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# A Technical Overview and Comparison between PET and MRI Scanning

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ABSTRACT
About a century ago, doctors were unable to view the inside of their patient's body other than cutting the body open. However, this changed literally upon the invention of various useful medical imaging techniques which were able to produce images of the internal organs and bones without causing pain to the patient. Over the years, vast developments resulted in the establishment of several cross-sectional imaging scans. This paper aims to provide a critical review on the use of two of the famous techniques; MRI and PET scans. The paper highlights the strengths and weaknesses of each of these techniques along with briefly mentioning the recent developments in this area concerning the use of these techniques. In addition, this manuscript also sheds some light on the novel and hybrid technology of integrating MRI and PET.

**Key words:** MRI, PET, hybrid technology

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## INTRODUCTION

Over the last couple of years, managing various deadly diseases such as cancer has become possible due to the widespread use of cross-sectional imaging, which plays a vital role in anatomically imaging modalities. Nowadays, several procedures such as scans exist that can be used for analysing and checking different diseases in humans and animals. To elaborate, medical imaging offers a deeper look into a patient's clinical information. These scans include ultrasound, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET). While the first three are able to provide illustrations of the internal organs and tissues in an individual's body, the latter can provide a clearer understanding of more complex systemic diseases by providing the cause of problems at cellular levels (Wolbarst, 1999). All these methods of medical imaging have been made conceivable due to the availability of powerful and inexpensive computers. Overall, all these procedures along with several more invasive and non-invasive techniques have their own advantages and limitations. Nevertheless, they all have served greatly towards the detection and diagnosis of diseases in several patients. Even then, it is worth mentioning that these scans may misdiagnose diseases leading to detrimental issues. Hence, it is important that each technique is understood carefully for an accurate diagnosis.

Based on the crucial importance of these techniques, this paper aims to provide a brief overview on two of the abovementioned techniques. This critical review is focused on the use of MRI and PET scans and intends to offer a comparison between these procedures while highlighting the advantages and disadvantages of each of these techniques. In addition, the review will also mention the recent developments and current research where a combination of these techniques is made possible.

### Magnetic Resonance Imaging (MRI)

MRI is a relatively new technique as compared to the other methods discovered in radiology. In 1895, Wilhelm Rontgen first revealed the technique of x-ray imaging (Röntgen, 1896). In the late 1940s, George Ludwig was the first to apply ultrasound for medical purposes (Ludwig and Struthers, 1949). In terms of the computed tomography (CT) scanners, these were comprehended in 1967 (Richmond, 2004). As far as nuclear MR is concerned, this dates to the most noteworthy works carried out in 1938. In these, Isidor Isaac Rabi directed a beam of molecules through a magnetic field. This helped him demonstrate that radio waves can emitted in this manner at a specified frequency. Later, Felix Bloch and Edwards Mills Purcell both elaborated the works of Isidor on solids and liquids. Following on, in 1971, Raymond Damdian was able to suggest that MR relaxation times could be a good use for distinguishing cancer from healthy tissues (Damadian, 1971). Two years later in 1973, Paul Lauterbur showed the possibility of using nuclear MR for creating images. Finally, in 1977, the first human MR images were generated. This was six years after the production of first CT imageries. In a few years, noteworthy articles started to publish in journals such as Radiology (Swartz and Wiesner, 1972; Crooks et al., 1980; Hansen et al., 1980; Wolff et al., 1980). By the start of 1980s, publications related to major body organs such as the brain, spine, chest and pelvis started to appear (Modic et al., 1983; Ross et al., 1984; Lee et al., 1985; Lee and Deck, 1985; Gomori et al., 1985; Felix et al., 1985; Brant-Zawadzki, 1988;

Chezmar et al., 1988; Heiken and Lee, 1988; Heywang et al., 1989). Thereafter, several remarkable advances took place in MR imaging technology (Blamire, 2008) including advances in the hardware, the magnet design (Alfidi et al., 1982), hybrid MR imaging systems (Pichler et al., 2010), RF systems (Ehman, 1985; Edelman et al., 1985), imaging techniques (Mansfield and Maudsley, 1977; Damadian et al. 1977; Edelstein et al., 1980), rapid imaging (Sodickson and Manning, 1997), cardiac MR Imaging (Manning and Edelman, 1993; Bundy et al., 1999), MR Spectroscopy (Stadlbauer et al., 2006) and the functional MRI of the brain (Basser and Jones, 2002) and the body (Taouli et al., 2003; Iacconi, 2010; Scherr et al., 2010). It is worth mentioning that Edelman (2014) provides an excellent and detailed review on the overall history of MR imaging.

