

Technical Innovation

## WHOLE-BODY IMAGING WITH PET/MRI

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**Abstract:** Whole-body positron emission tomography (PET) scanning with the radiolabeled glucose analogue 2-[fluorine-18]-fluoro-2-deoxy-D-glucose (<sup>18</sup>F-FDG) can identify areas of cancerous involvement and distinguish malignant from benign lesions and therefore, plays an important role in the diagnosis and management of patients with cancer. PET facilitates the evaluation of metabolic and molecular characteristics of a wide variety of cancers, but it is limited in its ability to visualize anatomical structures. Whole-body magnetic resonance imaging (MRI) is a promising diagnostic modality for the diagnosis and management of patients with cancer, because of its high anatomical resolution. Whole-body PET and whole-body MRI allow to evaluate both the primary tumor and for the presence of metastasis at the same time. The combination of these two excellent diagnostic imaging modalities into a single scanner offers several advantages in comparison to PET and MRI alone. A hybrid PET/MRI facilitates the accurate registration of metabolic and molecular aspects of the diseases with exact correlation to anatomical findings, improving the diagnostic value in identifying and characterizing of malignancies and tumor staging. Thus, hybrid PET/MRI could be a very important diagnostic imaging modality in oncological applications in the decades to come, and possibly for use in cancer screening and cardiac imaging.

**Key words:** Whole-body imaging, Positron emission tomography (PET), Magnetic resonance imaging (MRI), PET/MRI, PET-MRI, Image fusion

### INTRODUCTION

Imaging of the whole body can be performed by using several different approaches such as scintigraphy, conventional radiography, positron emission tomography (PET), x-ray computed tomography (CT) and magnetic resonance imaging (MRI). Nevertheless, each of these imaging modalities has specific advantages as well as disadvantages such as sensitivity, specificity, accuracy, radiation exposure, cost, and examination time. Therefore, the awareness of the hazards of radiation exposure has prompted several investigators to focus on techniques that enable whole-body scanning with low or without radiation dose.

Positron emission tomography (PET) has become an accepted and valuable diagnostic imaging tool for patients with cancer. The use of PET enables the assessment of metabolic alterations and molecular as-

pects that are fundamental to cancer detection, therapeutic response and recurrence. PET imaging can be performed with different radiotracers. The most commonly used radiopharmaceutical is a glucose analogue, 2-[fluorine-18]-fluoro-2-deoxy-D-glucose (<sup>18</sup>F-FDG). It relies on the detection of an increased rate of aerobic glycolysis. In most cancers, malignant cells are associated with increased metabolic activity. Therefore, increased uptake of <sup>18</sup>F-FDG molecules can be used to spot areas of malignancy and tumor growth. In general, this accelerated metabolic activity occurs before anatomical structure changes. Other imaging modalities, such as computed tomography (CT) and magnetic resonance imaging (MRI) rely primarily on anatomical structure changes for disease detection. The main difficulty with PET, however, is the lack of an anatomical reference frame.

The concept that MRI might become the ultimate whole-body imaging tool was initially proposed by the MRI pioneers Damadian and Lauterbur [4, 10]. Because of prolonged imaging time, limited availability of scanning facilities, and extensive costs, MRI was used primarily as a tool to image specific regions of the body.

The development of fast and ultrafast MRI techniques led to the possibility of rapid whole-body scanning. However, most investigators used the body coil for multi-station data reception. Thus, images suffered from either low signal-to-noise or poor spatial resolution [5, 6, 7, 12]. To overcome these limitations other investigators examined patients on a sliding table platform with an integrated phased-array surface coil [2]. Although this approach improves signal-to-noise, the distal limbs were not included [9]. In addition, the advantages of parallel acquisition techniques to achieve higher spatial resolution or shorter acquisition times were not used.

The new development of Total Imaging Matrix (TIM) allows for the first time to perform a high resolution full whole-body coverage from head to toe within a single examination for patients without the need for patient or surface coil repositioning in excellent high resolution image quality. The basic idea of TIM is the revolutionary matrix coil concept that allows the combination of 76 coil elements with up to 32 channels – a combination that enables considerable improvements in both acquisition speed and image quality.

