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Advancements in Diagnostic Imaging Techniques for Early Cancer Detection

Mahnoor Kashif

ABSTRACT

The field of medical imaging has evolved at a blinding pace, and recent developments in molecular imaging have sparked significant interest in the healthcare industry. Cancer is a leading cause of mortality across the globe, and this review explores advancements in diagnostic imaging techniques that facilitate early cancer detection. The review further highlights that although traditional techniques, computed tomography and magnetic resonance imaging, have improved the diagnostic abilities and patient outcomes, they still face limitations such as time constraints and radiation exposure. Comparatively, cutting-edge modalities, such as molecular imaging and hybrid technology, offer enhanced sensitivity and specificity to ensure a more favorable prognosis for patients. Future research must revolve around the integration of artificial intelligence into medical imaging to develop personalized treatment plans, paving the way for improved accuracy and more effective cancer diagnosis and treatment.

Keywords: Diagnostic imaging, Hybrid imaging, Magnetic resonance imaging, Molecular imaging, Positron emission tomography, Single-photon emission computed tomography

Introduction

Cancer has become increasingly prevalent worldwide and imposes a significant burden on society. In the UK alone, over 386000 new cases were reported annually, translating to more than 1000 diagnoses each day as suggested by the 2017–2019 report of Cancer Research UK.¹ The obstructive impact of cancer is further highlighted by the 167000 deaths it causes annually in the UK, with individuals aged 75 years and above being the most affected.¹ Another research conducted in the UK depicted that if the current trends persist, the count for new cancer cases will escalate from 384000 per year to 506000 by 2040, as shown in Figure 1.² This statistical data underscores the exigency for early cancer diagnosis to improve the outcomes and reduce the societal implications of cancer. In fact, no debate on oncology attracts as much energy and trepidation as cancer screening and surveillance. All stakeholders, including patients, clinicians, oncologists, and researchers, look forward to the development of imaging techniques that might facilitate earlier cancer diagnosis, detect recurrence promptly, and improve prognosis, leading to higher rates of successful treatment.³

Screening in both healthy individuals and high-risk population allows early cancer detection, ideally before symptom onset and metastases. In certain cases, if detected at an earlier stage, surgical intervention alone is sufficient for treating cancer. This eventually leads to decreased morbidity and an improved

survival rate. For instance, the study of Loud and Murphy⁴ highlighted that the goal of cancer screening and early detection is solely to detect the malignancy, or its precursor lesion, prior to initial symptoms for effective cancer treatment. Loud and Murphy⁴ also suggested that from 1990 to 2015 the overall mortality rate has declined by 25% and a massive 39% decrease in the mortality rate for breast cancer has been observed.⁴

Imaging remains the most broadly adopted technique for cancer diagnosis in earlier stages, which analyzes the phenotypic traits of tissues within the tumor masses. Imaging can be employed for screening, staging, and surveillance of tumor progression, predominantly because of its non-invasive approach and easier access. In their research, García-Figueiras et al⁵ proclaimed the significance of this diagnostic technique by stating that imaging techniques improve the assessment of tumor-specific characteristics in clinical practice.⁵

Cutting-edge imaging techniques including positron emission tomography (PET), PET/computed tomography (CT), nuclear medicine, and other modalities provide numerous advantages in improving the efficiency of cancer treatments, unlike the past when such advanced radiological technologies were not accessible.⁶ Additionally, some of these techniques also discuss the physical structure, metabolic activity, and the functional status of cancer within a clinical setting.⁷ Each of these imaging techniques has inherent variations in resolution, sensitivity, and contrast generation, which enable enhanced detection, characterization, and surveillance of tumors.⁸ Figure 2 depicts the relative sensitivity of different imaging modalities.⁹

These advanced imaging technologies facilitate significant improvements in early detection, diagnosis, staging, monitoring, and treatment planning of cancer. Besides improving the accuracy of diagnosis, these cutting-edge technologies also replace invasive interventions.⁷ This review delves into the advancements in diagnostic imaging techniques that promote early cancer detection, evaluates the strengths and limitations of each approach, and explores the potential for future improvements in imaging modalities.

Traditional Imaging Techniques

Over the years, the field of oncology has witnessed considerable advancement in diagnostic imaging approaches. This review categorizes the most frequently employed and postulated imaging techniques into conventional and cutting-edge methods to accentuate on the improvement in diagnostic technologies. Figure 3 presents the categorization based upon the evolution of imaging technology.

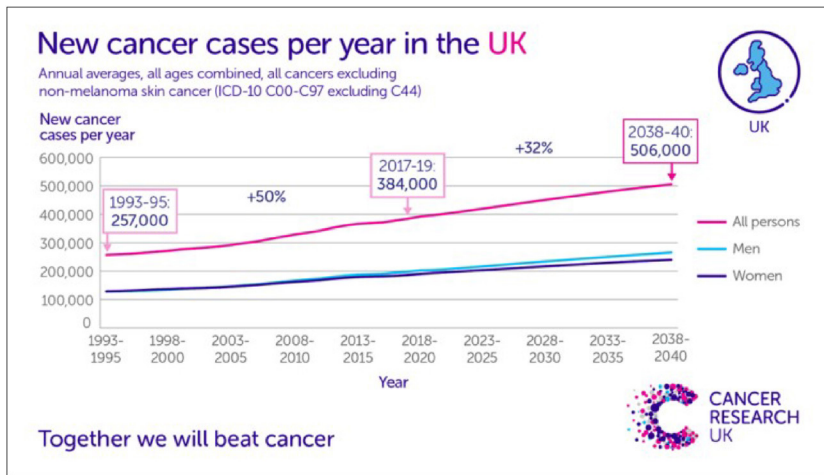


Fig 1 | Prevalence of cancer as per UK research

Source: <https://www.mouthcancerfoundation.org/news/cancer-cases-will-reach-500000-a-year-by-2040/>

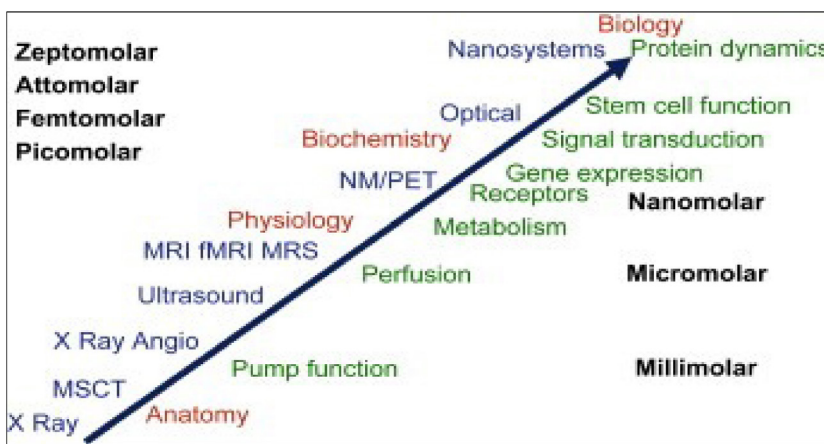


Fig 2 | Relative sensitivity of imaging technologies

Source: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5527766/>

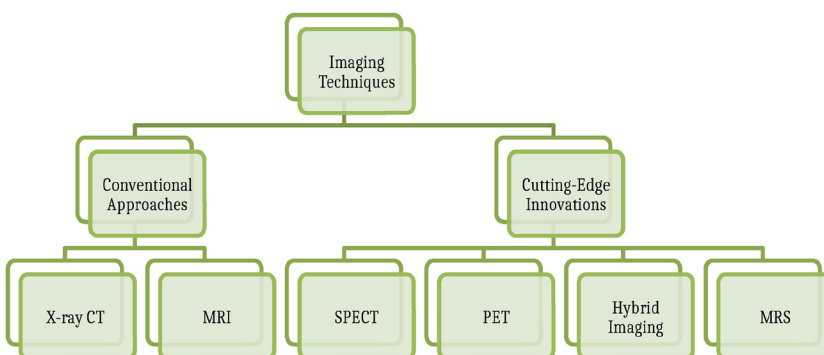


Fig 3 | Categorization of diagnostic imaging technologies

X-ray CT

CT, also referred as X-ray CT, was first invented by Hounsfield (1969) and was employed by radiologists, biologists, and even archaeologists to develop cross-sectional images that aid in the diagnosis of abnormalities and other therapeutic measurements.¹⁰