The MRI technique utilises the body's natural magnetic characteristics so that complete images can be produced of the body part under investigation. In order to produce images, a hydrogen nucleus is utilised as it is found in very large quantities in waters and fats. This hydrogen nucleus acts in a similar manner to a bar magnet. Normally, this single proton spins in the body with its axes randomly aligned. As the body is situated in a strong magnetic field, that is, during the investigation of a MRI scan, the proton's axes all tend to line-up. This even aligning results in the creation of a magnetic vector, which is focused along the MRI scanner's axis. Upon application of additional energies, which are in the form of radio waves, to the magnetic field, the magnetic vector deflects. Also, the frequency of the radio wave, which leads to the resonation of the hydrogen nuclei is reliant on the element utilised (which is hydrogen, here) along with the power of the magnetic field. It is worth mentioning that MRI scanner are available in varying field strengths, normally between 0.5 and 1.5 tesla. By electronic means, the strengths of the magnetic fields can be modified down the length of the body with the use of electric coils along with modifying the local magnetic fields. This allows for the varying resonation of different parts of the body as varying frequencies are directed. Finally, as the radio frequency source is shut, the magnetic vector then goes back to its resting state. This process results in a signal to be released, which can be utilised to produce Magnetic Resonance images. The presence of a receiver coil helps in acting as an aerial to enhance the finding of the emitted signal, around the body part being analysed. The received data can be post-processed by plotting the obtained signal and producing cross-sectional images (Berger, 2002; Vijayalaxmi et al., 2015). Figure 1 shows the equipment used in MRI scans.

**Figure 1:** A typical MRI scanner equipment (Vancouver Radiologists, P.C., 2019).

Overall, MRI scans utilise magnetic fields and radio waves to produce illustrations of body parts, organs and tissues inside the human or animal body. Hence, these illustrations can allow for the determination of any injuries or unhealthy tissues within the body. In addition, these tests can also help analyse the post treatment recovery.

**Applications of MRI**

An MRI scan can be performed on several parts of a body. Figure 2 shows the various body parts which are commonly investigated by an MRI scan (Vijayalaxmi et al., 2015).

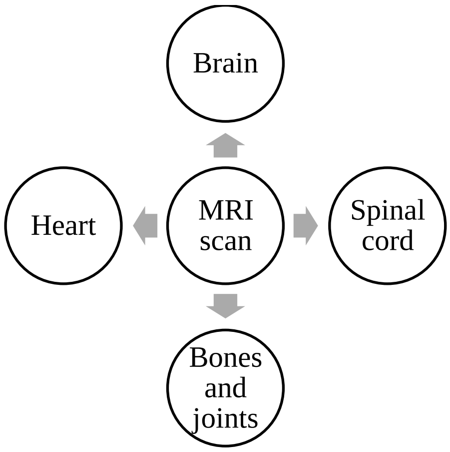


**Figure 2:** Several body parts which are commonly investigated by an MRI scan.

An MRI scan of the brain and spinal cord is based on determining the following; any damages to the respective blood vessels, injuries in the brain (Vijayalaxmi et al., 2015), cancers, multiple sclerosis, spinal cord injuries and stroke. Also, it can predict the possibility of an Alzheimer's disease (McGeer et al., 1986; Patil et al., 2015). An MRI scan of the heart and blood vessels is able to determine the blocked blood vessels in the heart and any possible damages due to heart attacks. In addition, cardiac MR imaging can help in predicting heart diseases and any issues with the structure of the heart (Saeed et al., 2015; Vijayalaxmi et al., 2015; Captur et al., 2016). An MRI scan of the bones and joints helps in the analysis of bone infections and any damages to joints or disc issues in the spine. In addition, it also helps determine any related cancers and pains in the nerve endings in neck and lower back (Vijayalaxmi et al., 2015; Gaweł et al., 2018).

Further, MRI scans can also be performed to analyse the health of various other vital organs such as breasts and ovaries (in women), liver, kidneys, pancreas and prostrates (in men) (Vijayalaxmi et al., 2015). Also, several more hybrids of MRI exist which are suitable to certain specified locations of the body.MRI is an excellent investigation technique for investigating neurological and musculoskeletal problems.