In this article, we discuss the expected value and clinical impact of the combination of a whole-body

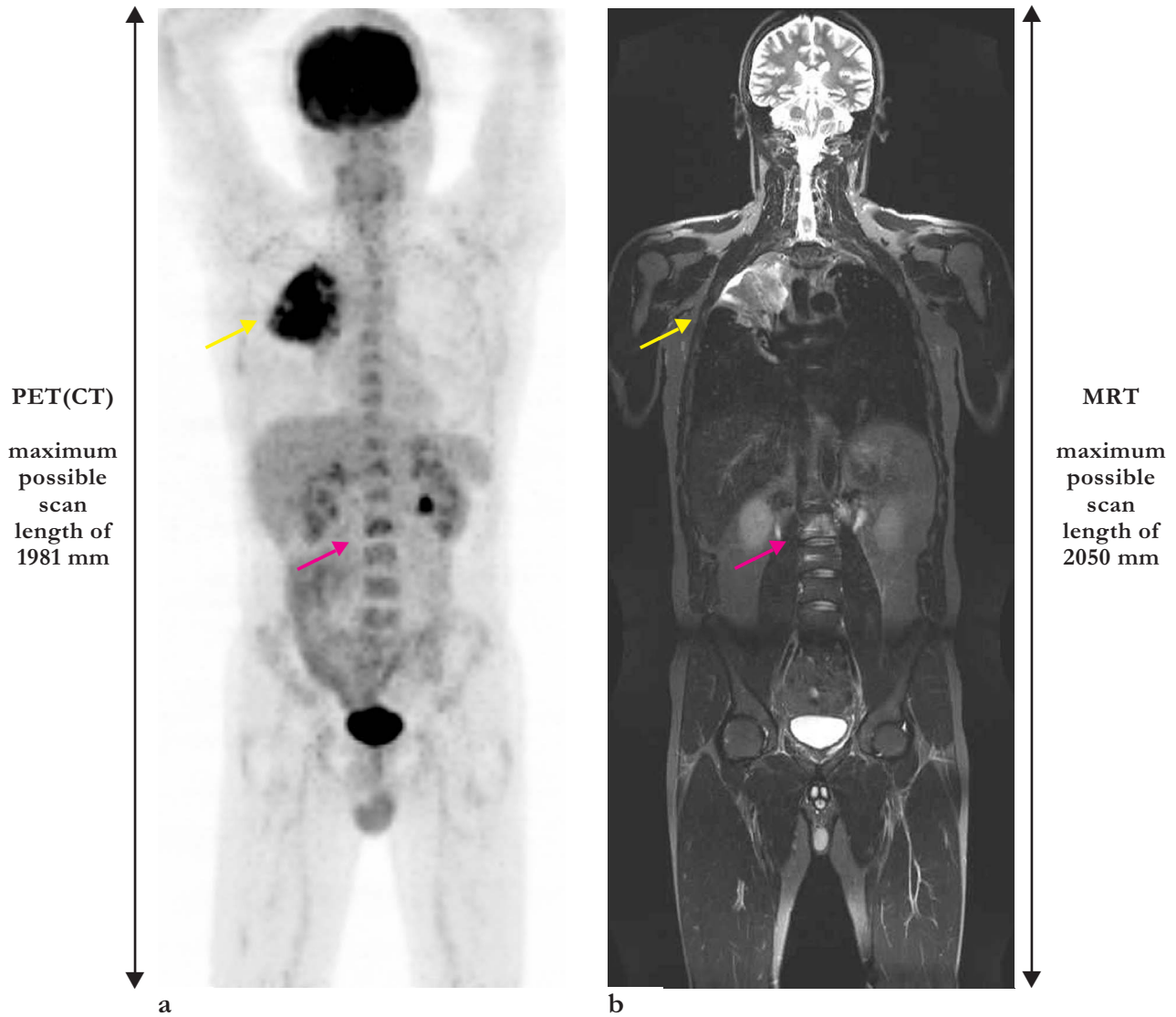


Fig. 1. 37-year-old male patient with diffuse pulmonary (arrow, blue) and osseous (L 2) (arrow, red) metastastatic disease of a non-small cell lung cancer (arrow, yellow) in the right upper lobe. Coronal overview (a,b) of  $^{18}\text{F}$ -FDG PET (a) and MRI (T2-weighted Turbo-STIR) (b), coronal centered view (c-e) of  $^{18}\text{F}$ -FDG PET (c), MRI (T2-weighted Turbo-STIR) (d) and image fusion of PET and MRI (e) and axial view (j-o) of  $^{18}\text{F}$ -FDG PET (f,i), MRI (T2-weighted Turbo-STIR) (g,j) and image fusion of PET and MRI (h,k) showing the non-small cell lung cancer (a-h), the pulmonary metastases (g) and the osseous metastasis (a-e,i-k). The pulmonary metastases were only seen on the MR images (arrows, yellow).