In CT technology, X-rays are produced from different angles and a sonogram is obtained using raw form of data. This scanned data is processed by computers to generate tomographic images. With passage of time, CT technology has improved significantly, resulting in higher-resolution reconstructed images.¹¹

CT is an effective imaging technique that aids in the monitoring of numerous cancers including those of the bladder, kidneys, skeleton, neck, and head and is also capable of detecting metastases of distant organs, such as lungs, liver, and brain.¹² Zhou et al.,¹² conducted an analysis using a feature set consisting of clinical features and 485 radiomic features, which were extracted employing pre-therapy CT images. Their study concluded that radiomic features from CT images when combined with a patient's gender and tumor T and N stage information can be used to assess the risk of distant metastases in lung cancer.¹²

Bansal et al.,¹³ suggested that CT scan is an efficient modality for early diagnosis and monitoring of tumors, which guides oncologists to carry out the treatment adequately.¹³ CT scans are also useful in deciding the surgical technique that needs to be adopted, as suggested by Jahandideh et al and Kahveci et al.^{14,15} CT technology provides precise spatial and temporal imaging of tumors supporting follow-up procedures, including biopsies, surgeries, and radio or chemotherapy.¹⁶ Numerous instrumentation advancements including scan speed, dual energy, iterative reconstruction, perfusion imaging, and reduction in radiation dose have improved the output of CT-based imaging techniques in clinical setups.¹⁷

A predominant drawback of CT imaging is that it intensifies the risk of radiation-induced cancers when used frequently, as it involves ionizing radiation. Moreover, CT scans often lead to false negatives because of their low sensitivity in detecting early-stage tumors and incompetence in showing tendons, ligaments, spinal cord, or intervertebral discs.¹⁸

Magnetic resonance imaging

Fundamentally, magnetic resonance imaging (MRI) serves as a non-invasive imaging tool designed for visualizing the body's anatomy and physiology under both normal and pathological states. In the late 1970s, an MRI-based approach called echo-planar imaging was first developed by two physicists named Peter Mansfield and Paul Lauterbur.¹⁹ MRI technology is more preferred as compared to CT scan as it utilizes non-ionizing radiations. This was further validated by the proclamation of Florkow et al.,²⁰ who stated that MRI is increasingly being adopted as a radiation-free substitute for CT imaging for both the diagnosis and treatment of musculoskeletal abnormalities.²⁰ MRI techniques include functional MRI, magnetic resonance angiography, susceptibility-weighted imaging, diffusion-weighted imaging, gradient echo, and spin echo.

An MRI scanner uses magnetic fields, electric fields, and radio waves to generate images of organs and body structure. The MRI machine produces a strong mag-

netic field during the scanning process. The hydrogen ions align in the targeted area of the patient's body due to a constant magnetic field. These aligned hydrogen ions are temporarily displaced on the application of radiofrequency waves, and later they return to their original equilibrium state. MRI radiological analysis develops images of the targeted body part as chosen by the physician to diagnose the malignancy.²¹

A whole-body MRI (WB-MRI) is usually employed to investigate the skeletal metastases. Figure 4 shows the visual representation of a full-body MRI. The MRI technique allows tumor visualization because of the high proton concentration within the tumor matrix. The WB-MRI technique is more sensitive than skeletal scintigraphy and easily detects lesions in the pelvis, spine, and femur, as put forward by Summers et al.²² Additionally, Petralia et al.,²³ proposed WB-MRI as a robust imaging technique for detecting and characterizing pathologies across multiple organs, offering broader anatomical coverage without ionizing radiation. Their research underscored that the advancements in scanner technology and improved pulse sequence optimization have shortened acquisition times, hence increasing the applicability of WB-MRI in a range of clinical settings.²³ According to the findings of Schmidt and Payne,²⁴ the cutting-edge imaging capability of MRI supports doctors to detect tumors as well as determine their size, location, and potential effect on the surrounding tissues.²⁴ This detailed scanning facilitates an effective cancer treatment plan, establishing the MRI tool as one of the most crucial instruments in early cancer diagnosis.

In the past decade, MRI has emerged as a potential imaging technique for the detection and diagnosis of breast cancer. Numerous studies indicate that women with higher chances of breast cancer can benefit from the use of MRI scans apart from mammography.^{25,26} The work of Radhakrishna et al.,²⁵ revealed that MRI tool is

superior to mammograms for screening breast cancer in high-risk population.²⁵ Wang et al.,²⁶ carried out a study which revealed that 4 out of 11 primary breast cancer cases were identified through MRI screening within a month after the first visit, which were not initially detected by mammography.²⁶ This study by Wang et al.,²⁶ suggests the benefit of conducting an MRI scan immediately subsequent to the detection of genetic risk factors. As per the findings of a very recent review published by Sardanelli et al.,²⁷ since 2000, around 10 intraindividual comparative studies have demonstrated the marked effectiveness of MRI, with sensitivity rates ranging from 25% to 58% for mammography, 33% to 52% for ultrasound (US), 48% to 67% for the combination of mammography and US, and 71% to 100% for MRI.²⁷

The MRI tool, besides being safe due to non-ionizing radiation, also generates adequate contrast of soft tissues, especially in demonstrating the white and gray matter structure in the brain. The groundbreaking research conducted by Krishnamurthy et al.²⁸ highlighted MRI as a superior imaging tool compared to other modalities because of its ability to generate flexible soft-tissue contrast to evaluate the pathology of brain and spine.²⁸ There are numerous other advantages of employing MRI such as it is painless, is a non-invasive technique, has high spatial resolution, and does not require repositioning of the patient during the imaging process.²⁹ MRI also does not have side effects like other scans (specifically CT and PET) and does not compromise on the image quality due to scanning targeted body parts from different angles. Despite the advantages, this technique is very expensive, has low sensitivity, and is time-consuming as compared to other imaging techniques. Moreover, many patients do not prefer MRI because the enclosed space creates a suffocating environment, which can be overwhelming for some individuals.³⁰

Cutting-Edge Innovations: The New Era of Diagnostic Imaging

In recent years, the major advances in imaging techniques and the integration of molecular biology have converged to form a new research domain known as "molecular imaging." Molecular imaging is the ability to visualize and quantitatively measure the function of biological and cellular processes, and it includes techniques such as PET, magnetic resonance spectroscopy (MRS), and single-photon emission computed tomography (SPECT).³¹

SPECT

SPECT is an imaging technique that incorporates the use of gamma rays and radio-isotopes to produce three-dimensional (3D) images with exact accuracy. The radioisotopes used are responsible for emitting gamma rays, and the most commonly employed ones include technetium-99m, xenon-133, gallium-67, iodine-131, and thallium-201.³² As gamma rays are typically emitted uniformly in all directions, a collimator attached to the front of the detector allows gamma



Fig 4 | A full-body MRI allows doctors to detect cancer early before it has metastasized

Source: <https://www.uprightmideerfield.com/how-mris-save-lives-with-early-cancer-detection>

rays to be recorded and helps define the direction of the radiations. Hence, by rotating the detector around the patient, SPECT imaging facilitates in generating a complete 360° view of the patient undergoing the scan. Figure 5 depicts an SPECT imaging machine.