**Positron emission Tomography (PET)**

In terms of the technique of Positron Emission Tomography (PET), a lot of work has been performed over the last few decades. In 1929, a useful radionuclide was produced for the first time by Ernest O. Lawrence. This medical radionuclide was then delivered to a hospital for medical research in 1946. Soon, in 1951, Benedict Cassen and colleagues was able to invent a rectilinear scanner for providing illustrations of a thyroid gland (Abraham and Feng, 2011). This was based on the spread of an iodine radio tracer. Hence, this marked the start of imaging in nuclear medicine. Within a year, a new technique for nuclear imaging was invented with a gamma camera (BER, 2001). This was considered the mainstay for the upcoming 50 years. Finally, in 1953, Gordon Brownell constructed the first device for detecting and exploiting positron electron annihilation as an imaging too. This was a forerunner for forthcoming PET scanners (Portnow et al., 2013). In 1958, as a result of remarkable research, a generator system was introduced which made use of Technetium-99m, which later became one of the most used medical radioisotopes worldwide. In 1959, a scanner was produced which is now considered as the ancestor to CT scanners. Within just two years, a scientist developed a direct forerunner of PET (BER, 2001). After the invention of a more efficient method for producing Thallium-201, which is a commonly used radiopharmaceutical in medical imaging, the first PET scanner was built for humans in 1974 by a couple of researchers. The system involved making use of advanced algorithms for computing 3D images. Soon after, new radiopharmaceuticals were developed, which could be used as PET radio tracers. These included Fludeoxyglucose F 18 (Abraham and Feng, 2011) and Iodine-131. Further advancements and developments allowed for diagnosing and treating various cancers and tumours. By 1986, a high-resolution PET scanner was developed (BER, 2001).

As mentioned earlier, significant amounts of works have been done in PET. Hence, it is now a successful technique used frequently for the detection and studying of crucial diseases such as Alzheimer, strokes, epilepsy and to locate tumours within bodies (Abraham and Feng, 2011). Moreover, it has developed through several different disciplines. These include a number of discoveries, careful analyses, and experimental works.

Positron Emission Tomography (PET) is a kind of nuclear imaging technique, which has gained an increasing interest in the fields of nuclear medicine (Farhad et al., 1990; Shuklaand Utham, 2006) due to its ability to perceive metabolic processes in the body along with predicting and diagnosing any diseases (Berger, 2003). The basic principles behind this technique involves considering the process as a camera which can capture images of high-energy gamma-rays, which are emitted from the interior of a body (Gambhir, 2002). A radiopharmaceutical agent with a positron emitting isotope is the main component of such an examination. This is mainly a radionuclide, which acts as a radioactive tracer in the process. Some of the common isotopes are oxygen-15, nitrogen-13, carbon-11, gallium-64 and fluorine-18. This tracer is administered into the subject's body in small amounts. The PET facility then is able to detect any radioactivity, that is, by the detection of pairs of gamma-rays, which are emitted by the tracer. PET scans usually last for a few minutes and the data received can be used to produce 3D images of the tracer concentration with the aid of a computer analysis (Berger, 2003). This technique helps in successfully providing information about the biochemical and physiological functions in the body (Farhad et al., 1990). Hence, this technique provides quantifiable analyses, allowing for relative changes to be monitored over time inside the body. Figure 3 shows the equipment used in PET scans.

**Figure 3:** A typical PET scan equipment (nhs.uk, 2019).

**Applications of PET**

PET scans are normally performed to recognise lapses in cognitive functions. They are also done to check the functioning of the heart and in the diagnosis of cancers while also examining how the body is reacting to cancer. As Farhad et al. (1990) and Berger (2003) mention, PET scans are also useful in measuring the metabolic rates of glucose consumption in various body parts such as the brain and heart. In addition, the clinical use of this technique lies in its ability to differentiate between benign and malignant tumours. Hence, the examination can assist in cardiology. Thus allowing for the detection of several cancer types (Berger, 2003). Further, this technique can help medical advisors in pinpointing the locations of epileptic foci in seizure disorder patients (Farhad et al., 1990). Also, this process can aid in identifying the different types of dementia and degenerative diseases. These can include Alzheimer's disease and Parkinson's disease.

Section 4 lists the specific advantages and disadvantages of both these techniques while also providing a brief comparison between these two scans.

**Comparison between MRI and PET scans**

Both, MRI and PET scans are imaging exams performed to understand issues within an individual's body. However, there are some significant differences between these techniques, as shown in earlier sections. Also, while these two techniques are quite comparable, each one of them has its own benefits and limitations. Generally, MRI scans are able to generate images of internal organs in an individual's body (Berger, 2002). Whereas, PET scans are able to provide a much deeper look into the individual's body by generating images that can help a medical doctor to view complex systemic diseases at cellular levels (Berger, 2003).

