
BRIEF COMMUNICATION

The First Positron Emission Tomography–Magnetic Resonance Imaging in Hong Kong: Preliminary Experience

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ABSTRACT

A new hybrid imaging modality that combines positron emission tomography (PET) and magnetic resonance imaging (MRI) has emerged as an alternative to a combination of PET and computed tomography (CT). PET-MRI offers many advantages over PET-CT such as radiation dose reduction, superior contrast resolution, and the capability of multiparametric imaging. Our preliminary experience shows that PET-MRI can achieve reasonable workflow and scanning time. Compared with PET-CT, PET-MRI can provide comparable information with much less radiation (up to 77% reduction). It has a reasonable scan time (about 25 mins). In oncology, it has clear advantages in T- and M-staging. It is appropriate for tumour monitoring and surveillance owing to its reduced radiation dose.

Key Words: Magnetic resonance imaging; Positron emission tomography computed tomography; Radiation dosage

中文摘要

香港第一台正電子發射斷層掃描 - 磁共振成像器：初步經驗

賈亦尊、羅吳美英、倪浩光、歐陽啟明、陳義璘

結合正電子發射斷層掃描（PET）和磁共振成像（MRI）的混合成像（PET-MRI）已漸作為PET和計算機斷層掃描（CT）混合成像（PET-CT）的替代技術出現。PET-MRI有優於PET-CT的特點，例如輻射劑量減少、優異的對比度解析度和多參數成像的能力。我們的初步經驗表明，PET-MRI可以達到合理的工作流程和掃描時間。與PET-CT相比，PET-MRI能提供相似的資訊，但是輻射更少（高達77%的減少）。PET-MRI具有合理的掃描時間（約25分鐘）。在腫瘤學中，它在T和M分期中具有明顯的優勢。因其輻射劑量減少PET-MRI更適用於腫瘤監測。

INTRODUCTION

Hybrid imaging that combines metabolic functional information and anatomical detail plays an important role in clinical practice. A combination of positron emission tomography (PET) and computed tomography (CT) has played a vital role in disease screening,

diagnosis, staging, prognostic assessment, monitoring of treatment response, and assessment of recurrent disease. In recent years, a new hybrid imaging modality that combines PET with magnetic resonance imaging (MRI) has emerged as a promising alternative. PET-MRI offers many advantages over PET-CT such as radiation

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Table. Magnetic resonance imaging protocols and their sequence parameters.

	Field of view (mm)	Matrix	Repetition time (ms)	Echo time (ms)	Slice thickness (mm)	Flip angle (degrees)	Scan time (s)
Axial T2-weighted half-Fourier acquisition single-shot turbo spin-echo (HASTE)	430 x 430	256 x 256	1000	98	6	110	28
Axial T1-weighted fat-saturation volume-interpolated breath-hold examination	420 x 302	173 x 320	4.56	1.98	3	9	17
Coronal T2-weighted HASTE	500 x 375	269 x 448	1000	77	6	120	30
Axial diffusion-weighted imaging (Bo, B7000)	430 x 324	83 x 138	9100	78	6	180	100
Sagittal short T1 inversion recovery	380 x 380	269 x 384	3200	61	5	120	91

dose reduction, superior contrast resolution, improved lesion detection in certain organs, and multiplanar and multiparametric imaging. In patients who require both PET and MRI, PET-MRI reduces overall scanning time and number of hospital visits.

In March 2015, our hospital installed Hong Kong's first and only whole-body PET-MRI scanner (Biograph mMR; Siemens Healthcare). In December 2015, PET-MRI service was fully implemented and opened for referrals.

HARDWARE AND IMAGING PROTOCOL

The technical specifications of the Biograph mMR have been described in a performance evaluation paper.¹ In brief, this system consists of a 3-T MRI scanner featuring high-performance gradient systems (45 mT/m at 200 T/m/s). It is equipped with total imaging matrix coil technology (Siemens) that enables MRI acquisition of the whole body without the need to interrupt the examination for coil repositioning. All coils and equipment have been redesigned to minimise their attenuation and hence allow unimpaired PET acquisition.² Within the gantry, the MRI scanner harbours a fully functional PET system, equipped with lutetium oxyorthosilicate-based avalanche photodiode technology.