In the early 1960s, Kuhl and Edwards³³ pioneered and conducted the first research regarding SPECT.³³ Over time, the integration of computer systems and rotating gamma cameras led to the development of the

advanced SPECT technique. Today, SPECT is considered as a nuclear imaging technique, as it uses small amounts of radioactive materials, that is frequently used for cancer diagnosis, allowing clinicians to evaluate the perfusion and functionality of particular tissues.³⁴

Patients with head or neck cancer, specifically laryngeal/hypopharyngeal cancer, were analyzed in a study conducted by Chernov et al.,³⁵ to assess the efficacy of SPECT.³⁵ The findings revealed that the sensitivity of SPECT using 199Tl and 99mTc-MIBI was found to be 95% and for regional lymph node metastasis detection, 199Tl SPECT had a sensitivity of 75%, while 99mTc-MIBI SPECT had a sensitivity of 17%.³⁴ Therefore, SPECT can be used as a potential imaging tool for tumor detection.

As per the literature findings, SPECT imaging technique is considered a cost-effective method than PET for non-invasive diagnosis.³⁶ Moreover, this technique has an improved sensitivity and is capable of monitoring target bone metabolism, cardiovascular diseases, and cerebrum's blood flow.³⁴ Kugaya et al.,³⁷ proclaimed that SPECT is an essential development in imaging technology that can monitor the pathophysiology and other complex brain disorders.³⁷ Apart from these assets, a drawback of this technique is that it requires additional care and expertise for the handling of radioactive materials. Additionally, SPECT uses ionizing radiation which poses harmful radiation effects on patients.³⁸



Fig 5 | A SPECT scan to predict and monitor cancer treatment

Source: <https://kiranpetct.com/uses-of-spect-scan/>

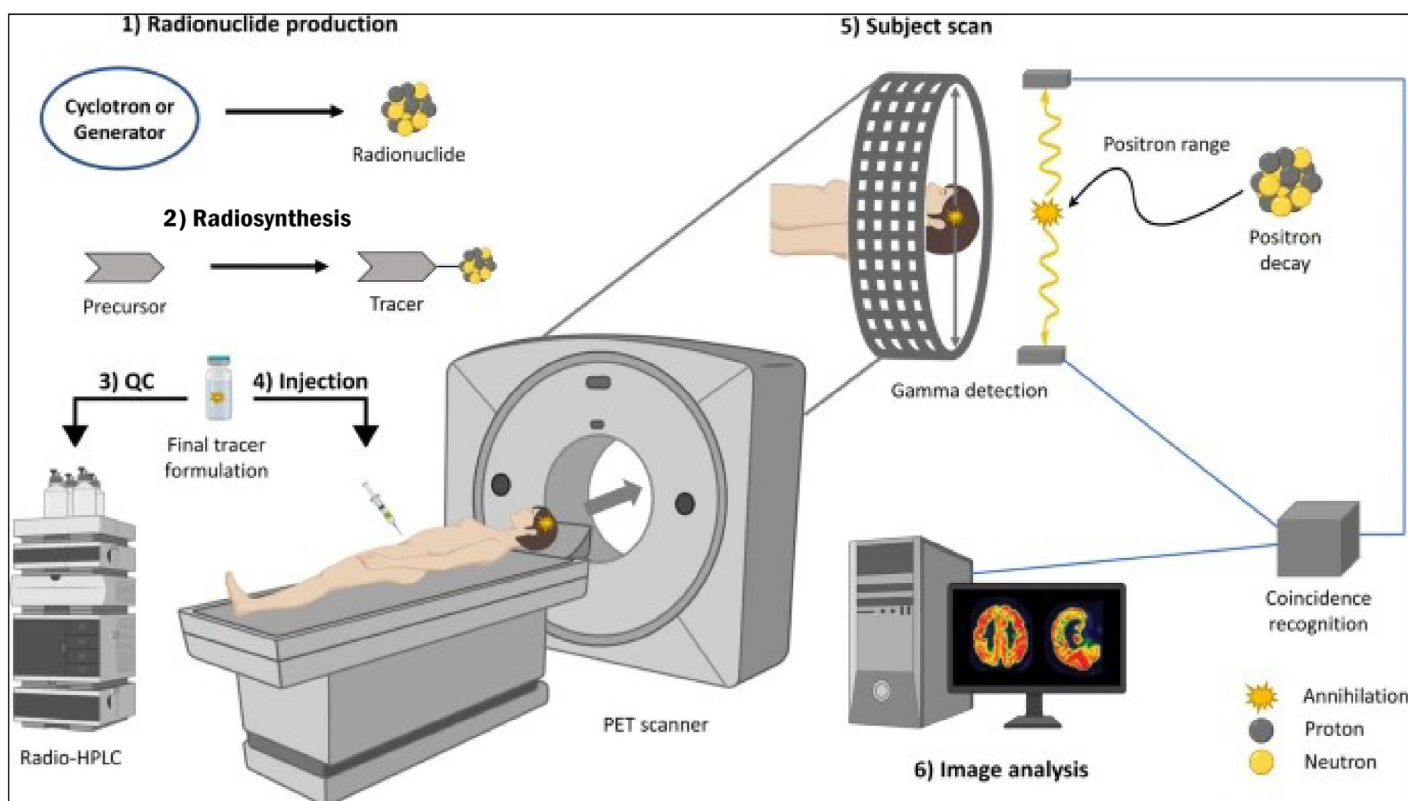


Fig 6 | (1) Radionuclide generation. (2) Tracer synthesis. (3) Quality control (QC). (4) Intravenous tracer injection. (5) PET scan: positron decay, annihilation, and coincidence detection. (6) Image analysis and data quantification

Source: <https://www.nature.com/articles/s41467-023-36377-4>

PET

PET is a functional technique in nuclear medicine that displays the concentration of radioactive markers within the body using clear and detailed images. PET is widely used in clinical settings because of its potential in diagnosing biological processes within the human body.³⁹ In oncologic imaging, PET is considered advantageous for carrying out a single WB assessment to accurately assess the disease development and its spread, hence facilitating the imaging of tumors and the search of metastases.⁴⁰

The recent technical advancements and improved sensitivity in PET have resulted in accurate image quantification, making it a broadly adopted technique for analyzing the progression of disease and supporting drug development.⁴¹ This technique requires minimal amounts of radioactive probes to produce high-quality images. Moreover, the high sensitivity trait allows PET markers to explore biological processes in a living body without triggering the therapeutic effect.

Figure 6 demonstrates the principles of the PET imaging technique. As shown in the image, initially, PET radioisotopes are generated either using nuclear reactions within a cyclotron or through particular decay mechanisms from a generator. These radioisotopes are incorporated into molecules through radiochemical reactions in order to yield tracers.⁴² A round-shaped scanner images the patient and the radioactive signals detected to provide information on tracer localization in different organs. The emitted positrons cover a pre-defined distance before they collide with electrons and as a result, annihilation occurs followed by the release of gamma rays in opposite directions. Spatial resolution is limited by the positron range, and the PET camera's array of detectors observe gamma ray coincidences, hence reconstructing the annihilation sources.⁴³

The ability of the PET imaging technique to detect cellular changes in organs and tissues makes it prevalent over MRI and CT scans. This intricate imaging technique facilitates the detection of the early onset of disease before it is evident on traditional image scans.⁴⁴ Griffith⁴³ confirmed the literature findings by putting forward that the accuracy of PET (86%–90%) is substantially higher than CT (63%–64%).⁴³ The groundbreaking research of Zytoon et al.,⁴² also confirmed the significance of PET modality in the early detection of the primary tumor site in patients with cancer of undetermined primary, helping clinicians to adopt adequate treatment protocols for efficient prognosis of patients.⁴² Zytoon et al.,⁴² highlighted that with the employment of PET along with CT, a sensitivity of 100% and a specificity of 93.3% in detecting unknown primary tumor location were achieved.⁴² Many studies have validated that PET-CT scanning is efficient in early cancer detection and substantially improves the treatment outcomes because of the detailed imaging, accurate diagnosis, and an effective treatment plan.^{43,45}

The predominant challenges of PET image reconstruction include correction for scatter, random coincidence events, and distinct signal attenuation caused

by various body tissues.⁴⁰ The concern regarding signal attenuation can be minimized by employing the combination of PET with CT.⁴⁶ Fundamentally, CT imaging generates an attenuation map that is used to adjust and improve the accuracy of PET imaging by compensating for signal loss. Hence, the integration of PET with CT underscores the significance of hybrid imaging, a notable advancement in diagnostic imaging that is the subject of future because of its diverse advantages.⁴⁷

Hybrid Imaging

The hybrid imaging technique is a combination of anatomic (US, CT, or MRI) and molecular (SPECT and PET) modalities that merges the strengths of different approaches to enhance accuracy, ameliorate diagnostic ability, and aid early diagnosis and staging, ultimately resulting in improved patient prognosis.⁴⁸ The commonly used hybrid imaging modalities are highlighted in Figure 7.

