

Multi-modality Assessment of Hepatic Focal Lesions: PET/CT-MRI Fusion

Thesis

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بسم الله الرحمن الرحيم

اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ * خَلَقَ الْإِنْسَانَ مِنْ عَلَقٍ * اقْرَأْ

وَرَبُّكَ الْأَكْرَمُ * الَّذِي عَلَّمَ بِالْقَلَمِ * عَلَّمَ الْإِنْسَانَ مَا لَمْ يَعْلَمْ *

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Abstract

The evolution of MRI, CT, and PET imaging and the availability of MDCT and fusion of PET and MDCT data sets as well as the MRI data sets have lead to gains in detection and characterization of hepatic lesions. To assess the added value of DW-MRI to PET/CT in the evaluation of patients with hepatic focal lesions, we included in our study 35 patients referred for assessment of hepatic focal lesions. The 35 patient underwent ^{18}F -FDGPET/CT followed by triphasic CT and DW-MRI; images of both PET/CT and MRI were fused on the work station. A consultant radiologist and aconsultant nuclear medicine physician interpreted all the images independently

Keyword: MDCT-MRI- APD-FDG-PET\CT.

Table of Contents

Table of Contents	i
List of Figures.....	ii
List of Tables	iii
List of Abbreviations	iv
Introduction	1
Aim of the Work.....	3
PET Physics and Instrumentations	4
Physics MRI.....	23
Pathology of Hepatic Focal Lesions	36
Imaging of Hepatic Focal Lesions	52
Patient and Methods	63
Results	69
Case Presentations	83
Discussion.....	97
Conclusion and Recommendations	106
Summary	107
References:.....	110
الملخص العربي.....	121

List of Figures

Figures	Page
Figure 1: Schematic diagram of positron annihilation.	8
Figure 2: A typical block detector in PET Scanner.	11
Figure 3: Block detector illustrating the quadrant sharing of PM tubes.	12
Figure 4: Schematic diagram of a photomultiplier tube.	13
Figure 5: Types of Coincidence Events	16
Figure 6: 2-D and 3-D imaging without lead septa between rings of detectors.	17
Figure 7: The physics of PET attenuation and a procedure for correction of the attenuation effect.	19
Figure 8: Coronal view through a whole-body FDG PET image of a patient: the image has been reconstructed without attenuation correction and b the image is attenuation-corrected.	20
Figure 9: Images reconstructed from the same raw data reconstructed with filtered backprojection (FBP) at left and ordered subsets expectation maximization (OSEM) at right.	22
Figure 10: spins in MRI.	24
Figure 11: Pulse sequence diagram for the basic spin-echo sequence.	28
Figure 12: Pulse sequence diagram for the gradient-echo sequence.	28
Figure 13: Scheme of a MRI system.	30
Figure 14: Slice Encoding, Phase Encoding, and Frequency Encoding.	32
Figure 15: HCC in cirrhotic liver	39
Figure 16: Multiple metastatic liver lesions	45
Figure 17: Hepatic cyst	49
Figure 18: Amebic liver abscess	51
Figure 19: Axial images of patient with a large HCC lesion in the right liver lobe	57
Figure 20: Features of local tumor progression	60
Figure 21: Final diagnosis of 35 patients with hepatic focal lesions.	70
Figure 22: Nature of the 98 hepatic focal lesions.	75
Figure 23: Distribution of the 98 hepatic focal lesions according to their size.	75
Figure 24: Case presentation 1	84
Figure 25: Case presentation 2	86
Figure 26: Case presentation 3	87
Figure 27: Case presentation 4	90
Figure 28: Case presentation 5	92
Figure 29: Case presentation 6	94
Figure 30: Case presentation 7	96