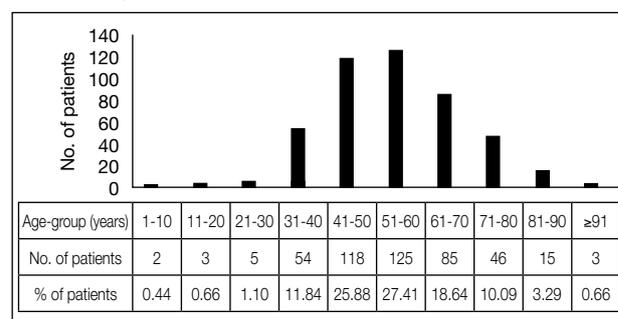
Whole-body examination is performed in a supine position. Combined PET-MRI acquisition begins in the pelvic region and moves towards the head. PET scans are obtained in 4-5 bed positions, with an acquisition of 4 mins/bed. For attenuation correction, attenuation maps generated on the basis of the two-point Dixon MRI sequences are obtained and applied. This approach has been demonstrated to provide results comparable with those of conventional attenuation correction by low-dose CT.^{3,4} MRI scans are obtained simultaneously. The dedicated MRI protocols and their sequence parameters

are summarised in the Table. After completion of PET-MRI data acquisition, a complimentary low-dose non-enhanced CT scan of the thorax (100 kV, 70 mA, 0.5 s per rotation, 5 mm thickness) is performed for comprehensive evaluation of the lungs.

OUR PRELIMINARY EXPERIENCE

Between March 2015 and May 2016, 359 whole-body and 238 regional PET-MRI scans were performed at our hospital in 456 patients (34% male and 66% female) aged 7 to 101 (mean, 55) years (Figure 1). Patient characteristics, scanning time, radiation reduction, referral pattern (Figure 2), radiopharmaceuticals used (Figure 3), and spectrum of diagnosis (Figure 4) were retrospectively reviewed. Contraindications to PET-MRI were the same as for MRI (e.g. metallic implants, pacemakers) and for PET (e.g. pregnancy). The mean scanning time for whole-body PET-MRI was 24 minutes 33 seconds (standard deviation [SD], 3 minutes 24 seconds).

Of the patients who were routinely referred for whole-body ¹⁸F-fluorodeoxyglucose PET-CT, 70 were recruited to undergo whole-body PET-MRI using our integrated scanner. No additional injection of ¹⁸F-fluorodeoxyglucose was given so there was no additional radiation exposure for the patients. Effective

Figure 1. Age distribution of patients.

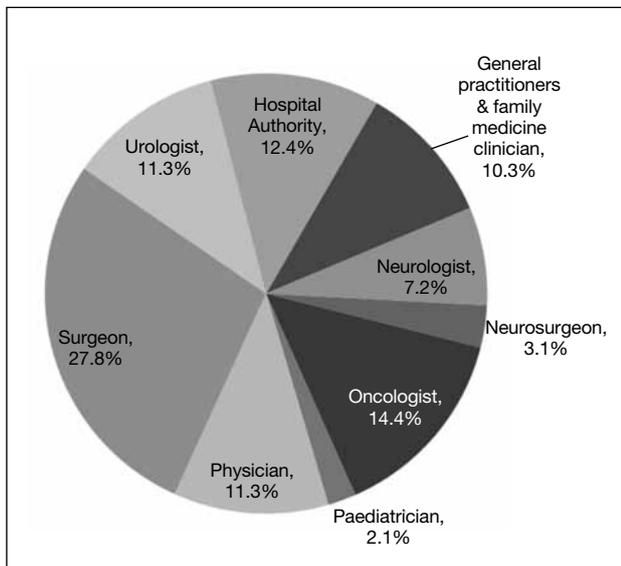


Figure 2. Referral pattern of patients by specialty.