Today, SPECT/CT hybrid modality has become a significant part of the nuclear medicine field and is being widely used to detect abnormal bone activity associated with inflammation, bone tumors, infections, and trauma, especially in complex joints such as knee, hip, foot, shoulder, and hand. Combining the high sensitivity of SPECT and the high specificity of CT, clinicians can be guided about adequate therapy planning and better prognosis of patients.⁴⁹ For instance, Mohan et al.⁴⁹ revealed in their study that hybrid SPECT/CT is a successful tool for patients with consistent limping issues, as it gives a reliable diagnosis of the bone pathology unlike the traditional imaging techniques. SPECT/CT is also typically employed to detect metastases in cancers with pronounced skeletal affinity, such as lung, breast, and prostate cancers.⁵⁰ Current practices use two types of SPECT/CT modalities, namely targeted and WB imaging. The research findings of Rager et al.⁵¹ put forward that WB SPECT/CT had a significantly higher sensitivity than targeted SPECT/CT to detect bone metastases ($p = 0.0297$) and to detect extra-axial metastases ($p = 0.0266$). Thus, the higher sensitivity of WB SPECT/CT makes it an ideal imaging method for evaluating metastases.⁵¹

Additionally, PET/CT modality is also widely recognized as an effective approach for detecting the presence and impact of metastatic diseases, offering a

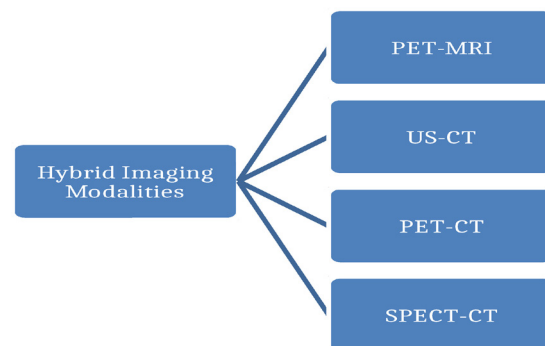


Fig 7 | Different types of hybrid imaging techniques

range of benefits over contrast-enhanced CT and other imaging techniques.⁵² In a recent study, Santos et al.,⁵³ proposed that with the correct imaging protocol, PET/CT meets the requirement and does not require bone scintigraphy (BS) for patients with breast cancer staging.⁵³ Their findings concluded that PET/CT hybrid modality presented higher values of accuracy (98%) and sensitivity (93.83%) in detecting bone diseases, overshadowing the accuracy and sensitivity values for BS (95.61% and 81.48%, respectively). Gammel et al.,⁵⁴ also contributed in the field of hybrid imaging by revealing that PET/MRI modality is an adequate approach for prostate cancer management and yields benefits, such as early diagnosis, staging, and effective therapy planning.⁵⁴

Along with improved sensitivity and specificity, hybrid imaging techniques such as US-CT offer another advantage of reduced radiation exposure when compared to fluoroscopy-guided procedures.⁵⁵ Hussain et al.,⁷ elaborated the advantages of hybrid imaging modalities by speculating that approaches such as PET/CT, US/CT, and PET/MRI have higher resolution, improved reliability, better diagnostic safety, and well-guided treatment strategies for managing complex patient anomalies.⁷ Therefore, the literature proposes that despite limitations such as higher cost, longer acquisition time, and the requirement of skilled professionals, the evolution of hybrid modalities is effective in detecting primary tumors, determining metastases, and developing adequate personalized treatment plans.⁵⁴

MRS

MRS is a method that combines the molecular differentiation ability of nuclear magnetic resonance (NMR) with the spatial localization imaging attributes specific to MRI. This opens a molecular window into the chemical composition of a tissue, providing valuable insights into physiological and pathological processes.⁵⁶ Weinberg et al.,⁵⁶ suggested that MRS is an important tool for imaging brain tumors and has substituted the traditional imaging techniques persuasively. Moreover, MRS ensures safety benefits as it does not involve injected contrast agents or ionizing radiations.⁵⁶

The scope of MRS has increased drastically and covers the classification and diagnosis of cancers in numerous organs of the human body. Shah et al (2006) conducted a review to reveal that MRS not only identifies the type and grade of brain tumors in clinical settings but also diagnoses tumors in other regions, such as prostate, colon, breast, cervix, pancreas, and esophagus.⁵⁷ Bolan et al.,⁵⁸ carried out the pioneer study and introduced breast cancer diagnosis using hydrogen 1 MRS (¹H-MRS) because of its higher sensitivity than phosphorous MRS (³¹P-MRS).⁵⁸ Their study also presented that the primary and most extensively researched application of breast MRS imaging is to differentiate between benign and malignant lesions prior to biopsy.⁵⁸ Sharma and Jagannathan⁵⁹ conducted a meta-analysis and documented that ¹H-MRS studies have achieved a pooled sensitivity between 71% and

74% and a specificity between 78% and 88%. Their analysis also propounded that the integration of MRS into traditional MRI technique has significantly improved the diagnostic accuracy, enabling clinicians to track the effects of chemotherapy in patients with breast cancer.⁵⁹

A very recent publication by Iqbal et al⁶⁰ highlighted the role of MRS imaging in diagnosis, treatment response, and future prospects of cervical cancer. Their study also proposed that MRS can be useful in identifying patients who are non-responders to a treatment, as indicated by higher lipid signals. Iqbal et al⁶⁰ further discussed the future of MRS technology, specifically advanced spectroscopic imaging and integration of artificial intelligence (AI), which are yet to be analyzed thoroughly in the oncological field.⁶⁰ MRS imaging modality has several drawbacks that prevent it from achieving its full potential in imaging tumors. First, although MRS theoretically has the ability to distinguish between various tissue types, there is a significant overlap in the spectroscopic profiles of different diseases, leading to diagnostic challenges. Besides this, MRS scans are often time-consuming, the results vary between different imaging locations, and artifacts make interpretation of scans difficult because of unwanted distortion or errors.⁵⁶ Despite these limitations, technological advancements continue to enhance the accuracy and applicability of MRS in clinical practice, making it a valuable tool for cancer diagnosis.

Weighing the Pros and Cons: Comparative Analysis of Imaging Techniques

Table 1 summarizes each imaging technique and its applications, strengths, and limitations, providing a clear comparison of traditional and cutting-edge methods in diagnostic imaging.