Similar to PET, MRI scans are able to determine the structural characteristics of the various organs along with providing vital information on their physiological status and pathologies (Wolbarst, 1999). With the invention of MRI, the resulting images had an overall low quality in terms of resolution. They also took a long time to produce. However, with the recent advancements in computing, much detailed and quicker images are produced with MRI scans.Types of MRI such as functional can also show the developments inside a brain by offering an insight into the brain's activity (Chen and Gary,2015).

In terms of PET scans, these have an intrinsically high sensitivity and an unlimited depth of penetration. PET scans are also quantifiable and have the ability to produce higher resolution tomographic images. Hence, PET is a versatile technique as it can potentially target any biochemical or molecular events, which might not be possible with a simple MRI scan. Whereas, MRI suffers from an inherently lower sensitivity, which can, however, be overcome through signal amplification. Furthermore, PET possesses the potential to revolutionise diagnostics along with therapeutic monitoring in both, clinical and pre-clinical situations (Nair-Gill et al., 2008). PET also has been used extensively in assessing the suitability of a heart for the bypass surgery (Wolbarst, 1999).

In terms of MRI scans, no known biological hazardsexist as compared to X-ray and Computed Tomography (CT) tests. Also, MRI makes use of the radio frequency range, which is present around humans and animals and thus is not likely to cause any damages (Berger, 2002). Even then, there are a few issues associated with MRI scans. Patients who have pacemakers in their bodies or metal valves can have some problems as these items can pose a danger in MRI scans due to possible movement with an introduction of a magnetic field. While metal prostheses and implants may not pose a serious problem, some distortion to the produced images is possible (Berger, 2002). Moreover, MRI can be considered a safer option for young individuals. However, possible limitations of MRI include it requiring longer periods of time, comparatively, for the examination. This is a problem as some people are claustrophobic. In addition, some precautions are necessary before the examination commences.

MRI scans can offer molecular and anatomical detailsinside a singleimaging mode. It can provide a high-resolution anatomical information with good soft tissue contrast. Whereas, the technique of PET involveslower spatial resolution, and usuallyhas limited anatomical information (Catana et al., 2013). Nevertheless, the molar sensitivity of MR for different metabolites is much lower in scale as compared to PET. Hence, there are potential limitations in terms of the kinds of targets which can be reached using MRI scans. Another challenge associated with the use of MRI is the absolute quantification of substrate concentration (Catana et al., 2013). Furthermore, if a specific medical issue is considered, for instance, the diagnosis of colorectal cancer, the best method to study this disease is to perform endoscopy followed by CT scans. In terms of the traditional techniques, the abovementioned ultrasounds and MRI are normally used in diagnosis. However, earlier reports have shown that these traditional modalities tend to have a suboptimal part in managing colorectal cancers. Therefore, researchers are now focusing more on molecular-based imaging techniques, such as PET. In spite of that, the main drawbacks of PET lie in its spatial resolution and the fact that the technique involves ionising radiation (Catana et al., 2013). The radiation exposure poses a possible risk on the patients and the health care professionals. Other limitations of PET include the costly preparation of the required radiopharmaceuticals which might not be readily available. Figure 4 shows an excellent comparison between the results obtained by a PET scan and a MRI scan.

An interesting study by McGeer et al. (1986) provides a detailed assessment of PET, MRI and CT scan in a patient with Alzheimer's disease. The study reveals that after the death of the patient, the gross appearance of the brain correlated with MRI and CT. These appeared considerably less revealing as compared to PET. PET was correlated with the microscopic discoveries of neuronal losses. Finally, the study concluded that the integrated version of PET provided a better analysis on the severity of the disease as compared to MRI or CT scans.

The following section briefly mentions the recent developments in the medical imagining fields, where possible integration of different techniques is made possible.

**The integration of MRI and PET medical imaging techniques**

As mentioned earlier, both approaches, MRI and PET have their own strengths and weaknesses. Based on their complementary natures, researchers in the past attempted to integrate both of these techniques. This was done to achieve a hybrid method, which may offer better and promising results. The integration of PET and MRI in a single exam can provide the positive characteristics of both the techniques. In addition, this would allow for the mitigation of some of the disadvantages related with the individual practice of these techniques (Catana et al., 2013). Research shows that this novel approach has assisted in the diagnosis of the potential oncologic, cardiac and neuro-psychiatric diseases. In addition, Catana et al. (2013) confirmed that the investigation of PET and MRI has the scope of benefitting future developments, where this hybrid approach might have a broader impact. Figure 4 shows an excellent comparison where the results of a PET scan are shown with the MRI results. In addition, the figure shows the resulting image which is generated with the integration of the two techniques.

