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Perspective

Multimodal Medical Imaging Approaches in Oncology and Tumor Detection

Linpei Jia*

National Institutes for Quantum and Radiological Science and Technology. Capital Medical University, Beijing, China

DESCRIPTION

Oncology, the study and treatment of cancer, relies heavily on accurate diagnostic tools for detecting, characterizing and monitoring tumors. Medical imaging has become a cornerstone in cancer management, providing non-invasive methods to visualize internal structures and assess disease progression. Traditional imaging modalities such as X-ray, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET) and ultrasound each offer unique advantages, but also possess inherent limitations in sensitivity, resolution, or functional assessment. To overcome these constraints, multimodal medical imaging approaches have emerged, combining two or more imaging techniques to enhance tumor detection, improve diagnostic accuracy and guide personalized treatment strategies.

Multimodal imaging leverages the complementary strengths of different modalities. For example, CT provides high-resolution anatomical information, allowing precise localization of tumors and structural assessment of organs. MRI, on the other hand, offers superior soft tissue contrast and can characterize tissue composition, enabling differentiation between benign and malignant lesions. PET imaging adds a functional perspective by detecting metabolic activity, often using radiotracers such as Fluorodeoxyglucose (FDG) to highlight hypermetabolic cancerous tissues. By integrating anatomical and functional data, multimodal imaging provides a more comprehensive understanding of tumor biology, aiding clinicians in both diagnosis and treatment planning.

One widely adopted multimodal approach is PET/CT, which combines the functional imaging capabilities of PET with the detailed anatomical mapping of CT. PET/CT is particularly effective in oncology because it enables precise localization of metabolically active tumors, detection of metastatic lesions and monitoring of treatment response. For instance, in lung cancer, PET/CT allows clinicians to distinguish malignant nodules from benign structures, guide biopsy procedures and assess therapy effectiveness over time. Similarly, PET/MRI has emerged as a valuable tool in brain, prostate and pediatric cancers, combining the functional and molecular insights of PET with MRI's superior soft tissue contrast while reducing radiation exposure compared to CT-based techniques.

Multimodal imaging also includes hybrid approaches beyond PET-based systems. Ultrasound combined with MRI or CT, for example, is used in liver and breast tumor assessment. Contrast-enhanced ultrasound can highlight vascular patterns in tumors, while MRI provides detailed tissue characterization. Optical imaging techniques, such as fluorescence imaging, are sometimes integrated with MRI or CT to improve intraoperative tumor visualization, guiding surgeons during resection and ensuring clear margins. Such combinations enhance both preoperative planning and real-time intraoperative decision-making, improving patient outcomes.

Another major advantage of multimodal imaging lies in its role in personalized oncology. Tumors vary widely in their anatomical, cellular and metabolic properties and a single imaging modality may not capture all relevant aspects. By combining structural, functional and molecular imaging, clinicians can gain insights into tumor heterogeneity, aggressiveness and response to therapy. Advanced image analysis techniques, including machine learning and radiomics, further extract quantitative data from multimodal images, enabling prediction of treatment outcomes, risk stratification and optimization of therapy regimens modified to individual patients.

Despite its numerous benefits, multimodal imaging faces several challenges. High costs, complex imaging equipment and the need for expert interpretation limit accessibility in some healthcare settings. Additionally, integrating data from multiple modalities requires sophisticated software, accurate image registration and careful calibration to avoid misalignment artifacts. Radiation exposure, particularly in PET/CT, is also a concern, necessitating strategies to minimize dose while maintaining diagnostic quality. Nevertheless, technological advancements, such as faster scanners, improved radiotracers, AI-assisted image analysis and hybrid imaging platforms, are steadily addressing these limitations.

Multimodal imaging continues to play a transformative role in oncology, not only improving tumor detection and staging but

Correspondence to: Linpei Jia, National Institutes for Quantum and Radiological Science and Technology. Capital Medical University, Beijing, China, E-mail: anny_069@163.com

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also enhancing monitoring of treatment efficacy and early detection of recurrence. By combining anatomical, functional and molecular information, clinicians can make more informed decisions, reduce unnecessary procedures and deliver targeted therapies with greater precision. Future directions include the integration of novel imaging agents, advanced computational models and real-time image-guided interventions, which will further refine cancer diagnosis and personalized care.

CONCLUSION

In conclusion, multimodal medical imaging represents a critical advancement in oncology, offering comprehensive visualization of tumors by merging complementary imaging techniques. These approaches enhance diagnostic accuracy, support personalized treatment planning and improve patient outcomes by combining anatomical, functional and molecular insights. As technology continues to evolve, multimodal imaging is poised to become an even more powerful tool in cancer management, guiding clinicians toward precise, effective and individualized therapies while shaping the future of oncological care.