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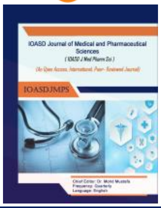

Integrating CT and MRI in Cancer Staging and Treatment Monitoring: Challenges and Innovations

Urooj Fatima[1], Saqib Zameer[2], Zeeshan Akram[1], Mohd Faraz[1], Areeb Daniyal[1], Zarrin Anwar[1], Kashif Abbas[3], Mudassir Alam[4*]

[1]Department of Radiodiagnosis, Paramedical College, Faculty of Medicine, Aligarh Muslim University, Aligarh, Uttar Pradesh, India
[2]Department of Microbiology, Paramedical College, Faculty of Medicine, Aligarh Muslim University, Aligarh, Uttar Pradesh, India
[3]Department of Zoology, Faculty of Life Sciences, Aligarh Muslim University, Aligarh, Uttar Pradesh, India
[4]Indian Biological Sciences and Research Institute (IBRI), Noida, India

Corresponding Author: Mudassir Alam
Indian Biological Sciences and Research Institute (IBRI), Noida, India.

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ABSTRACT

Imaging technologies such as computed tomography (CT) and magnetic resonance imaging (MRI) are widely used to identify and monitor cancer patients. Although CT and MRI are based on structural or anatomical abnormalities to identify disease, some advanced MRI techniques can identify cancer by analyzing chemical changes occurring within the tumor. Radiological early diagnosis makes timely action possible, essential for improving treatment results. Innovative methods including Multimodal imaging methods, artificial intelligence (AI), and hybrid approaches like PET-CT and PET-MRI are the results of advancements in cancer imaging. Some challenges are faced during MRI scanning like the duration of the scan, claustrophobia, and risk of injury because of any metallic implant. All these methods and advancements improve the quality of the treatment plan and elevate the accuracy of the diagnosis.

Keywords: Computed tomography, Magnetic resonance imaging, Cancer staging, Diffusion-weighted imaging, Hybrid imaging.

Review Article

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1. INTRODUCTION

Cancer is one of the major causes that leads to cell destruction and becomes a leading cause of death all over the world. Cancer detection at an early age is not an easy task, sometimes it is misjudged by radiologists and clinicians. Diagnostic imaging modalities such as X-ray, mammography, Computed Tomography (CT) scan, Magnetic Resonance Imaging (MRI), ultrasonography, and Positron Emission Tomography (PET) scan are promising tools for cancer detection (Gillies & Schabath, 2020). These modalities provide structural, metabolic, and functional information about the cancer. A combination of CT and PET can be used to identify the nature of the tumor and indicate the need for a biopsy. It also helps in defining the stages of cancer and how far cancerous cells have spread (Pesapane et al., 2020). CT and MRI are most commonly used for cancer detection. CT is an imaging modality that uses ionizing radiation to examine the body and provides cross-sectional information on the internal structures of the body (Rong & Liu, 2024). MRI works on the principle of magnetic resonance and provides detailed images of soft tissue, as well as chemical information with high resolution. Both techniques are non-invasive and increase the efficiency of work (Kuber et al., 2024). These modalities are used to assist in tracking the effect of the treatment. Usually in some cases after a few rounds of chemotherapy, physicians could advise a CT scan to see a change in the size of the tumor (Patel & De Jesus, 2025).

2. Principles of Cancer Staging with CT and MRI

Imaging techniques are used to determine the cancer stage and extent of cancer, which helps clinicians for treatment (Farjah et al., 2024). CT scanning is a non-invasive technique that uses ionizing radiation to provide cross-sectional images of the internal structures. It is usually used for routine imaging procedures in the Tumor, Node, and Metastasis (TNM) staging of the patient with cancer (Asamura et al., 2023). The TNM system describes the stages of cancer with numbers from 1 to 4. In this system T staging describes the location, size, and spread of the main tumor, N describes the presence of nodal involvement in lung cancer, and M stands for metastases (Rosen & Sapra, 2025). In all these stages CT is an important modality for assessment. In a CT scanner, the X-ray tube rotates around the patient's body and collects information from all directions of the body. Modern CT scanner takes a very short time, scans can be completed within seconds. therefore, a good option for emergency traumatic cases. Excessive use of ionizing radiation may cause cancer, so radiation protection is necessary in radiation-prone areas (Hermena & Young, 2025).