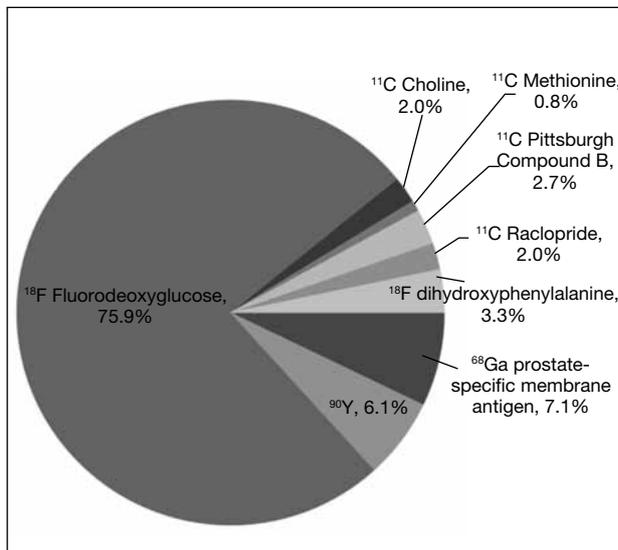


Figure 3. Radiopharmaceuticals used.

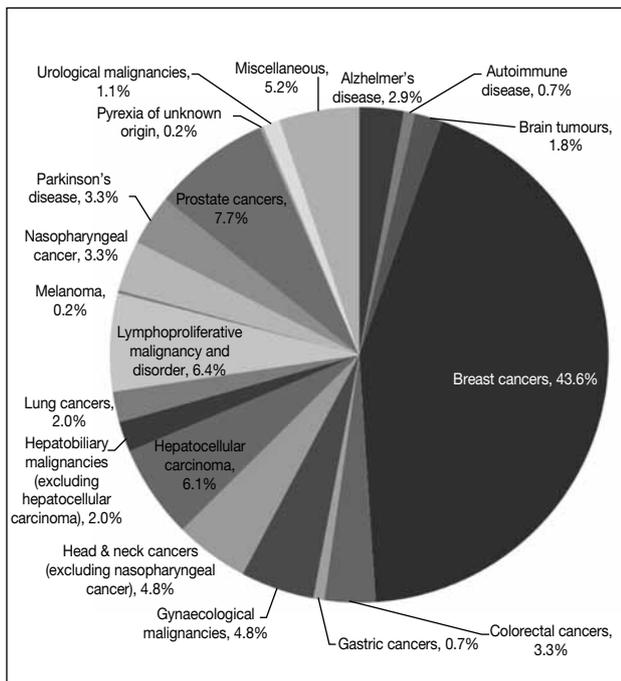


Figure 4. Spectrum of diagnosis of patients.

radiation dose of whole-body CT was estimated from the dose-length product.⁵ Effective radiation dose of PET was calculated from the applied activity.⁶ The mean effective dose of a posterior-anterior chest radiograph is approximately 0.1 mSv.⁷ These figures

were used to estimate the potential dose savings in PET-MRI compared with PET-CT. The mean effective dose of non-contrast whole-body PET-CT was 18.2 (SD, 4.2) mSv. Within this, PET accounted for 7.1 (SD, 0.8) mSv and CT accounted for 11.1 (SD, 4.1) mSv. The potential radiation dose reduction achieved using PET-MRI was 11.8 (SD, 4.5) mSv. This corresponded to a radiation reduction of 51.7% to 77.6% (mean, 62.8%; SD, 6.8%). This is of particular importance in children, young adults, and oncology patients who require repeat examinations.

DISCUSSION

PET-CT is routinely used in clinical practice, especially in the field of oncology. PET-MRI was introduced in 2010 and there are now approximately 70 such systems worldwide, mostly in academic centres. Equipment and operational costs as well as logistics probably account for the its relatively slow adoption.⁸

PET-MRI provides superior soft tissue contrast and thus improved accuracy of T- and M-staging of malignancies through a combination of accurate anatomical and physiological information. Improved T-staging is observed particularly in cases where soft tissue contrast is important. Improved M-staging is demonstrated in malignancies with common metastasis to the brain, liver, and bone.⁹⁻¹² PET-MRI has further potential with its capability of functional and multiparametric

MRI (including diffusion-weighted imaging, dynamic contrast-enhanced imaging, and magnetic resonance spectroscopy). PET-MRI can also significantly reduce the patient's radiation exposure.