Current and Future Challenges in Cancer Diagnostic Imaging

The field of diagnostic imaging for cancer detection has made great strides, but several challenges persist. One of the key concerns is signal attenuation, which can reduce image quality and complicate diagnosis, particularly in techniques such as US, PET, and hybrid modalities. Hänni et al.,⁶¹ revealed that the signal attenuation of US technique results in poor image quality at depth, especially in cases when deep abdominal organs are being evaluated.⁶¹ Radiation exposure from diagnostic imaging methods also poses significant risks, especially for patients requiring repeated scans. The findings of Brower and Rehani⁶² suggested that a new phase of medical imaging has evolved, with modern techniques pushing the boundaries of what is possible but also raising new concerns about radiation levels. According to their study, 1 in 125 patients may receive more than 50 mSv of radiation from a single CT scan, and 3 in 10000 could get over 100 mSv in one day.⁶² With more scans being done, including newer methods like PET/CT, it cannot be identified that how much total radiation patients are exposed to. This is

Table 1 | Strengths and Limitations of Different Imaging Modalities

Technique	Description	Key applications	Strengths	Limitations
X-ray CT	X-ray CT creates cross-sectional images by rotating X-ray sources and detectors around the patient.	Used for diagnosing and monitoring cancers in organs such as bladder, kidneys, and head; detects metastases in lungs and liver.	Provides detailed spatial and temporal imaging; advancements include faster scans and reduced radiation dose.	Risk of radiation-induced cancers; lower sensitivity for early-stage tumors; not effective for soft-tissue imaging.
MRI	MRI uses magnetic fields and radiowaves to create detailed images of organs and tissues.	Effective for imaging brain, spine, and musculoskeletal tumors; used for breast cancer screening.	Non-ionizing radiation; excellent contrast for soft tissues; detailed imaging of tumors and surrounding tissues.	Expensive; time-consuming; can be uncomfortable due to confined space; has lower sensitivity for some types of cancer.
SPECT	SPECT uses gamma rays and radioisotopes to produce 3D images.	Diagnoses and evaluates perfusion in cancer patients; used for detecting bone metabolism, cardiovascular diseases, and brain disorders.	Cost-effective; good for monitoring bone and cardiac conditions; has high sensitivity for specific cancers.	Involves ionizing radiation; requires handling radioactive materials; less effective for certain cancer types.
PET	PET measures radioactive markers to visualize and quantify biological processes.	Assesses tumor development and spread; used in oncology for detailed WB scans.	High sensitivity for early disease detection; detailed image quantification; useful in drug development.	Signal attenuation and scatter; high cost; requires integration with CT for improved accuracy.
Hybrid imaging	Combines anatomical and molecular modalities for enhanced imaging accuracy.	Effective for staging and diagnosing cancers; used for assessing bone metastases and other complex conditions.	Improves diagnostic accuracy and staging; reduces radiation exposure; integrates the strengths of different imaging types.	Higher cost; longer acquisition times; requires skilled professionals.
MRS	MRS provides molecular-level information by combining NMR with MRI techniques.	Used for detecting brain tumors and other cancers; differentiates between benign and malignant lesions.	Non-invasive; no ionizing radiation; good for monitoring treatment response and cancer characterization.	Time-consuming; results can vary; diagnostic overlap between diseases; artifacts can complicate interpretation.

especially important for people with long-term illnesses, as they may experience the effects of this radiation over time.

Additionally, the high cost of advanced imaging technologies limits their accessibility, particularly in low-resource settings, which eventually restricts their widespread use.⁶³ Another challenge is the occurrence of artifacts which may result during scans because of hardware/software issues, human physiological phenomenon, or physical restrictions. Some artifacts can severely impact diagnostic imaging quality, while others might mimic or be confused as a different pathology.⁶⁴ Hence, artifacts and interpretation difficulties further hinder the accuracy of some techniques, where misinterpretation or errors can lead to diagnostic challenges.

Literature highlights that around 1%–30% of individuals undergoing MRI examinations may experience severe anxiety during the process.^{65,66} The factors contributing to anxiety during MRI examination include the small spatial dimensions of the MRI tube, long scan times, and loud machine noises. Therefore, patient comfort and long scan times are also problematic, particularly with techniques like MRI and MRS, where the duration of scans can cause discomfort, affecting patient compliance. Although AI and machine learning promise to revolutionize image interpretation and reduce errors, their integration into clinical practice is still in its early stages, with challenges in data standardization and regulatory approval.⁶⁷ Shah and Gautam⁶⁸ discussed that AI poses numerous challenges in diagnostic imaging technology, which include data quality, generalization, interpretability, and hardware limitations. Their work also explored the ethical and

regulatory implications of AI in imaging, highlighting the issues of bias and transparency.⁶⁸ Moreover, many new imaging techniques lack extensive clinical validation, requiring more trials to confirm their efficacy and safety before they can be widely adopted. Finally, there is a shortage of highly trained professionals capable of operating and interpreting advanced imaging technologies, which further limits their use in everyday clinical practice.⁶⁹

Looking Ahead: AI in Medical Imaging

The fields of medical imaging and AI are maturing dramatically, propelled by continuous research and technological advancements. Literature is continuously exploring AI algorithms, architectures, and methods to improve its potential in medical imaging.^{70,71} Moreover, partnerships between clinicians, researchers, and industrial professionals are mandatory to translate theoretical findings to practical applications that can improve the prognosis of patients worldwide. In a recent publication, Pinto-Coelho (2023) highlighted the exigency to pay attention on the latest innovations and applications of AI in medical field to improve patient care. Researchers have focused on some cutting-edge AI developments which include deep learning algorithms, convolutional neural networks (CNNs), and generative adversarial networks and how these advancements have improved the efficiency of imaging techniques. Jiang et al.,⁷² proposed that employing deep learning algorithms to interpret medical images can facilitate doctors to locate lesions, lead to early diagnosis, minimize medical misjudgments, and enhance the prediction results.⁷² Additionally, Gangurde et al.,⁷³ developed a CNN-nuclear pattern recognition (NPR)

architecture on a 5000-person sample and tested the gene profile. According to the findings of Gangurde et al.⁷³ the proposed model achieved an accuracy of 94%, showing that the CNN integration with NPR can be used successfully on a longer run for cancer diagnosis.⁷³ Dabeer et al.,⁷⁴ also suggested that deep learning is extensively utilized in the field of medical imaging and it serves as an efficient modality by training a CNN model and obtaining a prediction accuracy of 99.86%.⁷⁴ These innovations facilitate accurate detection of abnormalities, ranging from early diagnosis of a disease to identifying tumors during radiological assessments, by speeding up the interpretation of complex images to deliver improved outcomes for patients. The paradigm shift that AI has initiated in medical imaging will help clinicians in developing personalized treatment plans, hence optimizing the delivery of healthcare industry. The integration of innovative AI techniques into medical imaging and their practical applications will continue shaping the future of healthcare industry in a profound manner.

Conclusion

The field of oncology has seen a notable evolution in imaging techniques, transitioning from traditional methods like CT and MRI to newer modalities like nuclear and hybrid imaging. These advancements have greatly improved cancer diagnosis, leading to adequate treatment plans and higher survival rates. While traditional methods like CT and MRI still remain valuable, cutting-edge techniques such as PET, MRS, and hybrid imaging have a better sensitivity and provide detailed insights into tumor biology. The integration of AI into medical imaging holds immense potential and promises accurate image analysis with higher detection speed, better precision, and personalized treatment strategies. Further research will continue to refine these imaging tools, addressing present challenges and unlocking new possibilities for early diagnostics.

