A critical review on medical imaging techniques (CT and PET scans) in the medical field

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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; CT 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 CT and PET.

Keywords: imaging techniques, X-ray, CT, PET, virus, brain, medical devices.

1. Introduction
Advancements in medical imaging over the last few decades have improved the quality and efficiency of medical diagnosis. The choice of different imaging methods for different purposes helps to streamline and make improvements to enhance the scope of one method and not necessarily replace the other. A popular diagnostic tool in use is called Positron Emission Tomography (PET) Scan. The setup makes use of biologically active tracers which is usually ingested or injected into the body [1, 2, 3; 4]. The nature of the biologically active tracer can be varied to suit the requirements of the desired measurement. The computer then processes the data measured to produce a contour plot of the body or the section required. Another method in use today is known as a Computed Tomography (CT) Scan. This process makes use of X-ray measurements taken from multiple angles to create a cross-section image [5]. In certain situations, PET scan and CT scan are used in combination to obtain a
comprehensive diagnostic report. This paper aims to discuss the history and the science behind the two different methods, the key differences between the two methods, their limitations and their applications. Additionally, this paper will also discuss advancements in the integration of these two methods.

2. Computed Tomography Scans (CT)

With advancements in computers and technology, researchers in 1960s were able to produce computed tomographic images using computers. In the late 1960s, the first CT scanner was invented, as demonstrated in Figure 1a, and by early 1970s, the first CT scan on a patient was performed. Dramatic changes appeared in 1970s in the field of medical as the technique of Computed Tomography (CT), also referred to as CAT scanning, was introduced by two noteworthy researchers in the fields of medicine and science [6, 7, 8]. Over the next couple of years, clinical CT scanners developed and were used. While the initial invention dealt with head scans only, later improvement made whole body scans possible, as shown in Figure 1b. By 1980s, CT scans were well known and widely used. Today, there are nearly 30,000 CT scanners installed in the world [8, 9]. Enhancements and improvements included work done on the speed, patient comfort and resolution. This further allowed for an increase in the anatomy scanned. In addition, the problem of organ movement due to respiration is avoided in CT scans. In fact, current CT scans are more user-friendly and provide superb image qualities [11, 12]. CT scan opened the doors for better treatment for different fatal diseases like cancer, strokes, heart issues, orthodontics and injuries due to accidents [13, 14]. Recently, due to the epidemic COVID-19 the CT was used in china to diagnose the detected patient with corona virus and it was reported it is high sensitive which needs to be studied carefully with further researches [15].

There are several imaging modalities available, but the technique of CT scans is fast and easy for use by several medical teams and physicians. It also allows the relevant authorities to make conclusive decisions regarding the nature of illnesses. CT scans have a crucial part in the reduction of surgeries. This is because after a patient has a CT Scan, it is known that the test rate of surgeries is reduced from 13% to 5% since an alternate treatment is recommended. On the contrary, the use of CT scans has declined the number of patients visiting clinics and hospitals repeatedly [16, 17]. Nowadays, this technology is improving and moving forward progressively in imaging modalities and successful results are seeming to appear due to less scanning times required along with higher resolution images produced. As a result, the field of CT scan has expanded in a larger range. For example, colonography, angiography and urography are all now covered and tested using CT scans. The use of CT scans in medical field has been an effective technology as number of CT scans have tended to increase from 3 million in 1980 to 62 million in 2007, in USA alone [18, 19, 20]. However, the fact of radiation exposure to the patient by the application of CT scans cannot be ignored. It has been noted by a study in the USA in 2009 that the 75.4% of effective radiation doses delivered from CT scans are about 7 times higher than X-ray based tests [21, 20].