PET-MRI is in strong concordance with PET-CT in respect of confidence and degree of inter- and intra-observer agreement in anatomical lesion localisation.¹³ Both have a high correlation in background and lesion

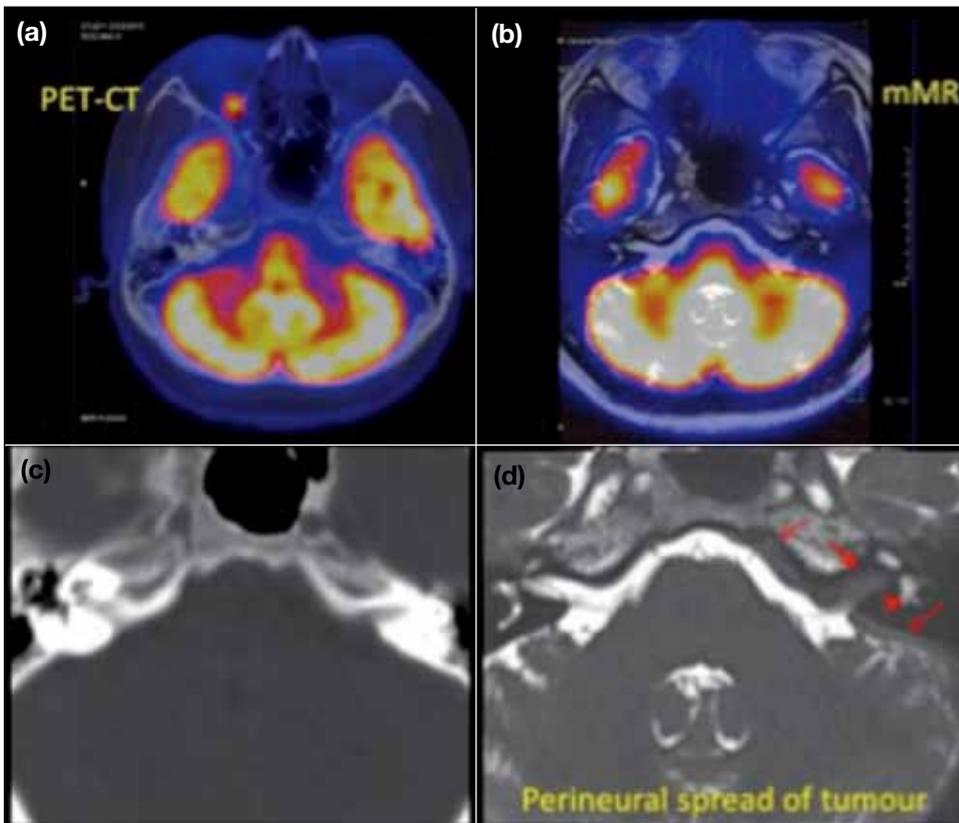


Figure 5. Fusion (a) positron emission tomography (PET)-computed tomography (CT) and (b) PET-magnetic resonance imaging (MRI) in a patient presenting with left facial paralysis. (c) Non-contrast PET-CT does not demonstrate evidence of tumour extending along the left facial nerve shown on (d) PET-MRI. Pathological diagnosis turns out to be cerebral mucosa-associated lymphoid tissue lymphoma.

