodistribution of antiretroviral drugs and in vivo imaging of neuroimmune dysfunction associated with ARV and drug abuse. To achieve these goals, his lab has developed innovative imaging and image analysis techniques.

Funding
Not applicable.

Availability of data and materials
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
J.R. and Y.L. serve as guest editors of the BMC Methods Collection "Advances in medical imaging techniques". J.R. is also serving as an editorial board member of BMC Methods.

Received: 5 July 2024 Accepted: 22 July 2024
Published online: 01 August 2024

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