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FUSION IMAGING - THE BROADENED HORIZON IN MAXILLOACIAL IMAGING- A REVIEW

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ABSTRACT: Fusion imaging is the amalgamation of various advanced imaging modalities used in oral and maxillofacial imaging today, which takes a lion share in improvising diagnostic and formulation of effective treatment outcomes. In today's scenario, this has been widely accepted in various disciplines of dentistry in a broadened horizon for capturing the head and neck pathologies. This review paper therefore aims to highlight various aspects of fusion imaging with its bird's view in various dental specialties.

KEY WORDS: PET scan (positron emission tomography), PET-CT (positron emission computed tomography), PET-MRI(positron emission tomography with magnetic resonance imaging), SPECT- CT(single positron computed tomography), SPECT-CT with Scintigraphy.

INTRODUCTION

Since the inception to advancementsin, x-rays and to the introduction of computers and digital images, imaging has never ceased to reinvent its technology in order to improve patient care. Today diagnostic imaging is on the cusp of explosive growth in an arena known as **Fusion imaging**.[1] FUSION IMAGING technology melds two imaging modalities- Typically a procedure that demonstrates an organ's function with one that depicts organ's anatomy –to produce a diagnostically & clinically superior study.[2] Nuclear medicine procedures such as positron emission tomography (PET) and single positron emission computerized tomography (SPECT) are unparalleled in their ability to assess information about metabolic function, while computerized tomography (CT) and magnetic resonance (MR)are superior in depicting anatomy.[3] Until recently, clinicians had to obtain physiological and anatomical information on separate machines and use special registration software to digitally superimpose the two images.[1] Today new hybrid equipment is capable of performing both types of examinations simultaneously, automatically merging the data to form a composite image. By uniting metabolic function with anatomic form, fusion imaging depicts the human body with a level of precision as never before achievable.[2]

Principle of fusion imaging:

Fusion imaging developed as an innovative concept in Radiology which basically encompasses/ combines the principles and methodologies of the positron emission tomography (PET) and the computed tomography (CT). These two imaging have been having a lion share in the field of oral and maxillofacial imagingand are based on their modified anatomic and biologic forms.[1]

Fusion imaging commonly includes:

- Positron emission computed tomography(PET-CT)
- Positron emission tomography-magnetic resonance imaging(PET-MRI)
- Single positron computed tomography (SPECT)
- Spect CT with scintigraphy.[2]

Positron Emmission Tomography (PET)

Positron emission tomography (PET) is a nuclear medical imaging technique that produces a three-dimensional image or picture of functional processes in the body.[3] The system detects pairs of gamma rays emitted indirectly by a positron-emitting radionuclide (tracer), which is introduced into the body on a biologically active molecule[4]. For example FDG is a radiotracer chosen for PET which is an analogue of glucose which explores the possibility of cancer metastasis (i.e., spreading to other sites). PET is both a medical and research tool. Main clinical fields of PET scan are oncology, cardiology, and neurology.[5]

Principle of PET scan

PET is based on the principle of annihilation coincidence detection (ACD) of the two colinear 511-keV γ rays resulting from the mutual annihilation of a positron (positively charged) and a negatron(negatively charged), its antiparticle. When the positron has dissipated all of its kinetic energy and both the positron and negatron are essentially at rest, annihilation occurs.[3,4,5,6]

Advantages

i. The FDG-PET scan has shown better sensitivity and specificity than CT/MRI in staging, detecting recurrences (particularly in whom anatomic imaging is inconclusive due to locoregional distortions rendered by surgery and radiotherapy).
ii. Detection of unknown and second primary malignancies and in monitoring treatment.
iii. Provide functional detail.[3,4,5]

Disadvantages

i. High negative predictive value.
ii. Lack of anatomic detail because anatomic contrast and resolution is inherently little and there are various normal physiological uptakes which can be confused withpathology.[3,4,5]

New developments of PET scan

New developments in the area of PET detectors are aimed at improving spatial resolution and sensitivity. Most recently, new, fast and luminous scintillators have been characterized. One example is LaBr3 which may improve the signal-to-noise ratio in whole-body PET, or could even be used for time-of-flight PET. [6,7,8]

Positron emission computed tomography(PET-CT)

