



Combined PET/MR Imaging

- Combined PET/MR scanners acquire PET and MR data simultaneously, allowing for accurate temporal and spatial matching of PET and MR data.
- MR has better soft-tissue contrast than CT and can acquire functional data with, for example, diffusion-weighted imaging (DWI).
- In a study that compared PET/CT and PET/MR, PET/CT was found to be superior in detecting lung nodules, but PET/MR revealed additional findings not seen on PET/CT in 55/134 (41%) oncology patients.
- Radiation dose from PET/MR is substantially less than PET/CT.
- PET/MR takes longer than PET/CT and is only feasible in patients who can remain still and breath-hold.
- PET/MR is currently available for patients with selected indications that satisfy enrollment criteria for ongoing clinical research studies.

While combined PET/CT scanners have been widely adopted for more than a dozen years, combined PET/MR scanners are relatively recent developments. Contributing factors for the delay included the challenges of developing PET detectors that are not affected by magnetic fields and the limitations of narrow bore magnets used in MR scanners. Now these problems have been overcome with the development of PET detectors that, for example, use avalanche diodes instead of photomultipliers and large bore magnets that allow installation of PET components between the MR gradient and radiofrequency body coils. Such combined PET/MR scanners were approved in both Europe and the United States in 2011.

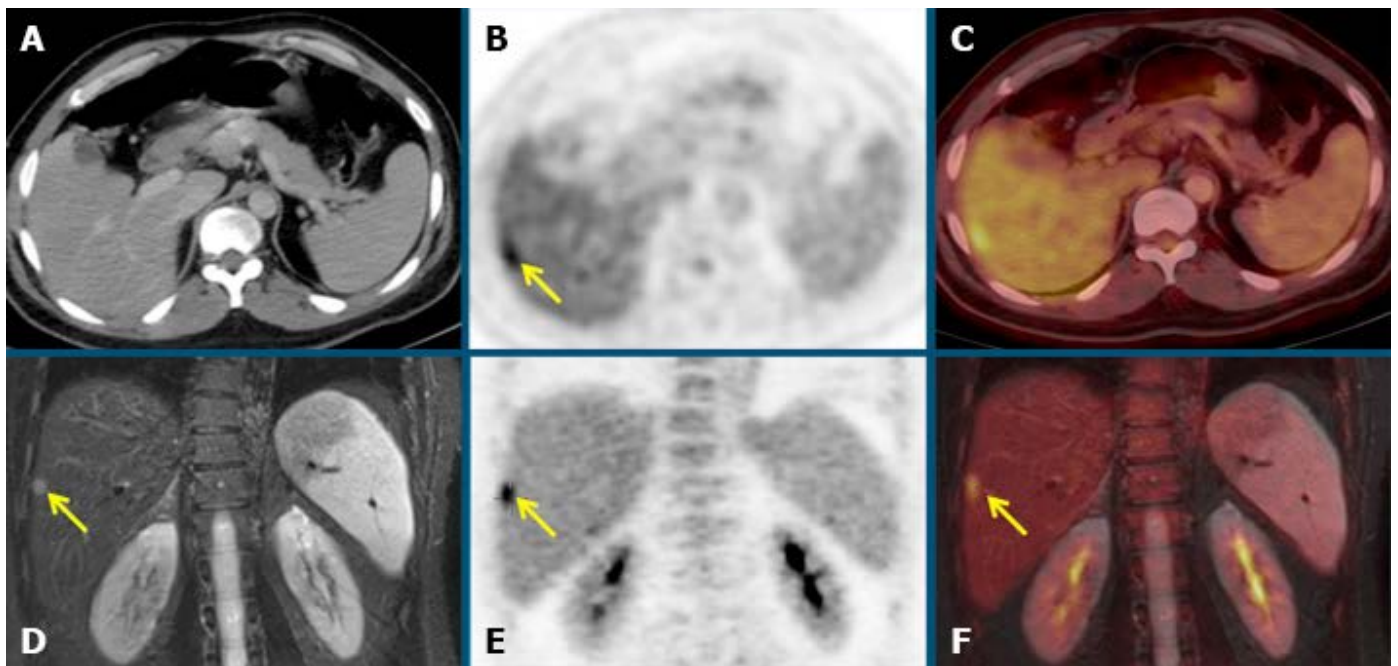


Figure 1. Consecutive combined abdominal PET/CT (top row) and PET/MR (bottom row) examinations of a colon cancer patient. **(A)** CT image does not show any lesions although **(B)** a hot spot (arrow) is seen in the PET image, which can be located in the liver by image fusion **(C)**. **(D)** MR image shows a liver lesion (arrow) that corresponds to **(E)** a hot spot in a PET image and is **(F)** co-localized in a PET/MR fused image.

