Fusion imaging: Applications in maxillofacial radiology

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Abstract

Dentistry has witnessed tremendous advances in all its branches over the past three decades. With these advances, the need for more precise diagnostic tools, especially imaging modalities, has become mandatory. Many advanced imaging modalities like CT, MRI, CBCT, PET imaging are available which has made diagnostic imaging very accurate. Some of these modalities give a very good anatomic location and extent of the pathology, while others are able to image the pathology when the organ is in function. But, when both ie the precise anatomic location and functional imaging are required, than fusion of images made by more than one advanced imaging modality is required. This is where fusion imaging plays a significant role.

"Fusion Imaging is the process of registering and combining multiple images from single or multiple imaging modalities to improve the imaging quality and reduce randomness and redundancy to increase the clinical applicability of medical images for diagnosis and assessment of medical problems". It was designed to overcome the disadvantages of anatomic and functional imaging modalities and attempts to provide inputs that improve the image quality by combining the advantages of anatomic and functional imaging modalities for improvising treatment plans.

The fusion imaging information is ultimate and it allows not only better understanding of various physiological and disease process but also helps in monitoring & predicting the course of the treatment and predicting the prognosis.

Keywords: Fusion Imaging, PET-CT, PET-MRI, F18-FDG.

Introduction

Imaging fusion is the process of combining relevant information of single or multiple images into a single image. The resultant image is more diagnostic and informative than any of the input image. In the medical imaging environment, sources of data include modalities such as Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET) and Single Photon Emission Tomography(SPECT).[1]

The combination of two imaging modalities is known as Hybrid Technique or Fusion Imaging.[2] The aim of fusion imaging is uniting metabolic function with anatomic form.[3]

Radiographic interpretation in some clinical situations can be difficult but the combination of two imaging modalities is more informative and diagnostic.[4] The various anatomic and functional imaging modalities with their advantages, disadvantages and the fusion modalities are summarized in Table 1[5] and Table 2.[5]

Combined Imaging

When fused, the anatomic imaging data from CT/MRI and the functional imaging data by PET, provides additional clinical relevant information. Thus, it improves the diagnostic value of the modalities because it almost eliminates all the negative findings (false negative and false-positive) of PET.[6]

At present, the most frequently used radiotracer in clinical PET scanning is Fluorine-18 Fluorodeoxyglucose (F18-FDG). It is primarily used because it has a longer half-life (110 minutes) there by permitting more flexibility in transport time to the effected sites and better administration to patients.[7]

The three major areas of focus in studies on image fusion are:[8-10] (a) identification, improvement and development of imaging which are useful. (b) different techniques developed for image fusion (c) assessment of medical conditions by the application of fusion imaging to human organs.

Need of fusion imaging

Anatomic and Functional imaging like CT, MRI, PET etc, are the diagnostic procedures have certain limitations. In both MRI and CT, size, contour, enhancement pattern exist but detection of small occult lymph node metastasis is limited.[11] In PET, Anatomic detail is less because of contrast and resolution is little and as pathology is confused with physiological uptake.[11,12] To reduce all limitations then a 'FUSION IMAGING' comes with all the advantages of the functional and anatomic image data.

Historical View

In the early 1970s, introduced of the first x-ray CT system, initially for the brain imaging and then later the whole body x-ray studies.[13] Following CT, the 1980s witnessed the appearance of clinical MRI, a technique of particular importance for imaging patients because it does not require the use of ionizing radiation. These two helps in anatomic imaging but do not provide the complete picture. The first human tomographic images

with positron emitting isotopes were presented in 1972,[14] thus establishing PET on the map of medical imaging technologies, to be joined by SPECT a year or so later, following on from the pioneering work of the early 1960s.[15]

Hasegawa and colleagues are credited for the conception and design of the first combination of SPECT and CT in the 1990s.[16,17] Now the physicists and scientists have moved towards the modern era that is fusion imaging. In 1998, Townseed and coworkers at the University of Pittsburg pioneered the development of a combination of PET/CT imaging.[18,19]

Recently, cost effective and compact designs of dual modility with the more economic approach to multimodality imaging for institutions are available.[5]

Principle of fusion imaging

Fusion Imaging is developed as an innovative concept in Radiology which basically combines the advantages of anatomic and functional imaging for example PET /CTand PET/MRI. These current imaging modalities in oral and maxillofacial region give more information to detect pathologies.[20]

There are two stages of any classical image fusion :
(a) Image registration
(b) Fusion of relevant features from the registered images.

