Hybrid PET/MR systems for whole-body diagnostic imaging

SUMMARY

A new design of scanner combines two existing types of technology, PET (Positron Emission Tomography) and MRI (Magnetic Resonance Imaging) in one piece of equipment for the first time. Two such systems are currently available. The Biograph mMR system takes simultaneous images. The Ingenuity TF PET/MRI system takes PET and MR images one after the other, using separate scanners at opposite ends of a single machine. Both can be used for PET-only or MRI-only imaging as well. It is claimed that hybrid PET/MR scanners are faster, help to make diagnosis more accurate, and reduce radiation exposure compared to other advanced scanning systems. The types of patient who may benefit from PET/MR imaging is not yet clear, but may potentially include cancer patients, dementia patients and children.

BACKGROUND

Doctors use medical imaging techniques to see inside the body in order to diagnose and investigate a wide range of diseases, such as cancer. PET imaging (positron emission tomography) produces pictures that show up functional processes going on in the body. MR (also called MRI, magnetic resonance imaging) and CT (computerised tomography, also called computed tomography, and often abbreviated as 'CAT') both produce pictures of anatomical structures within the body. Using information from both types of picture put together can be very useful. For example in cancer diagnosis, PET can identify places where biological processes are changing from the norm, such as ‘hotspots’ of faster metabolism (typical of growing tumours), and MRI can pinpoint the exact location.
CURRENT PRACTICE

At the moment, patients who need to have this very detailed functional and anatomical imaging done have to have two different types of scan (usually a PET or PET/CT scan and an MRI scan). These are done on different machines in different parts of the hospital, and at different times (sometimes hours or days apart). The pictures are matched up later using sophisticated computer software. Only some patients need to have such detailed functional and anatomical imaging, for example to detect and stage cancers in soft tissues where CT cannot provide the quality of anatomical information that is needed. PET scans produce a 3D image showing where groups of cells in the body exhibit unusual changes in their biological processes (e.g. their metabolic rate). Before the scan, a radioactive dye is injected which circulates around and collects in these cells. These 'hotspots' may be a sign that a tumour is growing. Increasingly, PET scanners are being combined with CT scanners. These hybrid PET/CT scanners provide more detailed pictures, with both metabolic and anatomical information. PET/CT scanners use higher levels of radiation than PET alone, although they are still well within acceptable safety limits. PET scanners are expensive, and only larger hospitals have them. They are not routinely used to diagnose cancer, but are often used to check how far a cancer has spread and whether treatment has worked. They are also used to diagnose other conditions including Alzheimer's disease, epilepsy and heart disease. Around 40,000 PET scans are done every year in the NHS in England. PET/CT scanning is generally thought to be more accurate than PET for diagnosing cancer, although the machines are expensive and only a few hospitals in the UK have them. More than 90% of PET/CT scans are done on cancer patients (to diagnose, stage and monitor disease), but they are also used to image the heart and brain.

MRI produces very detailed 3D pictures of soft tissues and structures within the body. It is useful for imaging the brain, muscles, connective tissues (e.g. tendons), heart and cancers. The patient lies inside a large ring-shaped magnet. The scanner picks up tiny responses that the cells make to a rapidly changing magnetic field, to produce a 3D picture. The main advantages of using MRI rather than CT are that it is very safe (as it does not use potentially harmful 'ionizing' radiation), and it produces pictures with better soft tissue contrast. MRI cannot be used for patients with certain kinds of medical implants, e.g. some heart pacemakers.

In 2010-2011, 3,986,831 CT scans and 2,129,973 MRI scans were done in NHS hospitals in England. In 2010 there were 426 CT scanners and 304 MRI scanners in use in the NHS in England. There are wide variations in the costs of both MRI and CT scans. In the NHS in England, the average cost per scan is around £121 for CT and £184 for MRI.

NEW TECHNOLOGY

Siemens Medical's Biograph mMR system can do PET and MR scanning simultaneously, to produce a whole-body 3D picture showing structure, function and metabolism. The scan takes around 30 minutes (the patient having been injected with the special dye 60-90 minutes before), and the picture is ready in 10 minutes. In technical terms, the high count rate PET data are attenuation-corrected from the 3 Tesla MR data sets. The axial field of view of the PET detector is 25.8cm, giving a peak ‘noise equivalent count’ (NEC) rate of more than 155kcps. According to the company, their system would be better for children who currently need PET/CT scans, because the exposure to radiation is lower than for conventional PET. It could also be useful for some cancer patients to find out the stage that
the disease has reached and also how well treatments are working, and for diagnosing diseases of the nervous system such as dementia.

**Philips Healthcare**’s Ingenuity TF PET/MRI system is a single machine with a separate scanner at each end. Instead of simultaneous scanning, it does one scan at one end and then moves the patient 2.5 metres along (on an automated rotating bed) to the other end for the second scan. The two pictures are combined into a whole-body 3D image within about 30 seconds. The two scanners involved are called the Achieva 3 Tesla MRI scanner and the Astonish TF PET scanner (which uses a technology called ‘time-of-flight’ to improve image resolution). The company state that their system uses 70% less ionising radiation than PET/CT, and produces very high quality pictures that may make diagnosis more accurate for patients with cancer and diseases of the nervous system and heart.