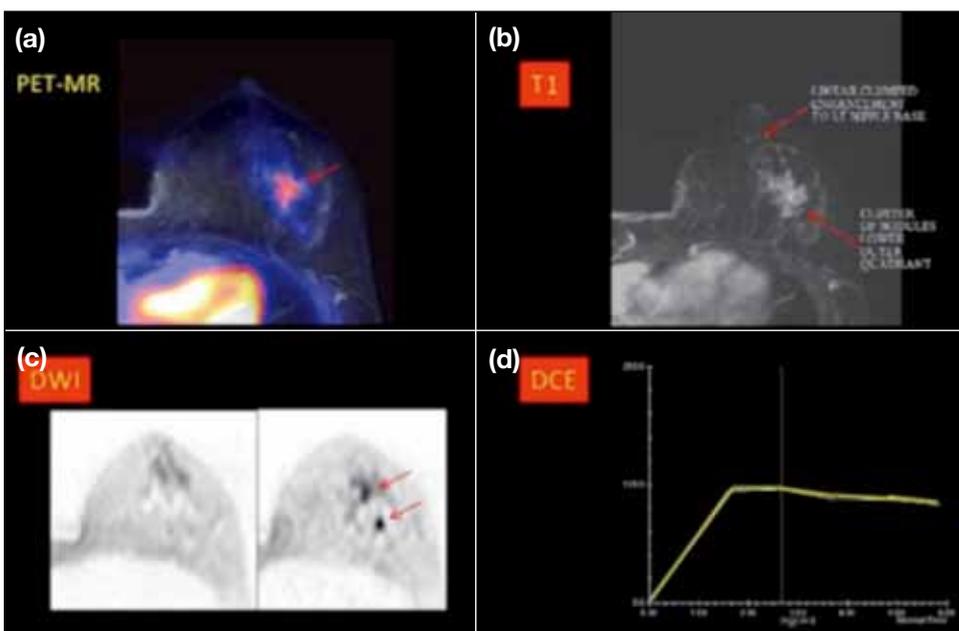


Figure 6. (a) Multiparametric positron emission tomography (PET)-magnetic resonance imaging (MRI) in a patient with newly diagnosed carcinoma in the left breast. (b) PET-MRI showing evidence of tumour extension to the left nipple; an important finding that potentially affects the choice of surgical treatment. (c) Positive restricted fluid diffusion and (d) mild washout on signal intensity-time graph are demonstrated on simultaneous multiparametric MRI.

standardised uptake values; PET-MRI is suitable for quantitative evaluation (e.g. of a therapy response).¹⁰

Our preliminary experience shows that clinical PET-MRI can achieve reasonable workflow and scanning time. Compared with PET-CT, PET-MRI can provide comparable anatomic and molecular information (Figures 5-7), but with much less radiation. Minimising radiation exposure using the ‘as low as reasonably achievable’ principle is encouraged. MRI involves no radiation. With PET-MRI, the radiation dose from CT is omitted. The actual radiation exposure is hence limited to the radiation dose from the PET component that is substantially minor compared with that from CT.⁴ In an epidemiological study, the organ doses corresponding to common CT studies (30-90 mSv) resulted in an increased risk of cancer.¹⁵ There is a need to minimise radiation exposure in vulnerable populations such as paediatrics, young adults, and patients requiring multiple follow-ups. In our comparison of PET-MRI with non-contrast PET-CT, we achieved a 51% to 77% radiation dose reduction. In patients requiring contrast-enhanced and / or delayed PET-CT, the expected dose reduction will be even more.

Nonetheless, PET-MRI has a potential weakness in assessing small (<5 mm) non-fluorodeoxyglucose avid

lung nodules. In patients with known malignancy, 21% of lung nodules missed on PET-MRI turn out to be malignant.¹⁶ Manufacturers are developing newer MRI sequences that can be migrated to the PET-MRI platforms and used to detect these tiny lung nodules. Until then, the complimentary low-dose CT thorax (mean, 0.51 mSv; SD, 0.06 mSv) can address this issue, enabling a comprehensive and all-inclusive evaluation.