List of Tables

Tables	page
Table 1: Select list of radionuclides that decay by positron emission and are relevant to PET imaging	6
Table 2: Requirements for PET detector material	9
Table 3: Principal detector materials that have been used in PET	9
Table 4: Sensitivity, specificity, positive predictive value, negative predictive value and accuracy for CT, PET, DW/MRI, PET/CT, fused PET/MRI and PET/CT/DW-MRI in 35 patients with hepatic focal lesions.	70
Table 5: Differences in sensitivity and specificity between PET/CT/DW-MRI and Ce-CT on patient-basis	71
Table 6: Differences in sensitivity and specificity between PET/CT/DW-MRI and PET on patient-basis	72
Table 7: Differences in sensitivity and specificity between PET/CT/DW-MRI and DW-MRI on patient-basis	72
Table 8: Differences in sensitivity and specificity between PET/CT/DW-MRI and PET/CT on patient-basis	73
Table 9: Differences in sensitivity and specificity between PET/CT/DW-MRI and PET/DW-MRI on patient-basis	74
Table 10: Sensitivity, specificity, positive predictive value, negative predictive value and accuracy for Ce-CT, FDG-PET, DW/MRI, PET/CT, PET/MRI and PET/CT/MRI in hepatic focal lesions.	76
Table 11: Differences in sensitivity and specificity between PET/CT/DW-MRI and Ce-CT on lesion-basis	77
Table 12: Differences in sensitivity and specificity between PET/CT/DW-MRI and PET on lesion-basis	77
Table 13: Differences in sensitivity and specificity between PET/CT/DW-MRI and DW-MRI on lesion-basis	78
Table 14: Differences in sensitivity and specificity between PET/CT/DW-MRI and PET/CT on lesion-basis	79
Table 15: Differences in sensitivity and specificity between PET/CT/DW-MRI and PET/DW-MRI on lesion-basis	79
Table 16: Lesion size less than 1 cm.	80
Table 17: Lesion size 1-2 cm.	81
Table 18: Lesion size more than 2 cm.	81
Table 19: post-intervention delectability on lesion-basis	82

List of Abbreviations

ACD	Annihilation Coincidence Detection
ACC	Accuracy
ADC	Apparent Diffusion Coefficient
APD	Avalanche Photodiode
BaF	Barium Fluoride
BGO	Bismuth Germinate
Ce-CT	Contrast enhanced Computed tomography
CI	Confidence Interval
CT	Computed tomography
DWI	Diffusion Weighted Imaging
DW EPI	Diffusion Weighted Imaging Echo Planner
E	Energy
¹⁸F	Fluorine 18
FBP	Filtered Back Projection
FDG	Fluorodeoxyglucose
FLLs	Focal Liver Lesions
FN	False Negative
FP	False Positive
GSO	Gadolinium Orthosilicate
HCC	Hepatocellular Carcinoma
KBq	Kilobecquerel
Kg	Kilogram
La Br	Lanthanum Bromide
LOR	Line of Response
LSO	Lutetium Orthosilicate
Max	Maximum

List of abbreviations

MBq	Megabecquerel
MDCT	Multi-detector Computed tomography
MEV	Million Electron Volt
MRI	Magnetic Resonance Imaging
N	Neutrons
NaI (TI)	Sodium iodide with thallium doping
NPV	Negative Predictive Value
OSEM	Ordered Subsets Expectation Maximization
PET	Positron Emission Tomography
PPV	Positive Predictive Value
P+	Protons
ROI	Region of Interest
SEN	Sensitivity
SEP	Specificity
SUV	Standard Uptake Value
TN	True Negative
TOF	Time of Flight
TP	True Positive
VOI	Volume of Interest
ν	neutrino
$\beta +$	Positron
2D	2 Dimensional
3D	3 Dimensional

Introduction

The liver may host a variety of benign and malignant tumors. The most common benign tumors found in the liver are cysts, followed by cavernous hemangiomas. Ninety percent of malignant primary liver tumors are tumors from epithelial origin: primary hepatocellular carcinoma (HCC). However metastases to the liver from various primaries occur 20 times more common than HCC and are often multifocal. Although many tumors may metastasize to the liver, the most common primaries producing liver metastases are colorectal, gastric, pancreatic, lung and breast carcinoma.¹

Hepatic imaging is essential in the management of patients with suspected cancer. Computed tomography (CT), ultrasound and magnetic resonance imaging (MRI) have been used to evaluate these patients. MRI is preferred when further characterization of hepatic focal lesions is needed.²

MRI is frequently used as a problem-solving technique for the evaluation of focal hepatic lesions that are deemed indeterminate with other imaging modalities. Such evaluation can be challenging, particularly in patients with a history of malignancy or in those with underlying liver disease, such as cirrhosis, that carry an increased risk for cancer. Although it has some advantages over CT and ultrasonography, MRI also has some limitations. MR image quality can be affected by patient motion and most MR imaging protocols produce lower spatial resolution images than CT.³

The use of positron emission tomography (PET) has been increasingly recognized as a useful tool in detecting hepatic malignancy

and this technique is rapidly being superseded by combined ^{18}F -fluorodeoxyglucose positron emission tomography/computed tomography (^{18}F -FDG PET/CT). For overall patient management, ^{18}F -FDG PET and PET/CT have the added advantage over MRI and CT of providing not only anatomic but also functional information. More recently combined ^{18}F -fluorodeoxyglucose positron emission tomography/ magnetic resonance imaging (^{18}F -FDG PET/MRI) has been introduced. The combination of functional information derived from ^{18}F -FDG PET with anatomic information derived from MRI may be of further help in the detection and characterization of liver lesions.⁴

For our knowledge this is the first study to evaluate hepatic focal lesions using combined PET/CT-MRI fusion.