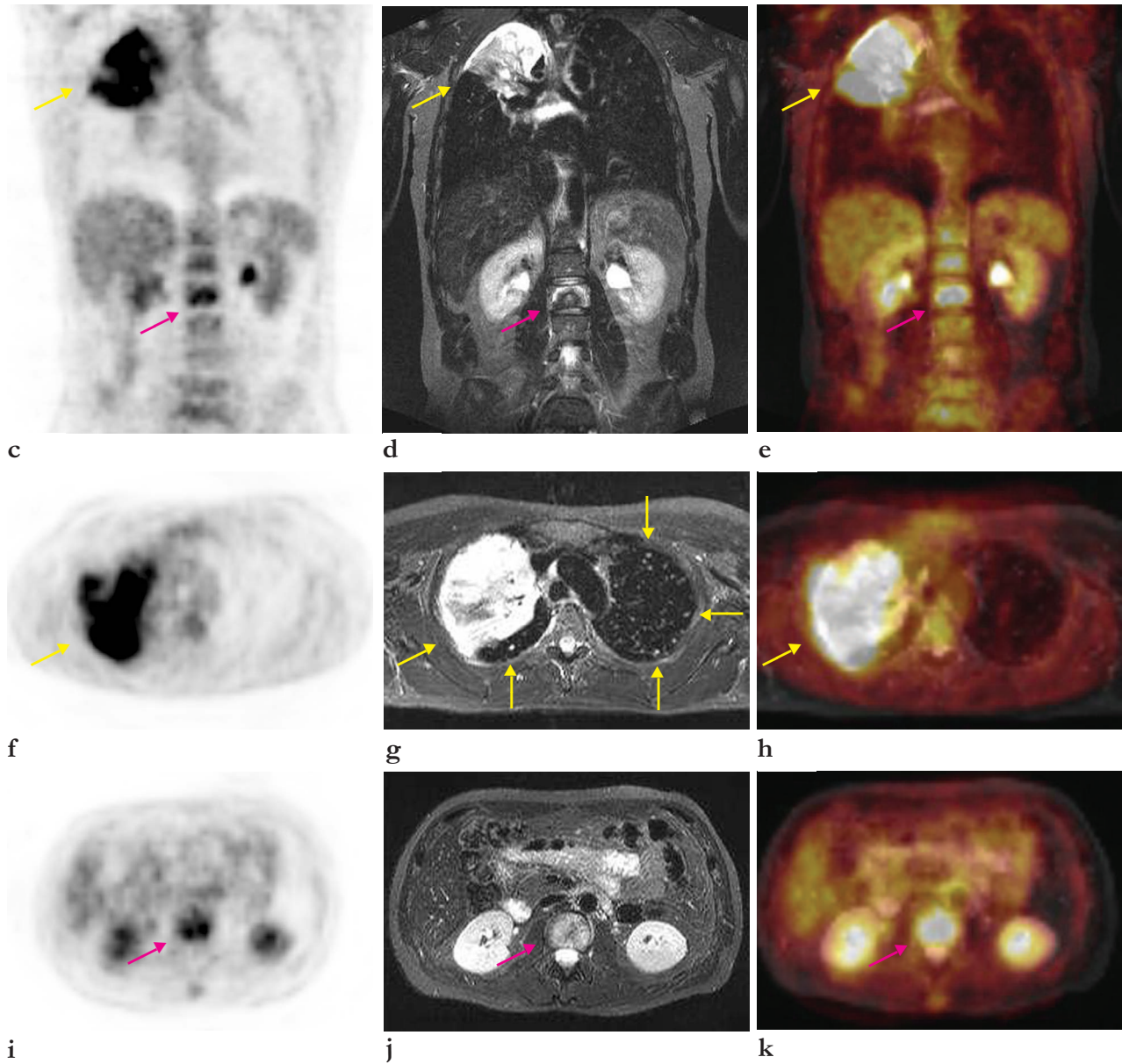
PET device and a whole-body MRI device to a hybrid whole-body PET/MRI scanner.

## TECHNICAL PRINCIPLES

### POSITRON EMISSION TOMOGRAPHY (PET)

A PET examination usually involves both the acquisition of an emission scan, which consists of detecting coincident 511 keV photons obtained from the decay of a positron emitting isotope that labels the administered tracer, and the acquisition of a transmission scan for attenuation correction, obtained from a 511 keV source or other high energy rotating around the body (usually a  $^{68}\text{Ge}$  rod source or a  $^{137}\text{Cs}$  point source). PET images can be reviewed without attenuation cor-

rection, but are usually reconstructed using an iterative algorithm, which takes an attenuation map obtained from the high-energy transmission scan into account to produce an attenuation correction image. The high-energy transmission map is usually noisy, has limited anatomic details and poor spatial resolution. With the segmentation of the transmission map, the noise level is reduced, allowing the acquisition of a “shorter” 3-min acquisition per bed position with a  $^{68}\text{Ge}$  source. The resulting attenuation correction data is smoothed with a 8-mm gaussian filter to adjust to the spatial PET resolution. These attenuation correction factors are then applied to the emission data, and the attenuation-corrected emission images are finally reconstructed with an ordered-subset expectation maximization (OSEM) iterative reconstruction algorithm.