MRI is the recommended imaging technique because it provides high soft tissue contrast resolution which assists doctors in identifying cancers and indications of metastasis, MRI improves the identification of big solid masses and the differentiation of benign from malignant tumors (Ashby et al., 2025). MRI is a promising technique to define the tumor's local staging, grading, and characterization. It uses radio waves (radio-frequency) instead of ionizing radiation to form images (Bruno et al., 2019). Compared to a CT scan, an MRI takes more time and the patient may suffer from claustrophobia. Patients having metallic implants are contraindicated for MRI except for MR-compatible implants (Titanium-based implants) (Hossain et al., 2024).

3. Advances in CT imaging for Cancer Staging

There have been many advances in CT scanners over the past decades which have improved the image quality and reduced the time of scan. Modern imaging techniques can detect cancer and other pathologies efficiently (Koetzier et al., 2023). The advanced techniques in CT imaging for cancer staging include High-Resolution Computed Tomography (HRCT) and Dual Energy computed tomography (DECT) (Shah et al., 2023). HRCT is a technique to enhance the resolution of images, its main aim is to diagnose problems like lung diseases such as pulmonary nodules, and lung cancer screening by assessing the lung parenchyma. It is performed by using a regular CT scanner and the technical parameters are adjusted to maximize spatial resolution (Lauri, 2017).

DECT is an advanced imaging technique, it is also known as spectral CT because it uses two different x-ray spectra to form an image. DECT enables the detection of material properties that are not visible on a traditional single-energy CT scan (Sodickson et al., 2021). It is highly helpful for distinguishing between benign and malignant tumors and for imaging minor lesions. The techniques that enable DECT applications in clinical practice are material differentiation and material identification and quantification. Appropriate detection of the concentration of iodine in a target lesion becomes possible by material identification and quantification (Sanghavi & Jankharia, 2019). For the enhancement of any abnormality or lesion contrast agents are used in CT imaging, usually iodine-based contrast agents are used, which are injected intravenously (IV) into the patient (Owens et al., 2023). Contrast media are radio-opaque substances, and through blood circulation reach the lesions and tumors and enhance the tumor cells.(Cobos Alonso et al., 2024).

4. Advanced in MRI Imaging for Cancer Staging

Advancements in MRI techniques have played an important role in improving the accuracy of diagnosis and treatment planning. Some advanced techniques are Functional MRI (fMRI) and Diffusion Weighted Imaging (DWI), both methods provide structural and functional information about the brain (Peeters & Sunaert, 2022). fMRI is an exciting modern development in MRI technique. It is used to assess neurological conditions, risks, functional and physiological state of the brain. It is a noninvasive approach to examining how the brain works when a task is activated (Leskinen et al., 2024). In radiation oncology, fMRI is used for many purposes, including tumor localization, staging, target defining, outcome, early response to therapy assessment, and complications monitoring (Olsson et al., 2019). Diffusion-weighted magnetic resonance imaging DWI-MRI on the other hand, measures the diffusion characteristics of water within tissues to provide picture contrast (Ermongkonchai et al., 2023). In practically every type of cancer, DWI is being used to identify benign from malignant lesions, differentiate between various malignant tumor grades, and forecast whether a treatment would work. Dynamic Contrast-Enhanced MRI (DCE-MRI) is another essential cancer detection and staging technique. IV contrast is injected and information is acquired before the administration of contrast, during administration, and after giving the contrast. Sequential MR images are obtained during the examination (Li et al., 2024). It helps to distinguish between tumor and normal tissue, evaluate the growth of blood vessels within the tumor, and spot early warning signs of tumor reappearance (Petralia et al., 2020). To assess the biochemical composition of metabolites in any cancerous lesion Magnetic Resonance Spectroscopy (MRS) technique is usually used in brain and prostate cancer (Hu et al., 2021). MRS forms the graph on the screen and shows different chemical peaks of metabolites (NAA, Cho, Cr, lipid, lactate, Myo-inositol, etc.) in brain tumors or cancerous lesions. Proton MRS is a widely used MRS method to monitor metabolic changes in cancer tissue (Gaillard, n.d.).