References

- 1 Cancer Research. Cancer Statistics for the UK [Internet]. Cancer Research UK. 2018 [cited 2024 Sep 3]. p. 1–4. Available from: <https://www.cancerresearchuk.org/health-professional/cancer-statistics-for-the-uk#heading-Zero>
- 2 Mouth Cancer Foundation. Cancer Cases Will Reach 500,000 A Year By 2040 [Internet]. 2023 [cited 2024 Sep 4]. Available from: <https://www.mouthcancerfoundation.org/news/cancer-cases-will-reach-500000-a-year-by-2040/>
- 3 Black GB, Lyratzopoulos G, Vincent CA, Fulop NJ, Nicholson BD. Early diagnosis of cancer: Systems approach to support clinicians in primary care. *BMJ* [Internet]. 2023 Feb 9 [cited 2024 Sep 3];380:e071225. Available from: <https://www.bmj.com/content/380/bmj-2022-071225>
- 4 Loud JT, Murphy J. Cancer screening and early detection in the 21st century. *Semin Oncol Nurs* [Internet]. 2017 May 1 [cited 2024 Sep 3];33(2):121. Available from: <https://pmc/articles/PMC5467686/>
- 5 García-Figueiras R, Baleato-González S, Padhani AR, Luna-Alcalá A, Vallejo-Casas JA, Sala E, et al. How clinical imaging can assess cancer biology. *Insights Imaging* [Internet]. 2019 Dec 1 [cited 2024 Sep 4];10(1):28. Available from: <https://pmc/articles/PMC6399375/>
- 6 Frush DP, Callahan MJ, Coley BD, Nadel HR, Paul Guillermin R. Comparison of the different imaging modalities used to image pediatric oncology patients: A COG Diagnostic Imaging Committee/SPR Oncology Committee White Paper. *Pediatr Blood Cancer* [Internet]. 2023 Jun 1 [cited 2024 Sep 4];70(Suppl 4):e30298. Available from: <https://pmc/articles/PMC10652359/>
- 7 Hussain S, Mubeen I, Ullah N, Shah SSUD, Khan BA, Zahoor M, et al. Modern diagnostic imaging technique applications and risk factors in the medical field: a review. *Biomed Res Int* [Internet]. 2022 [cited 2024 Sep 4];2022:5164970. Available from: <https://pmc/articles/PMC9192206/>
- 8 Bi WL, Hosny A, Schabath MB, Giger ML, Birkbak NJ, Mehrta A, et al. Artificial intelligence in cancer imaging: clinical challenges and applications. *CA Cancer J Clin* [Internet]. 2019 Mar [cited 2024 Sep 4];69(2):127–57. Available from: <https://pubmed.ncbi.nlm.nih.gov/30720861/>
- 9 Fass L. Imaging and cancer: a review. *Mol Oncol* [Internet]. 2008 [cited 2024 Sep 4];2(2):115. Available from: <https://pmc/articles/PMC5527766/>
- 10 Süsskind C. The invention of computed tomography. In *History of technology* [Internet]. 2016 [cited 2024 Sep 4];(Vol. 6, pp. 39–80). Available from: <https://www.criver.com/eureka/the-invention-of-computed-tomography>
- 11 Stock SR. Trends in the micro- and nanoComputed Tomography 2010–2012. <https://doi.org/10.1117/12.930157> [Internet]. 2012 Oct 17 [cited 2024 Sep 4];8506:850602. Available from: <https://www.spiedigitallibrary.org/conference-proceedings-of-spie/8506/850602/Trends-in-the-micro--and-nanoComputed-Tomography-2010-2012/10.1117/12.930157.full>
- 12 Zhou H, Dong D, Chen B, Fang M, Cheng Y, Gan Y, et al. Diagnosis of distant metastasis of lung cancer: based on clinical and radiomic features. *Transl Oncol* [Internet]. 2018 [cited 2024 Sep 4];11(1):31. Available from: <https://pmc/articles/PMC5697996/>
- 13 Bansal A, Dhamija E, Chandrashekhara SH, Sahoo RK. Role of CT in the detection and management of cancer related complications: a study of 599 patients. *Ecancermedicalscience* [Internet]. 2023 Apr 1 [cited 2024 Sep 4];17:1529. Available from: <https://pmc/articles/PMC10151087/>
- 14 Jahandideh H, Delarestaghi MM, Jan D, Sanaei A. Assessing the clinical value of performing CT scan before rhinoplasty surgery. *Int J Otolaryngol* [Internet]. 2020 Dec 18 [cited 2024 Sep 4];2020:1–7. Available from: <https://pmc/articles/PMC7803282/>
- 15 Kahveci OK, Miman MC, Yucel A, Yucedag F, Okur E, Altuntas A. The efficiency of Nose Obstruction Symptom Evaluation (NOSE) scale on patients with nasal septal deviation. *Auris Nasus Larynx*. 2012;39(3):275–9.
- 16 Lee JM, Yoon J-H, Joo I, Woo HS. Recent advances in CT and MR imaging for evaluation of hepatocellular carcinoma. *Liver cancer* [Internet]. 2012 Jun 12 [cited 2024 Sep 4];1(1):22–40. Available from: <https://pubmed.ncbi.nlm.nih.gov/24159569/>
- 17 Booi R, Budde RP, Dijkshoorn ML, van Straten M. Technological developments of X-ray computed tomography over half a century: User's influence on protocol optimization. *Eur J Radiol* [Internet]. 2020 [cited 2024 Sep 4];131:109261. Available from: <https://pubmed.ncbi.nlm.nih.gov/32937253/>
- 18 Bottari A, Cicero G, Silipigni S, Stagno A, Catanzariti F, Cinquegrani A, et al. CT scan. In *Anatomy for Urologic Surgeons in the Digital Era: Scanning, Modelling and 3D Printing* [Internet]. StatPearls Publishing. 2021 [cited 2024 Sep 4]. p. 89–98. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK567796/>
- 19 Mansfield P, Grannell PK. "Diffraction" and microscopy in solids and liquids by NMR. *Phys Rev B* [Internet]. 1975 Nov 1 [cited 2024 Sep 4];12(9):3618. Available from: <https://journals.aps.org/prb/abstract/10.1103/PhysRevB.12.3618>
- 20 Florkow MC, Willemsen K, Mascarenhas VV, Oei EHG, van Stralen M, Seevinck PR. Magnetic resonance imaging versus computed tomography for three-dimensional bone imaging of musculoskeletal pathologies: A review. *J Magn Reson Imaging* [Internet]. 2022 Jul 1 [cited 2024 Sep 4];56(1):11. Available from: <https://pmc/articles/PMC9305220/>
- 21 Prasad A. Making images/making bodies: Visibilizing and disciplining through magnetic resonance imaging (MRI). *Sci Technol Human Values*. <https://doi.org/10.1177/0162243904271758> [Internet]. 2005 Apr 1 [cited 2024 Sep 5];30(2):291–316. Available from: <https://journals.sagepub.com/doi/10.1177/0162243904271758?cid=int.sj-abstract.similar-articles.4>
- 22 Summers P, Saia G, Colombo A, Pricolo P, Zugni F, Alessi S, et al. Whole-body magnetic resonance imaging: Technique, guidelines and key applications. *ecancer*. 2021 [cited 2024 Sep 5];15:1164. Available from: <https://doi.org/10.3332/ecancer.2021.1164>