The injected activity of <sup>18</sup>F-FDG depends on patient size and body weight (e.g. size of 175 cm and body weight of 75 kg = 440 MBq). The effective dose after intravenous injection of <sup>18</sup>F-FDG is 0.0196 mSv/MBq.

MAGNETIC RESONANCE IMAGING (MRI)

Whole-body MRI was performed with a new developed 1.5T whole-body scanner (MAGNETOM AVANTO<sup>®</sup>; Siemens Medical Solutions, Erlangen, Germany) using the TIM technology. The scanner is equipped with 32 independent receiver channels with up to 76 array coil elements that can be connected simultaneously. The system is designed for parallel imaging in 3 spatial directions. Total scan range is 205 cm to allow a complete head-to-toe coverage.

Patients were positioned in the supine headfirst position. For the initial whole-body survey sagittal localizers were obtained to set up the plane for the follow-

ing coronal images that were acquired at five consecutive stations by sequential table movement. First a T2-weighted Half-Fourier Acquired Single-Shot Turbo Spin Echo (HASTE) sequence is applied followed by a T2-weighted Turbo-Short Tau Inversion-Recovery (STIR) sequence to image the whole body in 5 steps. To avoid respiratory motion induced artifacts the Turbo-STIR sequence in the chest and abdomen is performed with breath-holds. The Generalized Auto-Calibrating Partially Parallel Acquisition (GRAPPA) is set to 2. Total measurement time for both pulse sequences are 2.5 minutes and 9.5 minutes, respectively. If necessary an additional T1-weighted Fast Low Angle SHot (FLASH) sequence is used to confirm the presence of skeletal metastases. This is followed by high resolution axial cross sectional sequences to focus on the detected pathology and facultative techniques such as functional imaging, diffusion and perfusion imaging, spectroscopy and magnetic resonance angiography.



## CONCLUSION

The combination of whole-body PET and whole-body state-of-the-art MRI offers the ability for accurate registration of metabolic and molecular aspects of the diseases with exact correlation to anatomical findings with two excellent modalities in oncologic applications, improving the diagnostic value of PET and MRI in identifying and characterizing of malignancies and tumor staging (Fig. 1). PET can be used to spot areas of malignancy, tumor growth, therapeutical response and recurrence. Malignancies with low or normal metabolic activity (e.g. mucinous carcinomas, primary renal cell carcinoma and prostate cancer) may show clearly positive or suspicious findings in the MRI.

Antoch et al.[1] suggest the use of  $^{18}\text{F}$ -FDG PET/CT as possible first-line modality for whole-body tumor staging. Although PET/CT has shown its clinical value it might not be the ultimate diagnostic goal since MRI offers several advantages as compared with CT:

1. MRI is not associated with radiation exposure.
2. The injection of iodinated, potential nephrotoxic contrast agents is not necessary.
3. MRI has a much higher soft tissue contrast. This has been shown to be advantageous in neuroradiological, musculoskeletal, cardiac and oncologic (e.g. detection and characterization of focal liver lesions) applications.
4. MRI allows for additional techniques such as angiography, functional MRI (e.g. brain activation studies), diffusion and perfusion techniques within one single examination and spectroscopy (e.g. prostate cancer).
5. Finally, MRI is emerging as a particular advantageous modality for molecular imaging. This technique, possibly in conjunction with rational targeted therapies, could radically affect the practice of clinical diagnosis and therapy as these technologies continue to mature [15].

The combination of PET and MRI devices into a single scanner offers several advantages in comparison to PET and MRI alone. The repositioning of the patient and time interval between the scans makes the co-registration and fusion of separately obtained images difficult and inherently imprecise [8]. The simultaneous acquisition of co-registered anatomic and metabolic information has shown to improve the diagnostic accuracy of the staging of cancer over visual correlation of the images, allows the discrimination of variable physiologic radiotracer uptake (brain, thyroid gland, fat, striated muscle, myocardium, digestive tract, bone marrow and genitourinary tract) that can mimic metastatic lesions from pathological uptake and can help to avoid potential false-positive interpretations [3, 8, 11, 13, 14]. Hybrid PET/MRI could be a very important diagnostic imaging modality in oncological applications in the decades to come, and possibly for use in cancer screening and cardiac imaging.

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