5. Role of CT and MRI in Treatment Monitoring

CT and MRI can be used to assess early detection of cancer and other findings for better treatment, and can also be used for treatment planning in radiation therapy procedures (Volz et al., 2024). Medical professionals chose CT to track the response of chemotherapy and radiation therapy by comparing CT scans taken at various points during the therapy to find out whether a tumor returned after treatment (*The Role of Imaging in Radiation Therapy Planning: Past, Present, and Future - Pereira - 2014 - BioMed Research*

International - Wiley Online Library, n.d.). A novel approach is developed in MRI as a treatment method, Magnetic Resonance-guided Radiation Therapy (MRgRT) enables better tumor visibility and, in addition to real-time appearance monitoring and treatment adaptation, the tumor's internal analysis without biopsy (Eidex et al., 2024). Functional imaging is another technique for treatment monitoring; it is a non-invasive procedure that measures the tumor's physiological activity, tracks the movement of cells or therapeutic medications, and helps determine how effectively the tumor is responding to therapy (Bai et al., 2023).

6. Challenges in Integrating CT and MRI in Oncology

A challenging problem that frequently arises in image-guided surgeries and radiation planning is multimodality medical image registration. It is a technique that combines two or more imaging modalities to create detailed images (Alam & Rahman, 2019). Integrating CT and MRI in oncology has presented many difficulties, given the high cost of the equipment due to the very high cost not being available everywhere (Gignac et al., 2024).

MRI system is a complex imaging modality consisting of very expensive types of equipment. It required skilled workers to maintain and operate the system. In addition, artifacts have become an issue ("(PDF) MRI LIMITATIONS," 2024). When choosing protocols in CT it is not necessary to produce high-resolution images rather, the objective is to generate a diagnostic image with the lowest feasible dosage. For reducing radiation exposure dose reduction tools are used, which modify the radiation dose according to the body mass of the patients (Dudhe et al., n.d.). Several methods, such as anti-scatter grids, software-based algorithms, raising the tube current, and patient positioning, can be used to reduce artifacts in CT. MRI scans generally use quick spin echo sequences for minimal artifacts (Sayed et al., 2023).

7. Innovation Approaches to CT and MRI Integration

Technologies in medical imaging continue to evolve rapidly, and innovation has led to the development of Hybrid Imaging techniques such as CT, MRI, or SPECT (single photon emission computed tomography. Hybrid imaging combines anatomical and functional data to improve disease detection and therapy tracking (Alanazi, 2024). One of the most used imaging techniques for identifying cancer is PET-CT, which shows metabolic activity and increases the efficiency of tumor identification and treatment monitoring (Shetty, n.d.). The most often used radioisotope in PET scanning is fluorine, which is used as a fluorodeoxyglucose (tracer molecule), also known as FDG (Kapoor & Kasi, 2025). In several clinical indications, PET exams are conducted as combined PET-CT, which has been shown to have a higher diagnostic value than independent PET or CT imaging. In comparison, PET-MRI can be used to image any part of the body, has a low radiation exposure, and provides greater soft tissue contrast. However, the design of PET-MRI is complicated because of technical issues triggered by the existence of a magnetic field (Musafargani et al., 2018). The beginning of innovative clinical whole-body MR-PET systems provides new perspectives on the metabolic and functional mechanisms underlying neurological and oncological disorders (Reed et al., 2023). It can be performed in three ways: first, by attenuation correction as quickly as possible; second, by motion correction and third by reducing radiation exposure (Cui et al., 2023). The use of biomarkers, radiomics, and AI are additional advancements in integrating CT and MRI. A new age of opportunities in the healthcare industry has been brought about by artificial intelligence (Maniaci et al., 2024). Numerous additional aspects of medical practice have been altered by the combination of medical and artificial imaging, from accurate diagnoses and early illness detection to individualized treatment planning and better patient outcomes. And third, by carrying out a full additional MR whole-body examination. Radiomics is the technique of utilizing advanced statistical and mathematical algorithms to acquire high-quality data from medical images. Data collection and preprocessing, tumor segmentation, obtaining features, knowledge finding, selection, and analysis are just a few of the crucial processes that make up radiomics (van Timmeren et al., 2020). **Fig. 1** summarizes the challenges faced during the PET-MRI examination.