CT has been the cornerstone of oncologic imaging for over 20 years but lacks the ability to show crucial differences in physiology. PET has incomparable abilities to determine the metabolic activity of tissues but needs the assistance of higher-resolution, anatomic information that it cannot provide.[9] CT is the easiest and highest-resolution tomographic modality to integrate into PET imaging. The combination of the two offers the best of both worlds in an integrated data set and thus improves diagnostic accuracy and localization of many lesions.[9,10] For years, the primary means of merging the metabolic information with the anatomic information was visual fusion or having an expert review the separate PET and CT images and mentally synthesize the data. Morerecently, software fusion has been attempted by many, utilizing specialized software programs to realign and “fuse” the two separate sets of data. The first major step toward solving this dilemma, introduced in 2000 by the group of Dr. David Townsend, an imaging physicist then working at the University of Pittsburgh, was to actually put the two units together in one gantry. This allows for the immediately sequential collection of both the PET and the CT data sets, with minimal potential for misregistration.[11]

Contraindications of PET –CT

- Children below 2 years of age
- Pregnant women
- Persons over 60 years of age
- Persons with complications after the previous administration of a contrast medium
- Persons with acute and chronic circulatory and respiratory failure
- Persons with hepatic and renal failure (also dialyzed patients)
- Persons with asthma and pulmonary oedemas
- Persons with allergies

Advantages of PET –CT scan

- Provides anatomic and functional details accurately
- Less expensive
- Less time consuming
- Provides minimum inconvenience to the patient

Disadvantages of PET –CT scan

- Pregnant women are unsuitable for a PET CT scan
- More radiation exposure

Future advancement of PET-CT

The recent development is the improved speed of scanning. Even though PET/CT shortens the overall time of the PET scan from 60 minutes to just over 30 minutes in most patients, faster PET scanning is needed to improve patient comfort and scanner throughout.

In addition, organ-specific scanners are being developed; an organ-specific breast unit is already on the market, although its clinical utility is not yet certain and, in particular, its ability to stage the axilla is quite limited.

There is development of new tracers to help improve the detection of poorly FDG-avid tumors and to better distinguish malignant tumor from nonmalignant, FDG-avid tissues.[11,12,13]

Positron emission tomography with magnetic resonance imaging (PET-MRI)

Magnetic resonance imaging (MRI) is able to provide excellent soft tissue resolution and therefore anatomic detail and has the benefit of not using ionizing radiation. In recent years, there has been an ongoing trend towards expansion of the functional components of MRI and identification of their clinical utility.[15]As a consequence, MRI can now serve as a combined anatomical and functional imaging modality and is constantly evolving, with the modification of existing and the development of new sequences. Many studies over the past decade have combined data from independent PET and MRI studies, showing the potential utility of quantitative biomarkers from each modality. However, these investigations were not performed on simultaneous PET/MRI scanners and therefore had major limitations in respect of the interval between studies and the potential for misregistration of vital structures.[15,16] Although the concept of combining PET and MRI into a single scanner has been discussed for more than two decades, there have been several major obstacles to the development of a viable scanner.[17,18]

Advances in technology have overcome most of these hurdles, with the development of MRI-compatible photodiodes (avalanche photodiodes) and the use of a two-point Dixon technique(a method of fat suppression) for attenuation correction. The idea of combining PET and MRI imaging devices in a single system was first suggested in the early-mid 1990s (Hammer 1990, Hammer *et al* 1994). PET detectors capable of measuring in strong magnetic fields (Shao *et al* 1996) and prototype MRI-compatible PET scanners capable of imaging small animals simultaneously with MRI started to appear soon afterwards (Christensen *et al* 1995, Shao 1997). Only after a period of about 15 years of developments, have human systems capable of sequential (Zaidi *et al* 2011) or simultaneous PET and MRI acquisitions of the whole body become available commercially (Delso*et al* 2011).These advances resulted in the introduction in 2011 of the first generation of whole-body PET/MRI scanners.[17,18]

Indication of PET –MRI

1. Soft tissue tumors
2. In pediatric patients in turn reduction of radiation exposure
3. TNM staging

Contraindication of PET-MRI

The magnetic field created by the mri machine may interfere with the functioning of electrical devices including heart pacemakers and neurostimulators. Persons with implanted electrical devices must not enter the scanner room. During the examination, there is also a risk of temperature elevation in the adjacent tissues in patients with implanted metal parts, including hip replacements, vascular clips or foreign bodies.[19,20,21]

Absolute contraindications

- Implanted electric and electronic devices are a strict contraindication to the magnetic resonance imaging, and in particular:
- Heart pacemakers (especially older types)
- Insulin pumps
- Implanted hearing aids
- Neurostimulators
- Intracranial metal clips
- Metallic bodies in the eye