- 23 Petralia G, Zugni F, Summers PE, Colombo A, Pricolo P, Grazioli L, et al. Whole-body magnetic resonance imaging (WB-MRI) for cancer screening: Recommendations for use. *Radiol Med* [Internet]. 2021 Nov 1 [cited 2024 Sep 5];126(11):1434. Available from: /pmc/articles/PMC8558201/
- 24 Schmidt MA, Payne GS. Radiotherapy planning using MRI. *Phys Med Biol* [Internet]. 2015 Nov 11 [cited 2024 Sep 5];60(22):R323. Available from: /pmc/articles/PMC5137785/
- 25 Radhakrishna S, Agarwal S, Parikh PM, Kaur K, Panwar S, Sharma S, et al. Role of magnetic resonance imaging in breast cancer management. *South Asian J Cancer* [Internet]. 2018 Apr 1 [cited 2024 Sep 5];7(2):69. Available from: /pmc/articles/PMC5909298/
- 26 Wang X, Chang MD, Lee MC, Niell BL. The breast cancer screening and timing of breast MRI—Experience in a genetic high-risk screening clinic in a comprehensive cancer center. *Curr Oncol* [Internet]. 2022 Mar 1 [cited 2024 Sep 5];29(3):2119. Available from: /pmc/articles/PMC8947675/
- 27 Sardaneli F, Magni V, Rossini G, Kilburn-Toppin F, Healy NA, Gilbert FJ. The paradox of MRI for breast cancer screening: High-risk and dense breasts—available evidence and current practice. *Insights Imaging* [Internet]. 2024 Dec 1 [cited 2024 Sep 5];15(1):1–14. Available from: https://insightsimaging.springeropen.com/articles/10.1186/s13244-024-01653-4
- 28 Krishnamurthy R, Wang DJJ, Cervantes B, McAllister A, Nelson E, Karampinos DC, et al. Recent advances in pediatric brain, spine, and neuromuscular magnetic resonance imaging techniques. *Pediatr Neurol*. 2019;96:7–23.
- 29 Desale P, Dhande R, Parihar P, Nimodia D, Bhangale PN, Shinde D. Navigating neural landscapes: A comprehensive review of magnetic resonance imaging (MRI) and magnetic resonance spectroscopy (MRS) applications in epilepsy. *Cureus* [Internet]. 2024 Mar 26 [cited 2024 Sep 5];16(3):e56927. Available from: /pmc/articles/PMC11043648/
- 30 Hilabi BS, Alghamdi SA, Almana M. Impact of magnetic resonance imaging on healthcare in low- and middle-income countries. *Cureus* [Internet]. 2023 Apr 17 [cited 2024 Sep 5];15(4):e37698. Available from: /pmc/articles/PMC10112545/
- 31 Pysz MA, Gambhir SS, Willmann JK. Molecular imaging: Current status and emerging strategies. *Clin Radiol* [Internet]. 2010 Jul [cited 2024 Sep 6];65(7):500. Available from: /pmc/articles/PMC3150531/
- 32 Crişan G, Moldovean-cioroianu NS, Timaru DG, Andrieş G, Căinap C, Chiş V. Radiopharmaceuticals for PET and SPECT Imaging: A literature review over the last decade. *Int J Mol Sci* [Internet]. 2022 May 1 [cited 2024 Sep 6];23(9):5023. Available from: /pmc/articles/PMC9103893/
- 33 Kuhl DE, Edwards RQ. Image separation radioisotope scanning. *Radiology*. 1963;80(4):653–62.
- 34 Yandrapalli S, Puckett Y. SPECT Imaging. *J Clin Neurophysiol* [Internet]. 2022 Oct 3 [cited 2024 Sep 6];15(3):273. Available from: https://www.ncbi.nlm.nih.gov/books/NBK564426/
- 35 Chernov VI, Medvedeva AA, Zelchan RV, Sinilkin IG, Stasyuk ES, Larionova LA, et al. Radiopharmaceuticals for SPECT cancer detection.
- 36 van der Wall EE. Cost analysis favours SPECT over PET and CTA for evaluation of coronary artery disease: The SPARC study. *Neth Hear J* [Internet]. 2014 [cited 2024 Sep 6];22(6):257. Available from: /pmc/articles/PMC4031362/
- 37 Kugaya A, Fujita M, Innis RB. Applications of SPECT imaging of dopaminergic neurotransmission in neuropsychiatric disorders. *Ann Nucl Med* [Internet]. 2000 [cited 2024 Sep 6];14(1):1–9. Available from: https://pubmed.ncbi.nlm.nih.gov/10770574/
- 38 Brix G, Nekolla EA, Borowski M, Noßke D. Radiation risk and protection of patients in clinical SPECT/CT. *Eur J Nucl Med Mol Imaging* [Internet]. 2014 [cited 2024 Sep 6];41(Suppl 1):S125–36. Available from: https://pubmed.ncbi.nlm.nih.gov/24052089/
- 39 Berlin A, Glicksman R. Positron emission tomography. In Bailey DL, Townsend DW, Valk PE, Maisey MN, editors. *Emerging Technologies in Brachytherapy* [Internet]. 2017 [cited 2024 Sep 8]; (pp. 255–63). Springer London. Available from: https://link.springer.com/10.1007/b136169
- 40 Rong J, Haider A, Jeppesen TE, Josephson L, Liang SH. Radiochemistry for positron emission tomography. *Nat Commun* [Internet]. 2023 Jun 5 [cited 2024 Sep 8];14(1):1–23. Available from: https://www.nature.com/articles/s41467-023-36377-4
- 41 Ametamey SM, Honer M, Schubiger PA. Molecular imaging with PET. *Chem Rev* [Internet]. 2008 May [cited 2024 Sep 8];108(5):1501–16. Available from: https://pubmed.ncbi.nlm.nih.gov/18426240/
- 42 Zytoon AA, Elsayed EE, Nassar AI, Murakami K. Pivotal role of PET/CT in characterization of occult metastasis with undetermined origin. *Egypt J Radiol Nucl Med* [Internet]. 2020 Dec 1 [cited 2024 Sep 8];51(1):1–11. Available from: https://ejrm.springeropen.com/articles/10.1186/s43055-020-00357-1
- 43 Griffith LK. Use of PET/CT scanning in cancer patients: Technical and practical considerations. *Proc (Bayl Univ Med Cent)* [Internet]. 2005 Oct [cited 2024 Sep 8];18(4):321. Available from: /pmc/articles/PMC1255942/
- 44 John Hopkins Medicine. Positron Emission Tomography (PET) | Johns Hopkins Medicine [Internet]. 2022 [cited 2024 Sep 8]. Available from: https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/positron-emission-tomography-pet
- 45 Molnar O, Straciuc OM, Mihutiu S, Lazăr L. Impact of PET/CT imaging with FDG in locally advanced cervical carcinoma—A literature review. *Curr Oncol* [Internet]. 2024 Apr 29 [cited 2024 Sep 8];31(5):2508–26. Available from: https://www.mdpi.com/1718-7729/31/5/188/htm
- 46 Saber M, Shetty A. Positron emission tomography. *Radiopaedia*. org [Internet]. 2014 Jun 17 [cited 2024 Sep 8]. Available from: http://radiopaedia.org/articles/29716
- 47 Hicks RJ, Lau EWF, Binns DS. Hybrid imaging is the future of molecular imaging. *Biomed Imaging Interv J* [Internet]. 2007 Apr [cited 2024 Sep 8];3(3):e49. Available from: /pmc/articles/PMC3097677/
- 48 Even-Sapir E, Keidar Z, Bar-Shalom R. Hybrid imaging (SPECT/CT and PET/CT)-improving the diagnostic accuracy of functional/metabolic and anatomic imaging. *Semin Nucl Med* [Internet]. 2009 Jul [cited 2024 Sep 9];39(4):264–75. Available from: https://www.researchgate.net/publication/26267642_Hybrid_Imaging_SPECTCT_and_PETCT-Improving_the_Diagnostic_Accuracy_of_FunctionalMetabolic_and_Anatomic_Imaging
- 49 Mohan HK, Strobel K, van der Bruggen W, Gnanasegaran G, Kampen WJ, Kuwert T, et al. The role of hybrid bone SPECT/CT imaging in the work-up of the limping patient: A symptom-based and joint-oriented review. *Eur J Hybrid Imaging* [Internet]. 2018 Dec 1 [cited 2024 Sep 9];2(1):8. Available from: /pmc/articles/PMC5954706/
- 50 Bockisch A, Freudenberg LS, Schmidt D, Kuwert T. Hybrid imaging by SPECT/CT and PET/CT: Proven outcomes in cancer imaging. *Semin Nucl Med* [Internet]. 2009 Jul [cited 2024 Sep 9];39(4):276–89. Available from: https://pubmed.ncbi.nlm.nih.gov/19497404/
- 51 Rager O, Nkoulou R, Exquis N, Garibotto V, Tabouret-Viaud C, Zaidi H, et al. Whole-Body SPECT/CT versus planar bone scan with targeted SPECT/CT for metastatic workup. *Biomed Res Int* [Internet]. 2017 [cited 2024 Sep 9];2017:7039406. Available from: https://pubmed.ncbi.nlm.nih.gov/28812019/
- 52 Feng Y, Cheng B, Zhan S, Liu H, Li J, Chen P, et al. The impact of PET/CT and brain MRI for metastasis detection among patients with clinical T1-category lung cancer: Findings from a large-scale cohort study. *Eur J Nucl Med Mol Imaging* [Internet]. 2024 Sep 1 [cited 2024 Sep 9];51(11):3400–16. Available from: https://link.springer.com/article/10.1007/s00259-024-06740-8
- 53 Santos JC, Abreu MH, Santos MS, Duarte H, Alpoim T, Próspero I, et al. Bone Metastases detection in patients with breast cancer: Does bone scintigraphy add information to PET/CT? *Oncologist* [Internet]. 2023 Aug 3 [cited 2024 Sep 9];28(8):e600–5. Available from: https://dx.doi.org/10.1093/oncolo/oyad087
- 54 Gammel MCM, Solari EL, Eiber M, Rauscher I, Nekolla SG. A clinical role of PET-MRI in prostate cancer? *Semin Nucl Med*. 2024 Jan 1;54(1):132–40.
- 55 Dankerl P, May MS, Canstein C, Uder M, Saake M. Cutting staff radiation exposure and improving freedom of motion during CT interventions: Comparison of a novel workflow utilizing a radiation protection cabin versus two conventional workflows. *Diagnostics* [Internet]. 2021 Jun 1 [cited 2024 Sep 9];11(6):1099. Available from: /pmc/articles/PMC8235446/
- 56 Weinberg BD, Kuruva M, Shim H, Mullins ME. Clinical applications of magnetic resonance spectroscopy (MRS) in brain tumors: From diagnosis to treatment. *Radiol Clin North Am* [Internet]. 2021 May 1 [cited 2024 Sep 9];59(3):349. Available from: /pmc/articles/PMC8272438/
- 57 Shah N, Sattar A, Benanti M, Hollander S, Cheuck L. Magnetic resonance spectroscopy as an imaging tool for cancer: A review of