Image registration requires a method to correct spatial misalignment between the different image data sets, and often involves compensation of variability from scale changes, rotations and translations.[2]

[5]**Table 1: Anatomic imaging modalities**

Imaging Modalities	Advantages	Disadvantages	Fusion Modalities
1) Magnetic Resonance Imaging	Soft tissue is imaged with high accuracy No exposure to radiation.	Sensitive to movement Longer scan time	Ultrasound-MRI MRI-CT MRI-PET MRI-SPECT
2) Computed Tomography	Short scan time High imaging resolution	Limited tissue characterization because of nature of x-ray sources	MRI-CT SPECT-CT Ultrasound-CT FDG-PET-CT
3) Cone-Beam Computed Tomography	Short scan time Lower radiation exposure	Low image quality Unreliable density measurements	CBCT-PET MRI-CBCT
4) Ultrasound imaging	Cost effective No exposure radiation Easy access	Inferior morphological assessment Significant inter observer and intra observer variability	Ultrasound-MRI Ultrasound-CT MRIgFUS Real-time virtual sonography

Table 2: Functional imaging modalities

Techniques	Principle and Advantages	Disadvantages	Applications
1 Positron emission tomography (PET)	Transport of radiolabeled glucose into cells High sensitivity	Low resolution (better than SPECT) Cannot differentiate inflammatory sites from neoplastic processes Chance of false-positives (brown fat, infection, asymmetric muscle activity) and false-negatives (small tumor, low glycolytic activity)	Permits evaluation of residual or recurrent disease after treatment Allows treatment response assessment, but may only be valid at 10–14 weeks after completion of treatment Aids in gross tumor volume contouring and biology-guided adaptive radiation therapy planning
2 Single photon emission	Nuclear medicine tomographic imaging using	Poor resolution Time-consuming	Detection of condylar hyperplasia

computed tomography (SPECT)	gamma-rays or characteristic X-rays	Underestimation is possible in deep tissues through absorption of gamma-rays	Presence of metastatic lesions Prognostication in jaw osteonecrosis and cancer Evaluation of mandibular growth in asymmetries
3 Proton MR spectroscopy	Detects presence of specific metabolites (elevated Cho/Cr levels suggest higher membrane turnover) in tissues	Low signal-to-noise ratio	Benign neck tumors Differentiates between malignant and benign salivary gland tumors Evaluation of residual and recurrent tumors following treatment (early prediction possible) Has potential to predict response
4 Computed tomographic perfusion (CTP)	Continuous recording of X-ray attenuation over fixed area of interest during passage of a fast bolus of iodinated contrast medium through the region Evaluates blood volume, blood flow, mean transit time, and capillary permeability of a lesion Reproducible technique	Requires injection of contrast medium Large exposure to radiation	Differentiates malignant lesions from benign lesions Differentiation of recurrent tumor from posttherapy changes Predicts response to chemoradiation Non-invasive measurement of intratumoral MVD (risk factor for local recurrence, shorter disease-free survival, and distant metastases)
5 Perfusion-weighted MRI	Blood flow dynamics at microcirculation level Similar to CTP	Paramagnetic contrast medium injection Longer scan time Difficulty in optimization	Differentiates tumors from normal tissues
6 Diffusion-weighted imaging (DWI)	Tissues that are more compact at the molecular level (e.g., tissues with higher cellularity) tend to show relative reduction of water molecular motion expressed as lower ADC values Reproducible images in any MRI protocol	Lack of optimized threshold ADC values Susceptibility to dental fillings causing magnetic artifacts	Differentiates benign lesions from malignant lesions Evaluation of post-radiation therapy xerostomia Recurrent tumors show decreased ADC compared with non-malignant changes or radionecrosis Predicts response to chemoradiation (tumors with lower DC values respond better)
7 Diffusion tensor imaging	Characterizes 3-D diffusion of water	Nonspecific marker of neuropathology, thus	Still in experimental stages