Relative contraindications

Metal hip replacements, sutures or foreign bodies in other sites are relative contraindications to the mri. The first trimester of pregnancy is also a relative contraindication against the examination. The radiologist makes the final decision as to whether to proceed with the examination. In case of any doubts, please contact the Manager of the MRI Laboratory via telephone.[18]

Advantages

a) Better soft tissue contrast: The soft tissue entities in the area of concern can be better visualized analyzed & assessed on a PET MRI as compared to PET –CT which is more indicated in hard tissue.

b) Nonionisizng radiation

c) Exposing the patients with high doses of ionizing radiations forms the main drawback of PET-CT. Researchers have reported a single exposure of PET-CT to be almost equivalent to 1 year dosage of extra-terrestrial radiation. PET –MRI in this aspect proves to be better imaging modality by providing detailed, efficient, accurate, morphological, functional details in a 30 to 60 minute examination with nonionizing radiation.[18,19,20]

Disadvantages

1. Expensive : The high cost of integrated PET/MRI systems must be considered to establish what level of hardware integration is really mandatory to meet clinical requirements.PET MRI process is also time-consuming, and logistically demanding for patients and staff.

2. Diagnostic inaccuracy :

   a. Patient repositioning causes inaccurate anatomic matching, and side-by-side interpretation of images results in diagnostic inaccuracy.
   b. Software fusion of images is hampered by varying image properties such as spatial resolution, shifting, tilting, rotation, distortion, partial-volume effects, and nonrigid organ deformation.
   c. High demand for computer and software technology: Manipulating the vast amount of imaging—including multimodal—data and follow-up studies makes high demands on computer and software technology.

Future advancement of PET-MRI

Patients undergo PET/CT imaging and MRI during the course of their diagnosis and management,in such cases the opportunity to perform a combined scan will be beneficial to the patient pathway by reducing the number of patient visits. Reduction of the ionizing radiation dose with PET/MRI is another advantage. The radiation exposure from the hybrid PET/MR imaging has been reportedly 80% less than a PET/CT study. This is particularly important when considering serial scans in response assessment and when imaging those most vulnerable to the effects of radiation—the paediatric population.As work with novel tracers continues, it is important to validate imaging-based phenotyping from both PET and MRI with gold standards such as pathological correlates. For example, hypoxia in tumours may be evaluated using FMISO and Blood Oxygen Level-Dependent MR imaging during simultaneous PET/MRI, but this must be evaluated against hypoxia quantified from histopathology. Similarly, angiogenesis tracers such as rubidium and dynamic contrast-enhanced MRI performed simultaneously can be evaluated against histopathological quantification of angiogenesis. The optimal clinical applications of PET/MRI remain to be established. Finding the 'key application' will secure the role of PET/MRI in patient management. Currently, a large-scale indication remains elusive and until research can prove clinical benefit, against important outcome measures, the technology will remain in its infancy.[19,20,21,22]

Single positron emission computed tomography (SPECT-CT)

SPECT is a tomographic scintigraphic technique in which a computer-generated image of local radioactive tracerdistribution in tissues is produced through the detection of single-photon emissions from radionuclides introduced into the body. CT is a tomographic imaging technique that uses an external x-ray source to produce 3-dimensional anatomic image data. The first SPECT/CT system combined a dualhead g-camera and an integrated x-ray transmission system mounted on the same gantry.[23,24] The CT image is used for attenuation correction as well as anatomic imaging, and the CT and SPECT images are fused, with computer assistance, for display. More recently, additional integrated SPECT/CT devices have become available, including systems combining a multihead G-camera and multidetector CT scanner side by side with a common imaging table.Combined SPECT/CT devices provide both the functional information from SPECT and the anatomic information from CT in a single examination.[25,26]

Advantages

Image quality: Over the past decade, the introduction of SPECT/CT coincided with advances in computing power and iterative reconstruction algorithms and these have led to significant improvements in SPECT image quality obtained and use of parallel-hole or pinhole collimators improves the spatial resolution, contrast, and signal-to-noise characteristics of SPECT imaging, including those obtained with SPECT/CT .This helps to increase the quality of the image and enhance the contrast by reducing the overall attenuation of the rays resulting in a better Compton effect[27,28]

Determination of anatomy and extension of lesion: It is important for tumor imaging in terms of improving anatomical localization of disease, helping to define the extent of disease, and improving differentiation of physiological and pathological uptake.This parallels the clinical experience with 18F-FDG PET and PET/CT imaging with added information related to the disorder.[29,30,31]

Accurate anatomic location of the lesion from CT: With continuous higher-speed and thinner sliced CT, small lung lesions (less than 1 cm in diameter) showing interval increase in size may often be detected. Small non-specific lymph nodes, low-density hepatic or renal lesion, and osteolytic or osteoblastic lesion with interval increase in size are also incidentally identified. These lesions are generally beyond the resolution of our current SPECT or PET system and may require further short term follow-up studies to confirm/exclude the diagnosis of new metastases.