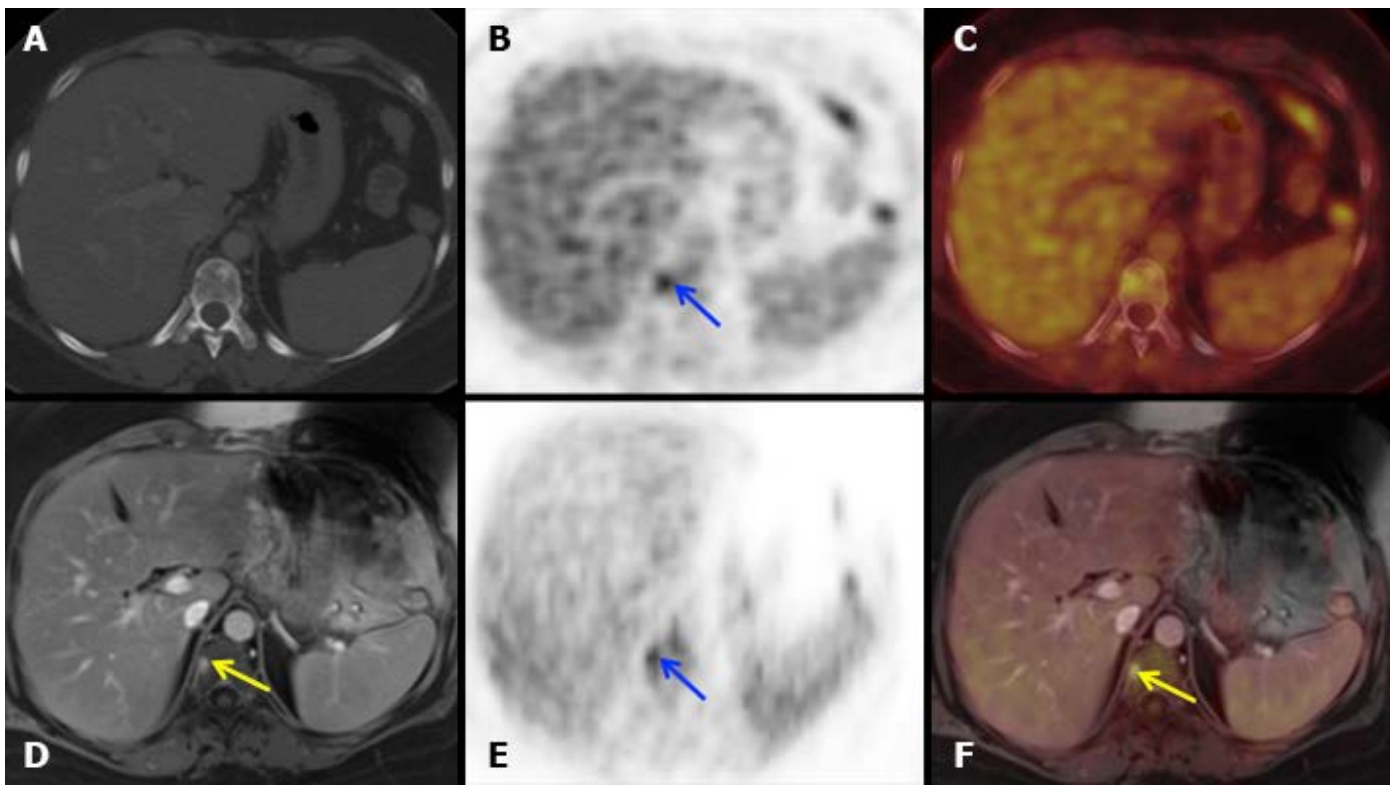


Figure 2. Consecutive PET/CT and PET/MR of a patient with breast cancer. **(A)** CT image does not show any lesions although **(B)** a hot spot (arrow) was observed in the PET image. **(C)** In the fused image, the hot spot is localized in the vertebra, but without any anatomic correlate. **(D)** An MR image shows a lesion in a thoracic vertebral body (arrow) that corresponds to **(E)** a hot spot seen in a PET image. **(F)** A combined PET/MR image clearly shows the location of the lesion in the vertebral body and the correspondence of the anatomic lesion and the area of increased metabolism.

PET/MR acquires data simultaneously, slice by slice. Therefore, it provides excellent image registration. The radiation dose is substantially lower than PET/CT, both because the PET tracer is the only radiation source in PET/MR and because it is possible to use a lower dose of tracer due to the relatively slow MR image acquisition time, giving more time for PET imaging. The low radiation dose is particularly important for children.

The superior soft tissue contrast of MR compared to CT allows improved assessment of fine anatomic detail, clear depiction of lesion margins, local infiltration, and the relationship of lesions to structures. Diffusion weighted imaging (DWI) is valuable because it assesses lesion cellularity and can detect lesions of less than 10 mm throughout the body. T2-weighted imaging can show central necrosis in a tumor. PET provides functional imaging data but lacks anatomic detail. Concurrent data acquisition with PET/MR can increase sensitivity because lesions can be seen in combined images that are not easily recognized in separate PET and MR images (Figure 1), increasing sensitivity of detection and reader confidence. In some cases, anatomic correlates to foci of high metabolism that cannot be seen on CT images are visible on MR images (Figure 2).