8. Clinical Applications of CT and MRI Integration

A variety of information on morphology, structure, metabolism, and activities can be obtained using medical imaging, imaging is an important component of cancer clinical protocols, and CT-MRI imaging has several cancer-specific applications (Tolonen et al., 2021). The most common cancer types for which these techniques are employed are lung, prostate, and breast malignancies (Moleyar-Narayana et al., 2025). The administration of IV contrast agents and the development of MRI with its great spatial resolution improved the identification of typical types of malignancies such as breast lesions and interior abnormalities of the chest (Filippone et al., 2024). Furthermore, because MRI can show the internal prostatic anatomy, prostatic margins, and the location of prostatic tumors, it offers a lot more information than CT (Schiavina et al., 2018). CT images, which physically define both the high-dose and low-dose zones, were previously used for the preparation of radiotherapy for prostate cancer (Hsieh, 2024). Imaging technology has also other clinical applications, that as image-guided radiation therapy (IGRT) to help deliver specific and reliable radiation treatment. Additionally, it can be utilized to treat malignancies in movable parts, such as the lungs (Grégoire et al., 2020).

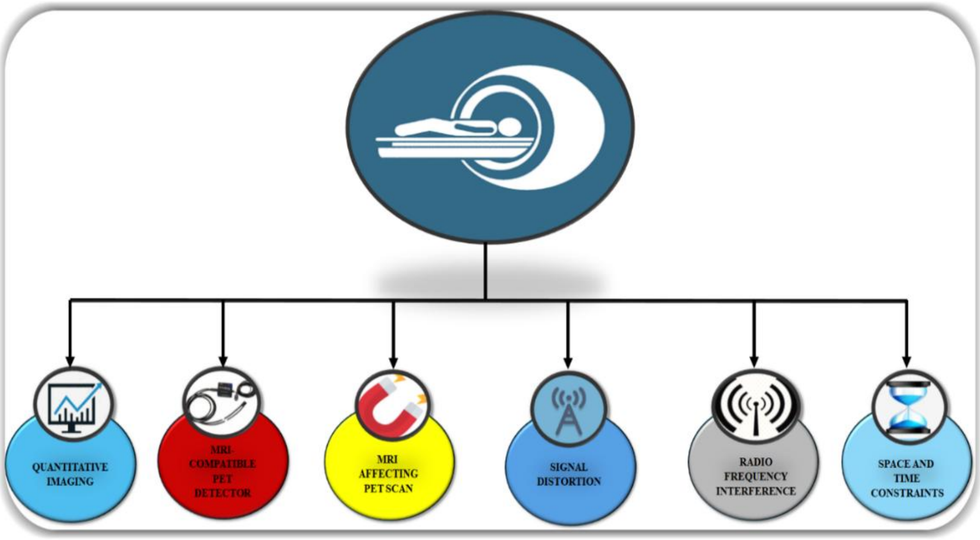

Figure 1: This figure depicts complications faced during PET-MRI scans and may lead to image distortion.

9. Future perspective

Medical imaging technologies have evolved day by day and provide accuracy in imaging cancer staging and various disease detection, also it may include advanced technologies such as AI, and 3D image processing techniques in CT (Khalifa & Albadawy, 2024). With the advancement of newer technology, the future of medical imaging is limitless. With time, more advanced technology will allow even faster safer, and more efficient imaging with a more advanced way of storing, sharing, and interpreting medical data (Pinto-Coelho, 2023). The fields of molecular imaging and molecular imaging-based diagnosis are strong and developing quickly. It has the potential to play vital roles in every aspect of oncologic practice, including early disease detection, diagnosis, staging, treatment, treatment monitoring, and follow-up (Woźniak et al., 2022).

10. CONCLUSION

Imaging technologies like CT and MRI scans enable the early detection of cancer, improving the chances of successful treatment. Advancement and innovation in imaging technologies include the techniques called hybrid imaging, which is the combination of two modalities such as PET-CT and PET-MRI. Integration of AI in medical imaging reduced the workload and improved the diagnostic accuracy. It provides better imaging for the accurate detection and location of cancer for the planning of therapy. A few challenges have been faced during the imaging, that is radiation exposure level, the accessibility of technologies in different locations, and some artifacts.

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