![Figure 1: (a) The first EMI head scanner with Godfrey Hounsfield and (b) the first whole body scanner with Robert Ledley [22].](image)
Nowadays, CT scans are a famous and common test based on images, which can describe the condition of a patient precisely. The advancements in computed tomography technology in the last few years are noticeable [8]. This is due to the introduction of techniques such as cone-beam, extreme multi detector, dual-energy, iterative reconstruction algorithms, portable and phase-contrast in CT technology [5]. Figure 2 is an excellent example of the advancements made in the CT Scan technology where Figure 2a shows the first scan ever made on a human tumour. The tumour is represented by the black shadow in the upper left of Figure 2a. Figure 2b shows a recent CT scan, which represents the bleeding in the brain, demonstrated by the light grey shading in the lower right of the image.

![Figure 2: (a) First CT scan of a human tumour and (b) a recent CT scan of the brain [22].](image)

### 2.1 Issues concerning CT Scans

Movement of body parts of a patient during a CT scan test is an unavoidable issue as produced images tend to be blurred, known by artefacts. The involuntary movements include respiratory, cardiac and gastrointestinal, which are the main causes of such blurred images [23, 24]. To compare these 3 types of motions, the largest organ movement is due to respiratory motion but is still conceivable. This issue is usually solved by introducing number of new and efficient ways, which can eliminate artefacts completely or partially from CT scans. Such improvements not only have a significant effect on CT scans but tend to also have a good impact on radiotherapy as it allows for the elimination of undesirable effects of organ motion in radiotherapy as well, leading to improved results being obtained [24, 8].

Radiation exposure and as a result cancer risks with CT scanning are becoming a common problem today. The side effects of CT scans on the community cannot be ignored due to the rapid increase of this examination being taken [14; 25, 26, 27]. During CT scans, the ionising radiation doses injected to a patient must be carefully checked. This is because in long-term, useful organs in the body might develop cancers and leukaemia issues in patients who have undergone CT scans (Royal, 2008). Hence, the chances of developing cancers during one’s lifetime increase in patients going through CT scans as they are subjected to large doses of ionising radiation. It is still ambiguous that low dose ionisation used in standard diagnostic tests can also cause cancers in the long-term or not [20].

To study the link between radiation and neoplasia, where the latter refers to the formation of abnormal growth of tissues, experts extrapolate the data from survivors of atomic bombs, which were directed in Japan in the year 1945 [20]. Researchers also evaluate the risk of neoplasia in people working in the nuclear industry and hence those who are exposed to radiations [28]. Using extrapolation, small hypothetical risks can be multiplied by a large number of patients. This further allowed Brenner and Hall (2007) to estimate and forecast the future of cancers in US. In their research, they were able to indicate that in the next few years, about 1 to 2% in the US would be developed due to ionising radiation, which is used in medical imaging. Furthermore, another study also projected that about 29,000 cancers and 14,500 deaths could be anticipated every year, in addition to the current statistics.
[25, 29]. Other disadvantages of CT scans include the cost associated with this procedure and the data produced from CT scans may be inadequate as compared to other imaging techniques [8, 30].

3 Positron Emission Tomography (PET)

Significant amount of work has been carried out in the fields of PET. The history of this technique shows that a useful radionuclide was first created in 1929, which was later transferred to a hospital for further research in 1946. In a few years, some researchers invented a type of scanner which could provide images of thyroid glands [31]. As a result, imaging started to take place for the first time in the fields of nuclear medicine. Gamma cameras in nuclear imaging also became important [32]. Soon, the first device to detect and exploit a positron electron annihilation was made. This was the beginning of the current widely used technology of PET scanners [33]. Further research in this field involved the use of Technetium-99m, one of the most widely used radioisotopes. Continuing research by investigators and researchers allowed for the invention of the first PET scanner in 1974 that was used for humans. 3D illustrations were computed through the utilisation of advanced algorithms. Afterwards, there was a growth in the introduction of new radio pharmaceuticals for use as PET radioactive tracers. Further advancements in this technique resulted in valuable predictions and treatments of several types of cancers, tumours, strokes, epilepsies and Alzheimer's disease along with the development of high-resolution scanners [3, 32, 34-40].