Both the Biograph mMR system and Ingenuity TF PET/MRI system are CE marked. The Biograph mMR has been available in the UK since January 2011, with one system installed so far (at University College London Hospitals NHS Foundation Trust in London).

**CLINICAL STUDIES AND RESEARCH QUESTIONS**

Small scale research studies are being carried out to find out what advantages hybrid PET/MR systems may have over existing scanners, and for which specific patient groups and uses. The studies that have been published so far describe the quality of PET/MR pictures taken for individual patients in highly technical terms, and discuss how they compare with standard imaging. The types of patients being studied include those with cancer of the head and neck, brain, prostate and breast. The results that are available so far include the following: for the Biograph mMR system\(^{12,13,14,15,16,17}\), for the Ingenuity TF PET/MRI system\(^{16,19}\); and for hybrid PET/MR\(^{20}\) (i.e. the system used was not stated).

Based on current knowledge it is not yet clear exactly how this new technology may improve health outcomes for NHS patients, and what the implications would be in terms of costs and savings and the provision of services. Further research in larger numbers of patients is needed before these questions can be answered.

A USA study\(^{21}\) has started recently that will compare the quality of pictures produced using the Ingenuity TF PET/MRI system with PET/CT in 100 patients with a range of cancer types (including colon, head and neck, and lung). The study is expected to complete in around October 2012.

**POTENTIAL IMPACT**

This new technology is relevant to several government policy priority areas, including the care of patients with cancer and dementia, and the care of children and young people. MRI imaging of the brain is a government priority area for improving earlier diagnosis of cancer in these patients\(^{22,23}\).

The patient groups that may benefit from hybrid PET/MR is still a matter of speculation, while we wait for the results of further research. Expert opinion suggests if research proves it to be more accurate, PET/MR is likely to replace PET/CT for diagnostic imaging of cancers located in the brain, head and neck, muscles, skeleton and pelvis (e.g. prostate, bladder, rectum, womb and ovaries). PET/MR could also potentially replace PET/CT for diagnosing cancers in other parts of the body if its diagnostic accuracy turns out to be equivalent and the lower radiation exposure needed would be of benefit. The lower radiation exposure needed for hybrid PET/MR systems compared to PET/CT is likely to be better for imaging
children and young people (who are more prone to its harmful effects), and for patients who need to have a number of repeated scans (e.g. cancer patients being monitored after treatment).

If hybrid PET/MR helps to diagnose patients more accurately and/or at an earlier stage, and helps to guide their treatment more effectively than current imaging systems (e.g. is more accurate for radiotherapy planning and checking response to treatment), then it may lead to improved quality of life and health outcomes for patients. It may also result in cost savings in the future. However, the clinical value of hybrid PET/MR needs to be evaluated in clinical trials before conclusions can be made. It should also be noted that for patients who suffer from claustrophobia (a fear of confined spaces), MRI is not an option and therefore PET/MR may not totally replace the need for PET/CT.

The greater ease of use of these ‘single machine’ systems may make them useful for imaging patients with dementia (who need both PET and MR imaging). Doing one scanning session in one location in the hospital may be more convenient and comfortable for patients, and it may reduce stress and the need for sedation. For new installations, the building costs may be lower because PET/MR systems are housed within a single room. However, some existing single scanner facilities would not be big enough to fit a hybrid PET/MR system into, in which case a new facility would have to be built. This is because PET scanners need to have an area for radioactive preparation and injection (not available in MRI facilities) and MRI rooms need space to contain shielding for the magnetic field and to deaden the noise of the machine (not needed in PET facilities).

The demand for complex diagnostic imaging (including MRI and CT) is rising. A new PET/CT system costs around £1.2-1.5 million. The costs of the new PET/MR systems are not yet publically available. Careful analysis would be needed to work out what impact they would have in terms of health service provision (e.g. staffing requirements, workflow and service efficiency). In terms of the specialist staff who interpret and report on the results of different types of imaging, radiologists report on MRI scans and nuclear medicine physicians report on PET scans. Therefore, one of the challenges of moving to the new hybrid PET/MR technology would be to ensure the efficient and standardised reporting of both types of results. This would involve additional staff training and changes to working practice. Another important practical issue would be the need for and additional benefit of using MRI contrast agents (dyes) in combined PET/MR.

**Lay summary**

*Bigraph mMR and Ingenuity TF PET/MRI* are new medical scanners that can - for the first time - do two different types of scanning together on one machine. These types of scanning are called PET and MRI and they are used together when doctors need to have very detailed 3D information about diseases, such as cancer, that may be developing inside the body. The companies claim that these joint PET/MR scanners may mean less radiation for patients than with some other scanners. They also say they may be better for diagnosing diseases, particularly in children and young people, and in patients with cancer and dementia. However, more studies are needed to say how true this is, and if so, which types of patients would be helped most by this new type of scanner.
REFERENCES

14 Gall CC, Quick H, Schmidt D et al. Lesion detection and SUV quantification in simultaneous whole-body MR/PET hybrid imaging: intraindividual comparison to PET/CT imaging. European Journal of Nuclear and Molecular Imaging 2011;38:S156.
21 Clinical Trials.gov. Evaluating attenuation correction methods applied to PET/MRI. 