Disadvantages:

Artifacts : Patient movement between acquisition of the SPECT and CT images will lead to misregistration, which not only affects anatomic localization but also produces an incorrect attenuation map, causing defects on the attenuation corrected images , Movement can result from respiratory and cardiac motion, sagging of the emission table, and patient motion between SPECT and CT acquisitions so It is essential that any SPECT/CT system use a coregistration program and associated quality control phantomon a regular basis to ensure correct alignment between the SPECT and CT scanners, in addition to routine quality control for both SPECT and CT.

Additional training /monitoring required: Nuclear medicine physicians who routinely interpret results of nuclear medicine studies may require additional training in evaluating the CT component of the study and vice versa. Some states do not allow nuclear medicine technologists to operate CT scanners. At present, no consensus has been reached as to who is permitted to perform these studies and interpret their results and the amount of training required.[29,30]

Future Developments in SPECT/CT

The scintillation camera technology currently in use for clinical studies still relies on the technology invented by Hal Anger in 1957 . Nevertheless, SPECT and SPECT/CT is continuing to evolve with the introduction of new technologies that have the potential to improve performance beyond that possible with Anger's pioneering approach. Recent advances in detector technology that incorporate silicon photodiode or solid-state materials offer the potential for improved spatial resolution and energy resolution, with greater stability and more compact size compared to conventional camera designs based on photomultiplier tube technology. At this early stage in their development, the use of solid-state and semiconductor detectors has focused on imaging of the heart , breast , and other small organs .[31,32]

SPECT-CT with scintigraphy

The advantages of bone scanning include good sensitivity, limited radiation exposure, and widespread availability. Bone scanning is usually performed as whole-body anterior and posterior planar images. The technique has been significantly improved by SPECT, which removes overlying radioactivity, provides spatial depth information, increases contrast resolution, and allows assessment of the anatomic relationships of osseous uptake. Software fusion to coregister SPECT with CT and MRI has been explored with good results, although it is time consuming and not practical for routine clinical use.[33,34] The introduction of hybrid SPECT/CT, first pioneered by Lang et al. in 1992 , allowed the addition of either low dose CT or, subsequently, helical CT information to be coregistered with SPECT in an efficient manner. The synergistic combination of functional and anatomic datasets improves lesion localization and characterization in combination with attenuation and scatter correction of radioactivity distributions. There is growing evidence in the literature that SPECT/CT applied to bone scintigraphy improves diagnostic performance, primarily by increasing specificity by better distinguishing between benign and malignant processes. Jiang and colleagues independently reviewed SPECT and SPECT/CT images obtained of 48 patients with indeterminate spinal lesions without a history of malignancy and reported that SPECT/CT had better diagnostic accuracy (79.2% vs 70.8%), specificity(50.0% vs 33.3%), positive predictive value (76.3% vs 70.0%), and negative predictive value(90.0% vs 75.0%) than did SPECT.[34,35]

SPECT/CT combines the high spatial resolution of CT and the high sensitivity of SPECT and is useful to evaluate for postoperative complications and for assessment of low back pain, bone infections, and chronic benign diseases of the joints . Others have found SPECT/CT useful for the assessment of compression fractures, including evaluation for vertebroplasty.[33,34]

Application of SPECT-CT with scintigraphy

The following examples are cases in which this diagnostic strategy successfully aided in the clinical diagnosis.

Head and Neck Region

In the calvaria, metastatic disease of the skull needs to be distinguished from benign uptake related to surgical trauma, hyperostosis frontalis, sinusitis, periodontal disease, bone islands, and metabolic processes such as fibrous dysplasia or Paget disease. SPECT/CT is potentially useful for this site to obviate additional skull radiographs or CT .Extraosseous radioactivity projecting over the calvaria has also been reported in association with cerebral infarction , meningioma, free pertechnetate within the choroid plexus, and binding to an ocular prosthetic implant .In the neck, micro calcification of the thyroid cartilage should be distinguished from radiotracer uptake in the thyroid gland shows significant uptake in the anterior neck on planar imaging that was diagnosed as being due to a multinodular goiter with internal calcifications on correlative imaging. Other considerations for this appearance would include free pertechnetate within the thyroid orprior radioiodine administration before thebone scan with down scatter of radioactivityinto the 99mTc energy window.[33,34,35]

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