PET is classified under nuclear medicine as it makes use of radioactive tracers to aid in diagnosis. There are several isotopes which are commonly considered such as 18-F, 64-Cu, 68-Ga, 86-Y, 77-Br, 76-BR, 124-I and 11-C [3, 41]. There are primarily two parts to the procedure. The first part consists of injecting a radioactive tracer with a short half-life into the patients' bloodstream. There is a small waiting period as the tracer flows around the body and pools close to the regions of interest. The tracer used depends on the variable that is to be measured or assessed. The most commonly used molecule is fluoro deoxy glucose (FDG) and usually has a 1-hour waiting period as the molecule concentrates close to the tissue. The second part is the scan itself. Since the molecules used in this process have a relatively short life, it makes it ideal for diagnosis that can be completed in a few hours instead of several days. As the molecule decays, it releases a positron which is also referred to as a positive beta decay process. The positron has a positive charge and as it travels upwards, it combines with an electron releasing gamma rays. This is specifically detected by the scanner. As it reaches the scintillator, located inside the scanning device, a photomultiplier tube captures the light. The process is very highly dependent on detecting photons which are not received in pairs, i.e., there exists a reasonable delay between two data points about a few nanoseconds [3; 41, 42, 43].

PET has widespread applications in different areas of medicine. It can be used as a research and also as a diagnostic tool. PET in clinical methods involve identifying head tumours, breast and prostate cancers, neurodegenerative diseases amongst others [44-47]. Figure 3 shows the images generated by a PET scanner for a normal brain and a brain with the Parkinson disease.

In oncology, 18-F, used as FDG is important in mapping organs with high glucose uptakes helping to isolate the brain, liver and cancerous cells. Neurology application involves mapping brain activity. Particular use can be pointed towards identifying Alzheimer’s disease. Alzheimer causes regions of the brain to reduce glucose and oxygen uptake and is can be identified using FDG-PET of the brain. Specific radiotracers that have been developed for specific neuroreceptors include 11CDASB and 11CMcN 5652 for serotonin transporters, 18F-fallypride and 11C raclopride for dopamine D2/D3 receptors, or enzyme substrates [3, 41, 46-50]. PET is known to be a growing technology. Several practices are anticipated to grow in the upcoming future, mainly in the fields of drug research and molecular medicines.
3.1 Issues concerning PET scans

While PET is known to be widely used and is an excellent technique, there remain some limitations associated with this technique. To elaborate, Cyclotron is required in producing the short-lived radionuclides in PET scans. Cyclotron is an expensive apparatus and thus increases the total costs of PET scans making this technique much costly as compared to other imaging techniques in the fields of medicine. In addition, for producing the relevant radio pharmaceuticals, specific onsite chemical synthesis equipment is needed. This again increases the complexity of the overall technique [3, 41]. Furthermore, even though the radionuclides are short-lived, these may raise some concerns, especially for pregnant subjects. The radioactive rays are not long-lasting, but the exposure may have some dangers to the patients. It is also known that PET imaging tools are very sensitive, hence are unable to filter any irregular chemical imbalances in the patients.

Nevertheless, researchers continue to perform works for minimising radiation doses of the use of radionuclides. Also, it must be appreciated that PET has a huge role in the diagnosis of crucial diseases such as cancers. Here, the prediction and awareness of the disease is much more important than the risk of test radiations [3, 41].

4. Integration of PET and CT scans

The integration of Positron Emission Tomography and Computed Tomography (PET-CT) results in the production of sophisticated, detailed and valuable medical reports relating to cancers, specially. While a CT scan deals with the collection of X-rays from various parts of the body to produce a 3D image, a PET scan makes use of a mild radioactive drug to review those areas in a body where cells tend to be more active than normal [3, 52, 53].