Aim of the Work

Is to explore the effectiveness and the added clinical value of multi-modality liver imaging utilizing PET/CT-MRI fusion for the characterization of focal hepatic lesions compared to PET/CT stand alone and MRI stand alone.

PET Physics and Instrumentations

Basic Physics

Positron Decay

Positron emission tomography (PET) is a technique that uses radioactive materials known as radionuclides to obtain images that map out metabolic activity in the body. Radionuclides are unstable compounds that decay to more stable compounds by the emission from the nucleus of radioactivity in the form of either particles, photons of energy, or both. A PET scanner consists of a set of detectors that surround the object to be imaged and are designed to convert these high-energy photons into an electrical signal that can be fed to subsequent electronics. All radioactive materials decay in an exponential manner with a rate that is characteristic to a specific type of radionuclide. In a typical PET scan, 10^6 to 10^9 events (decays) will be detected. These events are corrected for a number of factors and then reconstructed into a tomographic image using mathematical algorithms. The output of the reconstruction process is a three-dimensional (3-D) image volume, where the signal intensity in any particular image voxel is proportional to the amount of the radionuclide (and, hence, the amount of the labeled molecule to which it is attached) in that voxel. The radionuclides commonly used in PET scanning are produced in a device called a cyclotron. A cyclotron accelerates a beam of charged particles to very high velocity and then directs this beam into a block of material known as the target. The desired radionuclide can be produced as a result of the changes that take place in the target material due to the bombardment by the high-speed charged particles. The

radionuclide produced by the cyclotron can then be attached (labeled) to compounds that are of biological interest, such as glucose, ammonia, or water. The radiolabeled complex is usually injected intravenously and will then distribute throughout the body according to its biological properties.^{5, 6}

POSITRON EMISSION AND ANNIHILATION

The nucleus of an atom is composed of two different types of nucleons, known as protons and neutrons. These particles have similar masses but differ in that a proton has positive charge, whereas a neutron is uncharged. A cloud of negatively charged electrons surrounds the nucleus.⁷

If a nucleus has either an excess number of protons or neutrons, it is unstable and prone to radioactive decay, leading to a change in the number of protons or neutrons in the nucleus and a more stable configuration. Nuclei that decay in this manner are known as radionuclides.⁸ Radioisotopes that have an excess of protons may decay by electron capture or positron decay. Isotopes undergoing electron capture cannot be imaged with a PET scanner. Decay by positron emission is the basis for PET imaging.⁹ Examples of positron emitting isotopes used in PET imaging are shown in **Table 1**.

Table.1 Select list of radionuclides that decay by positron emission and are relevant to PET imaging⁹

<i>Radionuclide</i>	<i>Half-life</i>	<i>E_{max}(Mev)</i>	<i>β⁺ Branching Fraction</i>
¹¹ C	20.4 min	0.96	1.00
¹³ N	9.97 min	1.20	1.00
¹⁵ O	122 s	1.73	1.00
¹⁸ F	109.8 min	0.63	0.97
²² Na	2.60 y	0.55	0.90
⁶² Cu	9.74 min	2.93	0.97
⁶⁴ Cu	12.7 h	0.65	0.29
⁶⁸ Ga	67.6 min	1.89	0.89
⁷⁶ Br	16.2 h	Various	0.56
⁸² Rb	1.27 min	2.60, 3.38	0.96
¹²⁴ I	4.17 d	1.53, 2.14	0.23

Based on data from Table of Nuclides: www2.bnl.gov/ton (accessed October 17th, 2002)

In order to decay by positron decay, an isotope must have at least 1.02 million electron volts (MeV) more energy than the isotope to which it decays. Isotopes with transition less than this energy cannot undergo positron decay and will decay only by electron capture. In positron decay one of the protons (P+) in the nucleus changes to a neutron (N), and a positron (β⁺) and a neutrino (ν) are emitted. Positron decay can be written with the equation: $P^+ \rightarrow N + \beta^+ + \nu + E$

Where P+ is a proton, N is a neutron, β⁺ is a positron, ν is a neutrino, and E represents excess energy. A positron is the antiparticle that corresponds to the electron. A neutrino has very little interaction with matter, and it can be ignored for positron emission tomography (PET). The excess energy is shared between the positron and the neutrino with different amounts of energy going to each particle during decay.⁹ The energy spectrum of the emitted beta particles is continuous up to a