(DTI) Form of DWI	Tracks nerves from adjacent structures Characterizes microstructural changes	imposing diagnostic or therapeutic challenges	Future applications may be related to salvage of important structures during surgery
8 Hypoxia (optical-based, MRI-based, or PET imaging-based)	PET-based potential tumor hypoxia imaging agents include 18FFMISO and copper 60 (II)-diacetyl-bis (N4-methylthiosemicarbazone)	Suboptimal imaging Poor resolution	Crucial for prognostication of tumors (predicting aggressiveness, metastatic spread, and rate of recurrence) Response to chemoradiation
9 Cell proliferation (PET-based)	Injected 3′-deoxy-3′-F-18-fluorothymidine becomes concentrated in nucleosides	Tumor vs. normal tissue contrast is low Less marrow uptake	Differentiates tumor activity from inflammation caused by radiation Lymph node detection Reduction in proliferative activity of primary tumor
10 Inhibition of tumor neoangiogenesis	18F-galacto-RGD-PET imaging of avB3 expression, a receptor related to tumor angiogenesis and metastasis		Planning and response evaluation of avB3-targeted therapies

Applications of fusion imaging

PET-CT /PET-MRI has spured the development of multiple applications that can be categorized into oncological and non–oncological applications as follows:

Oncological Conditions:

a. F18-FDG used for detection of osseous metastasis and gives an extra advantage for detecting occult primary and unexpected metastasis .Figure 1[22]

b. F18-FDG also used for assessment of metabolic activity in malignant lesion, staging, treatment planning and prognostication.[23] Figure 2[5]

c. G68-DOTA-NOC (Gallium Ga 68-DOTANOC is a conjugate of the somatostatin

d. analogue 1-Nal3-octreotide (NOC) and gallium Ga 68-labeled 1,4,7,10-tetraazacyclododecane-N,N',N'',N'''-tetraacetic acid (DOTA))are used for tumors expressing somatostatin receptors most common in neuroendocrinal tumors.[24]

e. F18-choline is used to identify any lesion with high choline content(which ia cell membrane proliferation marker).[25]

f. F18-angiography can be used assessing the neuro vascularization of the tumors similar to CT and MRI perfusion.

g. PET-MRI has applications mainly in head and neck region in CNS tumors.[26,27]

Case 1

Beneficial use of retrospective image fusion in a case of recurrent tumour disease. The presented case has suspected recurrent disease after resection of a squamous cell carcinoma of the floor of the mouth and tongue and reconstruction with a microvascular radial forearm flap and adjuvant radiation. [Fig 1A, 1B, 1C]
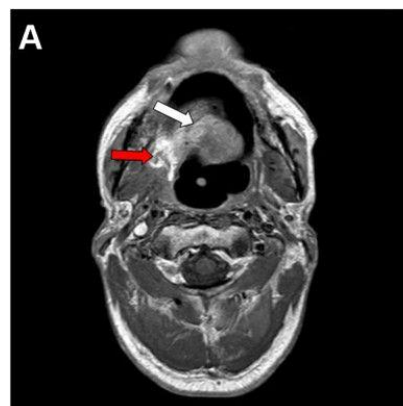

Fig. 1A: The tissue by MRI alone was rated as probably malign, attributable to the abnormal contrast enhancement in the right posterior site of the floor of the mouth (red arrow). The region near the midline of the residual tongue (white arrow) was interpreted as an anatomical alteration after surgery and irradiation
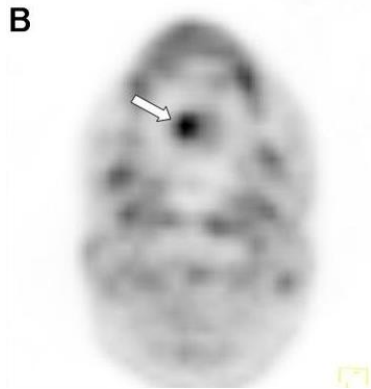
Fig. 1B: PET alone showed a moderate increase of tracer up-take near the midline and both PET alone and the side-by-side analysis were rated as "probably benign
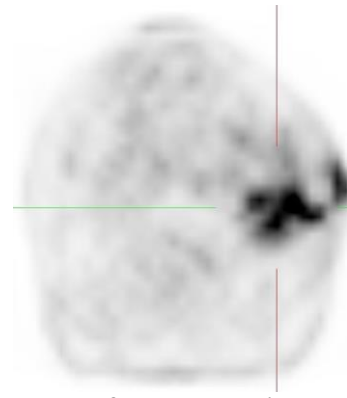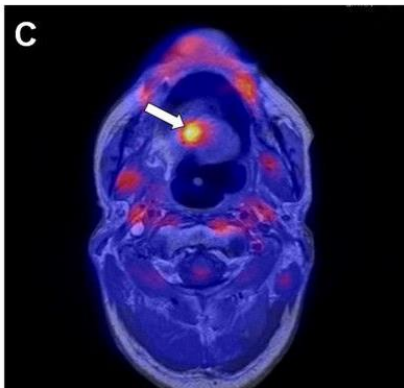