The combination of PET and CT scans is believed to result in more error-free and authentic results for the diagnosis of cancers. PET-CT scans are used to diagnose several kinds of cancers. In fact, they can assist in determining the intensity of a cancer and also the stage of a particular cancer. In addition, such scans are helpful in deciding if a surgery can take place to eliminate the cancer and the best possible treatment for treating the cancer. Also, PET-CT scans are able to evaluate if a previously removed cancer has returned. They can also be used to plan radiotherapy treatments along with reporting the recovery progress from cancer. Furthermore, further to a cancer treatment, it is likely that there is some scarring left. This might arise concerns in terms of if the cancer has not been eliminated completely. In such a case, PET-CT scans are able to determine if the scarring is an active cancer or not [54]. Figure 4 shows an illustration of the current generation of hybrid PET/CT scanners which can generate attenuation maps along with providing detailed anatomic information.
Figure 4: A combination of the PET and CT imaging systems for anatomic imaging [55].

Overall, the use of PET-CT scans is the subject of growing research and several researchers are investigating the possibilities and scopes of expansion to this new technology [56]. Further, the use of PET-CT scans has assisted in the correct localisation of small areas of enhanced radiotracer activity, which would not be possible or manageable to localise using PET technique alone. In addition, abnormal activity in structures can also be differentiated from normal activity by these scans. The technology of PET-CT integrates the benefits of both, PET and CT scans. While the PET portion in this integration offers the provision of high-quality functional information, the CT part not only offers excellent spatial and contrast resolution but is also able to show other crucial diseases in the patient’s body [57].

4.1 Possible risks of PET-CT scans

A number of people undergo PET-CT scans and overall it is a safe test but there are some risks associated with the use of this test, which must be considered by practitioner and radiographers. To elaborate, in case of pregnancy in women, doctors recommend the use of PET-CT scans only if there is an emergency. This is because the development of the embryo in the womb could be possibly affected by the radiations which are considered harmful for it. Hence, it is better that patients take precautions before undergoing such a test. In terms of breast-feeding women, they should inform the relevant authorities prior to the test. This is because doctors usually suggest discontinuing breast feeding for a while after taking a PET-CT scan as the breast-fed baby might be affected negatively. Overall, there are always slight possibilities of developing cancers in the future for those who are exposed to radiations during such PET-CT scans [58].

Minor issues associated with the use of PET-CT scans include the development of some bruising and swelling. Due to being injected by needles, some minor bruising may develop. Also, there are also chances that the radioactive tracer might leak outside the subjected vein during the test, resulting in pain and discomfort for the patient. In addition, it is also likely to develop allergic reactions due to radioactive tracers in the patients. This may also result in breathlessness in patients and increased
sweating. Allergies and intolerances may also cause vomiting, which can contaminate the equipment thus resulting in delays to subsequent examinations [59, 60].

5. Conclusion

It is well known that diseases occurring in humans and animals are usually biochemical in nature. Therefore, a biochemical solution is often the best way to predict these diseases. Diagnosis is very important in the fields of medicine in order to fully understand the health of the subject. Obtaining biochemical data of a patient is crucial for understanding the disease. To do so, several imaging techniques are available. Computed Tomography (CT) and Positron Emission Tomography (PET) are two widely used imaging techniques, which have been proven successful in diagnostic exams due to their enhanced sensitivities and specificities. These techniques are capable to precisely and correctly predict various diseases and can provide a look into a patient’s medical health. Overall, CT is a renowned technique, which makes use of a series of X-ray images at varying angles along with utilising computer processing. This integration allows CT scans to produce cross sectional illustrations of the tissues, bones and blood vessels inside the body. Hence, this technique is more accurate and useful than a simple X-ray. PET is a dedicated form of nuclear imaging technique. PET makes use of atomic nuclei to understand sensitive assays of range of biological processes. However, both CT scans and PET scans have some limitations associated with their use, mainly in terms of the radiation dose to the subject. Nevertheless, if improvement works are continued in these techniques, then it is expected that any possible issues associated with their use may be eliminated or reduced. Also, the hybrid integration of CT and PET is an excellent approach for providing detailed information about various diseases, specifically in the prediction of cancers. With possible cost reductions and enhanced research, these imaging techniques have a great scope to be expanded.

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