Spotlight on Positron Emission Tomography / Computerised Tomography Imaging
PET/CT Imaging Improves Outlook for Cancer Patients

The discovery of X-rays in 1895 heralded a new era for medicine. At last there was a way to see inside a patient, and since that time a variety of ever more sophisticated methods of scanning the human body have made their way from physics laboratories into hospitals. One of the latest is PET/CT (Positron Emission Tomography/Computerised Tomography) scanning.

As its name suggests, PET/CT combines two methods of imaging to create a powerful new weapon in the fight against disease. The scan reveals information about the growth and functioning of living tissues, as well as their shape and size, and can be performed over the entire body or on specific areas of the body such as the brain. One of its main uses is in oncology, as it can reveal tumour sites - even if they are very small - in areas such as the lungs, head and neck, lymph glands and oesophagus that can easily be missed by CT alone or by MRI (Magnetic Resonance Imaging). As well as revealing the presence of tumours, PET/CT can be used to monitor the effectiveness of cancer treatments such as radiotherapy. These can then be altered mid-course or replaced by another treatment if they are not having the desired effect.

Potential also exists for PET/CT to become a routine tool for assessing the extent of neurological conditions such as epilepsy and dementia. In addition, it can reveal details of the glucose uptake in the heart which can, for example, show how much heart muscle is still living after a patient has suffered a heart attack.

How PET/CT works

PET/CT scanners are hollow cylindrical machines that look similar to MRI scanners. The CT section of the apparatus has an X-ray generator and detectors that can rotate around the patient and record a CT scan - which is a series of X-rays taken at different angles through the body - immediately before or after the PET scan.

The PET portion of the scanner contains an array of sensitive gamma ray detectors arranged in a circle around the bore. These detect the low dose gamma radiation coming from the radiopharmaceutical (a radioactive tracing agent) that every patient is injected with before undergoing a scan. The most widely used radiopharmaceutical for PET is fluorodeoxyglucose or FDG which contains a radioactive form of fluorine. Our cells get the energy they need by taking in glucose from the bloodstream, and absorb FDG in the same way as ordinary glucose. Diseased cells will absorb a different amount of FDG than healthy cells, and so will be revealed in the scan by their different level of radioactivity. Cancer cells for example have a larger uptake of glucose (and hence of FDG) than normal cells because they grow and divide at a higher rate.

It is actually particles known as positrons - which are the antimatter version of electrons - that PET radiopharmaceuticals emit. Matter and antimatter cancel each other out, and each positron travels less than a millimetre within the body before it meets with an electron and undergoes an ‘annihilation’ in which the particles are converted into two gamma rays. These gamma rays travel out of the body and are detected by the scanner. The data gathered by the detectors is processed by computer using a mathematical technique known as a reconstruction algorithm, which allows it to pinpoint where these gamma rays have come from and so produce an image of the distribution of radioactivity within the body.

In total the scan takes about 30 minutes, and the images are processed in less than 10 minutes. The three images on the left illustrate the amount of information that a combined PET/CT scan can obtain. The uppermost image shows a CT scan. As would be expected from an X-ray, the various organs and bones show up clearly. However, what the CT scan does not reveal is that this patient has a cancerous tumour, which is detected by the PET scan.
A pattern of light beams is used to enable the operator to position the patient correctly before the scan begins. A computer system turns the raw data from the scanner into a recognisable image of the body using processing techniques similar to those used to create MRI images. Worldwide there are four main suppliers of PET/CT scanners: Siemens, Philips, CTI Molecular Imaging and General Electric (shown here). Systems produced by each of these companies are available for sale to healthcare providers in the UK.

Illustrated below the CT scan, and shows up as a dark spot. Whilst nuclear medicine physicians and radiologists working in the PET field are highly skilled at interpreting PET images like this, a combination of PET and CT - as shown in the bottom image - greatly aids them as it provides a much clearer indication of where tumours are located within the body.

**Manufacturing radiopharmaceuticals**

The radioactive elements within radiopharmaceuticals like FDG (in this case a radioactive form of fluorine) are made using a device known as a cyclotron. Fortunately FDG has a half-life (time in which the amount of radioactivity has decreased to half of its starting value) of almost two hours. This means it can be made then transported to hospitals within a two hour travelling distance while remaining active enough for clinical use. However some radiopharmaceuticals under development have such short half-lives - the radioactive oxygen used for brain studies has a half-life of just two minutes - that scans using these would have to take place at hospitals with their own cyclotron facilities.

**Advantages**

While PET/CT is too new for long-term studies on its effectiveness to have been carried out, evidence gathered in the US points overwhelmingly to its success in assessing a variety of different cancers. PET/CT certainly has a unique ability to indicate the precise anatomical location of the functional information it records. In the case of cancer, ultrasound scans, CT alone or MRI can miss early indications, as an organ with a tumour can look exactly the same structurally as a healthy organ even though its metabolic activity (which is the function that PET measures) has changed dramatically. Theoretical studies have also demonstrated that PET/CT is cost effective. This is not surprising, as although PET/CT scanners are initially expensive, their accuracy results in a reduction in the amount of unnecessary treatments carried out - including drug therapies and surgical procedures.

**Availability in the UK**

PET/CT scanning has become standard in the US and the number of scanners is fast increasing in mainland Europe. The UK is lagging behind this level of implementation with less than 10 scanners currently available to the NHS, although several new scanners will shortly be on-line including one in Nottingham. In addition there are several mobile PET scanners being operated by private companies. Experts suggest that all of the UK’s 43 cancer networks (which are each capable of delivering a full range of cancer therapies within their geographical area) should have at least one PET/CT scanner, and that there needs to be a cyclotron in close proximity to every scanner.

Simply buying new equipment will not be enough to provide a viable PET/CT service however. Training must be given, not only to nuclear medicine consultants and radiologists, but also to medical physicists, radiographers and clinical technologists so that the optimum advantage can be obtained from these systems. At the sites where cyclotron facilities need to be installed, additional specialist staff including radiochemists and radiopharmacy technicians will be required.
Perspectives on: physics and engineering in medicine and biology

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PET/CT scanners look very similar to stand alone CT or MRI scanners, but have wider bores to reduce patient claustrophobia. They are also relatively long as each scanner contains two sets of scanning equipment. In principle there is no reason why CT and PET scans of a patient could not be taken on separate scanners, then the results fused together by a computer. However a combined scanner has the advantage that it allows composite images to be produced on site, without having to transfer results between hospitals, and therefore create delay for both patient and consultant.