ArterioveAdult Body Oncological Applications of PET/MR

PET/MR appears to be particularly helpful in evaluating lesions in lymph nodes, liver, bone, pelvic organs, and breast tissue.

Liver

Some of the hepatic lesion that might be missed by CT, might be visualized more often by MR. With PET/MR, it is possible to: evaluate such lesions for malignancy; detect lesions in regions that are difficult to assess (such as the capsule and intrahepatic vasculature); and assess effectiveness of regional therapies. Unlike PET/CT, PET/MR is not limited by hepatic steatosis, which is commonly associated with chemotherapy.

Lymph Nodes

Standard methods to differentiate between malignant and benign lymph nodes using CT and MR are based on size, with a threshold of ≥ 10 mm for short axis diameter indicating malignancy. However, CT and MR have low sensitivity and low specificity because small lymph nodes may harbor malignant tissue and large ones may indicate other conditions. PET/MR using DWI is more sensitive than MR alone and is comparable to PET/CT for evaluating lymph nodes and detecting extranodal lesions in both adults and pediatric patients with lymphoma.

Bone

Although sclerotic bone metastases are readily detected by CT, lytic bone metastases might be overlooked. PET imaging commonly detects bone abnormalities before any CT correlate is visualized. However, uptake of PET tracer into bone may result from increased hematopoietic uptake in response to chemotherapy. With PET/MR, signal alteration on MR can provide an anatomic correlate of increased PET tracer uptake. This functionality may be helpful in many cases, such as detecting bone metastases in patients with breast cancer and multiple myeloma.

Pelvis

PET/CT in the pelvis is limited by low tissue contrast and by high radioactivity in the bladder due to excretion, which impairs the ability to assess adjacent structures. MR alone is also limited by the challenges of detecting lymph nodes metastases. PET/MR combines effective assessment of lymph nodes with superior T staging of MR imaging and may be advantageous in both the initial staging of pelvic cancers and in follow-up imaging after treatment.

Breast

PET/MR of the breast improves the characterization of small foci enhancement and improves the detection of synchronous lesions.

Lung

Motion artifacts associated with respiration limit the application of PET/MR for the detection of lung nodules smaller than 6 mm. Nevertheless, one study demonstrated a similar detection rate for PET/CT and PET/MR while another reported that PET/MR did not miss any clinically relevant lung nodules in cancer patients who were also examined with PET/CT.

Clinical Impact of PET/MR

In a study of 134 consecutive oncologic patients that were examined by both PET/CT and PET/MR, PET/MR revealed additional finding not seen in PET/CT in 55 (41%) patients; clinical management was affected in 24 (17.9%) patients. PET/CT revealed additional findings not seen in PET/MR in six (4.5%) patients (Table 1).

Finding	Altered clinical management decision (24/134 patients)
Detection of metastases	Chemotherapy (6 patients) Radiofrequency ablation (1 patient)
Ruling out malignancy	No biopsy (5 patients) Close follow-up (1 patient)
Incidental neoplasms	Subsequent surgery (4 patients)
Local infiltration	Chemoradiation before surgery (2 patients)
Lymphadenopathy	Radiation (2 patients) Radiation in addition to chemotherapy (1 patient)
Recurrence	Surgery (1 patient)
Confirmation of malignancy	No biopsy (1 patient)

Limitations of PET/MR

The principal limitation of PET/MR is motion artifact, especially in the regions of the diaphragm, heart, and bowel. Image quality can also be poor because of susceptibility artifacts. PET/MR takes 50–80 minutes, which is significantly longer than PET/CT and requires patient cooperation to remain still and breath-hold. Any contraindication for MR imaging also apply to PET/MR.

Scheduling

At Massachusetts General Hospital, PET/MR is performed in Building 149, Charlestown Navy Yard for patients with selected indications that satisfy enrollment criteria for ongoing clinical research studies. Physicians should contact [Onofrio A. Catalano, MD](#), for scheduling.

Further Information

For further technical details and information about PET/MRI research studies, please contact [Onofrio A. Catalano, MD](#), Abdominal Imaging, Department of Radiology, Massachusetts General Hospital and Athinoula A. Martinos Center for Biomedical Imaging; [Ciprian Catana, MD, PhD](#), Athinoula A. Martinos Center for Biomedical Imaging; or [Umar Mahmood, MD, PhD](#), Athinoula A. Martinos Center for Biomedical Imaging.

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Janet Cochrane Miller, D. Phil., Author
Raul N. Uppot, M.D., Editor