Furthermore, Schneider and Feussner (2017) explain that this integration combines the metabolic and molecular data of PET with the outstanding anatomic depths of MRI systems. This results in an overall enhancement to the image quality. Nevertheless, even this technology suffers from some limitations. While the integration can aid in improving the diagnosis and monitoring of treatments by providing intricate structural details, the system has relatively high associated costs. This is a challenging aspect, which needs to be carefully considered. Another advantage of this system is that the examination times are comparatively shorter as patients are not required to be moved from one system to another.

Chua and Groves (2014) mention that this integration is the most complex technology, which has evolved, specially in the field of biomedical. They indicate that the technology has the potential to target multiple molecules of interest, simultaneously. In addition, this hybrid system can be used for accurately examining different biological processes.

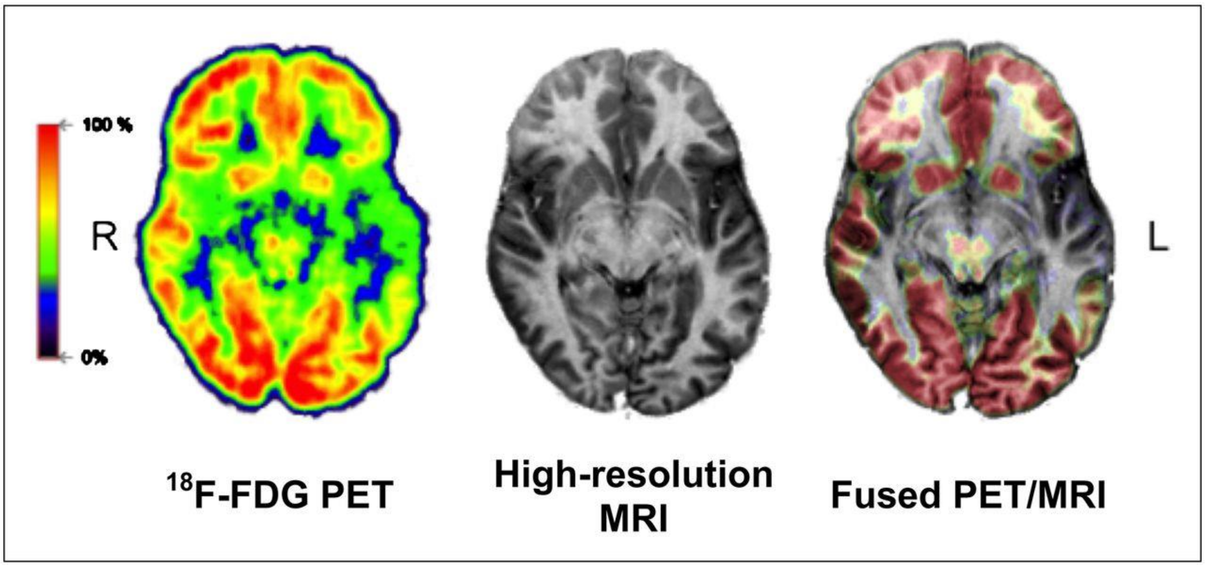


**Figure 4:** A comparison showing the results of a PET scan, MRI scan and a fused PET/MRI scan(Young Investigators Review, 2019).

## CONCLUSION

Human and animal diseases are biochemical in their nature. Hence, a successful approach to this issue would involve providing a biochemical solution. This suggests the importance of a diagnosis in medical patients. In the current practice of medicine, it is extremely important to obtain the biochemical information of the medical patient in order to fundamentally understand the nature of the disease. Different medical imaging, diagnostic exams with high sensitivities and specificities can assist in the accurate prediction of the biochemical knowledge inside the human and animal bodies. Both, MRI and PET scans have proved to be successful measures of assessing critical information related for analysing and checking different diseases in humans and animals. To elaborate, medical imaging offers a deeper look into a patient's clinical information.

Overall, MRI is an excellent approach that utilises magnetic fields and radio waves, which helps understand the structural details of the various body organs along with offering information on their physiological status and pathologies. PET is a highly specialised form of nuclear imaging technique, which makes use of a few unusual atomic nuclei to quantitatively study sensitive assays of a wide range of biological processes.

Finally, it can be stated that if improvements are continued in these instrumentations in addition to the hybrid integration of these two techniques along with possible cost reductions, their overall market has the scope to be expanded.

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