- the literature. *J Osteopath Med [Internet]*. 2006 Jan 1 [cited 2024 Sep 9];106(1):23–7. Available from: <https://www.degruyter.com/document/doi/10.7556/jaoa.2006.106.1.23/html?lang=en>
- 58 Bolan PJ, Nelson MT, Yee D, Garwood M. Imaging in breast cancer: Magnetic resonance spectroscopy. *Breast Cancer Res [Internet]*. 2005 Jul 12 [cited 2024 Sep 9];7(4):149–52. Available from: <https://breast-cancer-research.biomedcentral.com/articles/10.1186/bcr1202>
 - 59 Sharma U, Jagannathan NR. In vivo MR spectroscopy for breast cancer diagnosis. *BJR|Open [Internet]*. 2019 Nov 1 [cited 2024 Sep 9];1(1):20180040. Available from: <https://dx.doi.org/10.1259/bjro.20180040>
 - 60 Iqbal Z, Albuquerque K, Chan KL. Magnetic resonance spectroscopy for cervical cancer: Review and potential prognostic applications. *Cancers [Internet]*. 2024 Jun 5 [cited 2024 Sep 9];16(11):2141. Available from: <https://www.mdpi.com/2072-6694/16/11/2141/htm>
 - 61 Hänni O, Ruby L, Paverd C, Frauenfelder T, Rominger MB, Martin A. Confounders of ultrasound attenuation imaging in a linear probe using the Canon Aplio i800 system: a phantom study. *Diagnostics [Internet]*. 2024 Jan 26 [cited 2024 Oct 13];14(3):271. Available from: <https://www.mdpi.com/2075-4418/14/3/271/htm>
 - 62 Brower C, Rehani MM. Radiation risk issues in recurrent imaging. *Br J Radiol [Internet]*. 2021 [cited 2024 Oct 13];94(1126):20210389. Available from: <https://pubmed.ncbi.nlm.nih.gov/3528055/>
 - 63 DeStigter K, Pool KL, Leslie A, Hussain S, Tan BS, Donoso-Bach L, et al. Optimizing integrated imaging service delivery by tier in low-resource health systems. *Insights Imaging [Internet]*. 2021 Dec 1 [cited 2024 Oct 13];12:129. Available from: <https://pubmed.ncbi.nlm.nih.gov/3528055/>
 - 64 Budrys T, Veikutis V, Lukosevicius S, Gleizniene R, Monastyreckiene E, Kulakiene I. Artifacts in magnetic resonance imaging: How it can really affect diagnostic image quality and confuse clinical diagnosis? *J Vibroengineering*. 2018;20(2):1202–13.
 - 65 Zhou SP, Wan XC, Wang XD, Zhang XM, Yu YH, Wang WJ. Investigation and analysis of magnetic resonance imaging experience and psychological status of patients. *BMC Psychol [Internet]*. 2024 Dec 1 [cited 2024 Oct 13];12(1):1–10. Available from: <https://bmcp psychology.biomedcentral.com/articles/10.1186/s40359-024-01570-7>
 - 66 Dantendorfer K, Wimberger D, Katschnig H, Imhoff H. Claustrophobia in MRI scanners. *Lancet (London, England) [Internet]*. 1991 Sep 21 [cited 2024 Oct 13];338(8769):761–2. Available from: <https://pubmed.ncbi.nlm.nih.gov/1679897/>
 - 67 McKee M, Wouters OJ. The challenges of regulating artificial intelligence in healthcare: Comment on “Clinical Decision Support and New Regulatory Frameworks for Medical Devices: Are We Ready for It? – A Viewpoint Paper.” *Int J Heal Policy Manag [Internet]*. 2023 [cited 2024 Oct 13];12(1):7261. Available from: <https://pubmed.ncbi.nlm.nih.gov/40125205/>
 - 68 Shah RM, Gautam R, Shah RM, Gautam R. Overcoming diagnostic challenges of artificial intelligence in pathology and radiology: Innovative solutions and strategies. *Indian J Med Sci [Internet]*. 2023 Oct 19 [cited 2024 Oct 13];75(3):107–13. Available from: <https://ijmsweb.com/overcoming-diagnostic-challenges-of-artificial-intelligence-in-pathology-and-radiology-innovative-solutions-and-strategies/>
 - 69 BIR. The Global Future of Imaging [Internet]. 2009 [cited 2024 Oct 13]. p. 7–9. Available from: <https://www.bir.org.uk/get-involved/world-partner-network/global-future-of-imaging.aspx>
 - 70 Buaka ESD, Moid MZI. AI and medical imaging technology: Evolution, impacts, and economic insights. *J Technol Transf [Internet]*. 2024 [cited 2024 Sep 9];1–13. Available from: <https://link.springer.com/article/10.1007/s10961-024-10100-x>
 - 71 Ali O, Abdelbaki W, Shrestha A, Elbasi E, Alryalat MAA, Dwivedi YK. A systematic literature review of artificial intelligence in the healthcare sector: Benefits, challenges, methodologies, and functionalities. *J Innov Knowl*. 2023 Jan 1;8(1):100333.
 - 72 Jiang X, Hu Z, Wang S, Zhang Y. Deep learning for medical image-based cancer diagnosis. *Cancers (Basel) [Internet]*. 2023 Jul 1 [cited 2024 Sep 9];15(14):3608. Available from: <https://pubmed.ncbi.nlm.nih.gov/4010377683/>
 - 73 Gangurde R, Jagota V, Khan MS, Sakthi VS, Boppana UM, Osei B, et al. Developing an efficient cancer detection and prediction tool using convolution neural network integrated with neural pattern recognition. *Biomed Res Int [Internet]*. 2023 [cited 2024 Sep 10];2023. Available from: <https://pubmed.ncbi.nlm.nih.gov/4010377683/>
 - 74 Dabeer S, Khan MM, Islam S. Cancer diagnosis in histopathological image: CNN based approach. *Informatics Med Unlocked*. 2019;16:100231.