Short-term goals for improvement in PET-MRI service include continued optimisation of clinical workflow with development of organ- and disease-specific scanning protocols. Technical improvements with motion correction and time-of-flight capabilities may speed up scanning time. The future direction of PET-MRI should be focused on highlighting the synergistic power of simultaneous acquisition of functional MRI parameters (including diffusion-weighted imaging, dynamic contrast-enhanced imaging, and magnetic resonance spectroscopy) and metabolic PET information. Multiparametric PET-MRI may provide a more successful approach for treatment response assessment or N-staging.^{10,17} PET-MRI can play a role in quantifying a tumour’s vascular properties and tumour glucose metabolism.¹⁸ PET-MRI is useful in neuropsychiatric imaging and cardiovascular imaging. Development of new MRI contrast agents and PET

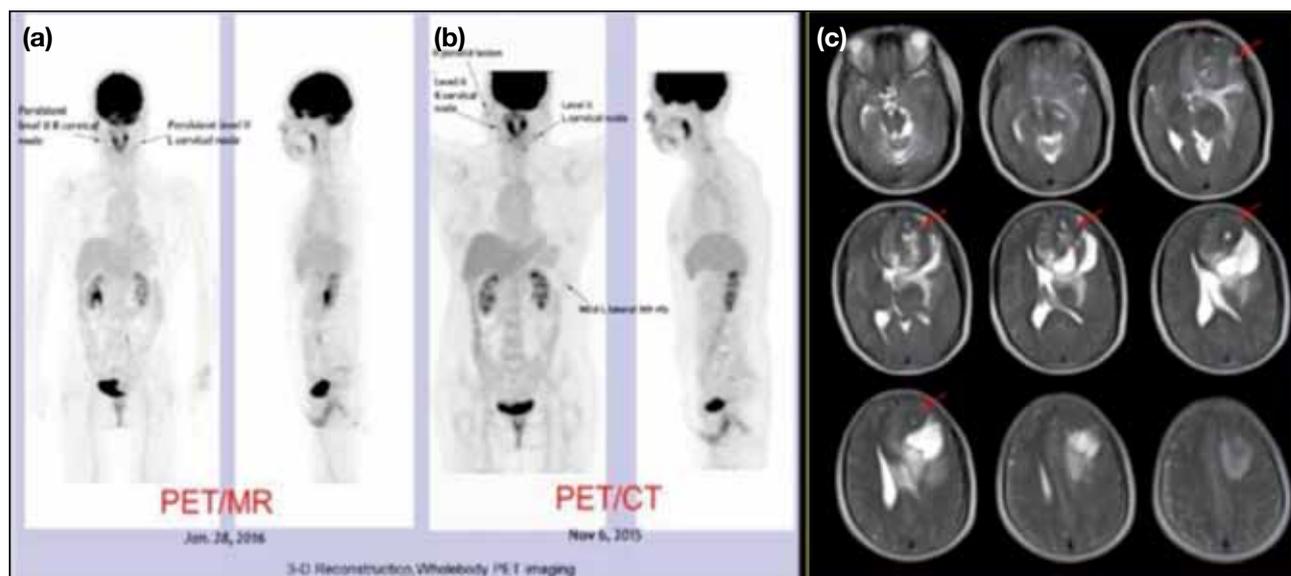


Figure 7. (a) Positron emission tomography (PET)–magnetic resonance imaging (MRI) and (b) PET–computed tomography (CT) of a 54-year-old woman with a history of carcinoma of the breast post neoadjuvant treatment and surgery. She was referred for PET-MRI due to increasing cancer antigen 15-3 despite a recent negative whole-body PET-CT scan. (c) PET-MRI showing the presence of a large frontal cerebral metastasis with mass effect and midline shift. Routine whole-body PET-CT usually starts from the skull base downwards, whereas PET-MRI enables scanning of the whole brain using high-quality T1- and T2-weighted images to detect cerebral lesions.

radiotracers may enable new applications, especially in oncology and neurological imaging. Some of these are still in the research phase, but the results can potentially change current clinical management.

CONCLUSION

PET-MRI provides valuable clinical information with significant radiation dose reduction. It has a reasonable scan time (about 25 mins) and covers a wide range of diseases. In oncology, it has clear advantages in T- and M-staging over PET-CT. With its significantly reduced radiation dose (up to 77%), it is well-suited for serial scans in tumour monitoring and surveillance,¹⁰ using the 'as low as reasonably achievable' principle.

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