Fig. 1C: Retrospective fused PET/MRI provided the correct diagnosis of recurrent tumour disease through the correct alignment of morphological and functional imaging data; however, the disease was present not in the dorso-lateral region (histology: scar fibrosis) but near the midline in the residual tongue
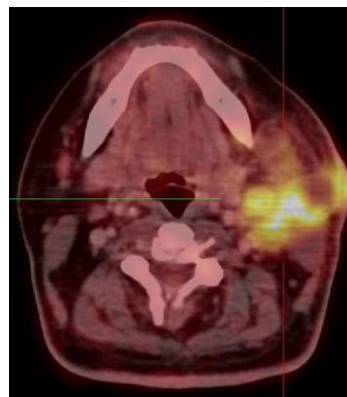
Case 2

Fig. 2A: Plain axial CT demonstrating a soft-tissue mass in the left parotid region

Fig. 2B: PET scan of the same patient showing hot spots in the tumor mass, suggestive of high metabolic activity

Fig. 2C: Fused PET-CT image providing both anatomic and functional detail

Non –oncological Conditions:

Neurological applications: In epilepsy and dementia,[28] CT and MRI detect unexpected clinically lesion in only 5% patients of dementia .

A metabolic mass in the brain or spinal cord can be well delineated morphologically by MRI. Hypometabolic areas of the brain can be epileptogenic foci in the interictal phase on ^{18}F-FDG-PET imaging.[28] Also, MR –tractography images can be fused with PET images asa well as routine MR images to demonstrate white and grey matter hypertrophy corresponding to hypometabolic areas on PET.[29,30]

Infection and inflammation: CT is the best choice for detection of thoracic and abdominal infection, while MRI is mainly preferred for soft tissue contrast and higher sensitivity to tissue edema and hypermia. In nuclear medicine, several agents are used for detection of sites of infection and inflammation,the commonest example indium-111, technetium-99m (^{99m}Tc) and gallium-67citrate.[31-33]

Advantages of fusion imaging [34-36]
1. It provides functional and structural information in the data image.
2. Accurate identification of size and location of tumor/metastasis margins, for better tumor staging.

3. This technique also permits a best identification for the small recurrent tumors.
4. The identification of lymph node metastasis or small tumor areas, as this is missed by CT/MRI.
5. It also helps in guiding in the treatment planning, biopsy, surgery, or radiation therapy and prognostication.
6. Helps in locating the primary lesion in cases with unknown primary tumors.
7. Also improves reading efficiency.
8. It improves confidence in diagnosis when one modality one is not definitive.

Disadvantages of fusion imaging[34,35]
1. Resultant image may be less clear than the original image.
2. It is high cost and low availability
3. Blurring of the image may affect the contrast of the resultant image.
4. Image distortion may be a problem such as ringing artifact or blocking effect
5. Procedure is complex.
6. Greater degradation of spectral resolution and Lower spatial resolution
7. Limitation are imposed by specific imaging modalities or nature of the clinical problem.
8. Most of the techniques are still in experimental stages and refinement.
9. It also permits quantification between the scans.

Conclusion

Fusion Imaging is the process of combining relevant information from a set of images into a single image, wherein the fused image becomes more informative and complete, and has increased applications compared with the input images. Interpretation of fused images like PET/CT and PET/MRI is better than the separate interpretation of either CT, MRI or PET images Although fusion imaging has wide clinical application in oncology and provide a more specific ,comprehensive picture of the disease, refinement of the existing techniques for a wide array of practical applications may serve to further expand the current fusion imaging protocols and applications.

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