Summary  Computed tomography utilises a rotating X-ray source combined with multiple detectors in the latest scanners. This data can then be processed in numerous ways to provide axial, multi-planar and 3D images for diagnostic purposes. This modality has rapidly developed since its inception in direct relationship to the exponential increase in computer technology with a corresponding increase in its range of applications.

History  Computed Tomography (CT) scanners are a relatively recent invention and their inception and development are closely linked to advances in computer technology. It is therefore not surprising to learn that Godfrey Hounsfield, who is credited with the development of the first EMI CT scanner, also developed the first all transistor computer. He jointly received the 1979 Nobel Prize in Physiology or Medicine in recognition of his pioneering work in this field.

Principle  The underlying principle of CT is to irradiate a slice of tissue from multiple angles measuring the output from the opposite side. Tissues have differing densities and will attenuate the incident X-ray beam to varying amounts, i.e. the denser the tissues in a plane the fewer X-rays will reach the detectors. The multiple measurements from a slice are then taken, and using Fast Fourier Transformations, a map of different density tissues within the slice examined can be produced. This data is then converted into an image for radiological analysis. Dependant upon the scanner up to 3000 levels of attenuation can be demonstrated. The computer arbitrarily assigns a value to various tissues known as the Hounsfield scale:

- Bone +2000
- Acute blood +60
- Soft tissues +40
- Water 0
- Fat —100
- Air —1000

To generate an image, the computer then assigns a grey scale to the values obtained. Unfortunately, the eye can only appreciate 11 different shades of grey rather limiting what can be viewed. To take
advantage of the large amount of data available different “windows” are used.

For example, in an abdominal CT scan the soft tissues of the abdomen are the most important structures to visualise so the grey scale is arbitrarily centred at a value of 20 with the width of the window being restricted to no more than 200 (Fig. 1). This means that any structure with a number less than $-80$ will show up as black and any structure registering 120 or above will be white. However, the subtle density differences of the abdominal soft tissues will be well demonstrated.

Different types of CT scanner

**Single slice**

The first CT scanners were very slow and limited to examination of the head and brain. Indeed, the scan time for the pre-production scanner was measured in hours and took several days to process with a mainframe computer. The original clinical scanners required a water bath around the area of interest limiting the range of applications. The hardware used consisted of a single X-ray source and a single detector, these were rotated around the patient obtaining data from a single location for processing before moving onto the next point.

Various advances on this technique were produced but the next big step forward came with the development of spiral scanning. Instead of the source and detector rotating around a fixed point and then moving down the patient in a stepwise manner, the table moves down during the scan resulting in a “spiral” data acquisition through the volume of interest. The spacing between the spirals directly affects how detailed the scan obtained is. Therefore, the smaller the distance the more detailed the resultant scan. However, the payback is that this limits the volume that can be covered. The radiologist therefore has to balance the choice between the detail and volume.

**Multi-slice**

The latest leap in technology has been the development of multi-slice technology. This means the use of multiple detectors at the same time vastly increases the amount of data that can be acquired in a single acquisition. It is possible to get a far more accurate representation of the anatomy and reduce the artefact, particularly from metal-work.
From a practical point of view, multi-slice scanners are far faster and it is now possible to scan from the top of the head down to the pubis in a single acquisition taking about 30 s. This means that the previous constraints upon coverage and detail no longer apply.

Careful use of this technology has led to a decrease in the dose required for image production; however, because multi-slice scanners are so flexible and fast there is now a trend to scan far larger areas leading to an increase in overall dose for the patient. One of the current challenges in radiology is to optimise the scan protocols to take advantage of the multi-slice technology and at the same time keep the doses reasonable.

Slice thickness

Careful choice of scanning parameters, in particular the slice thickness is key to any examination. This equates to the interval between consecutive passes of the scanning beam as this spirals down the patient. Choosing a small slice thickness results in a more detailed examination of the area in question and significantly better quality reformats or 3D models.

At first glance, it would seem attractive to perform all CT examinations using the smallest slice thickness possible to obtain the most detailed examination and to facilitate high-quality post-processing. Unfortunately, the thinner the slice thickness the greater the dose required for a set tissue volume and the greater the data acquired.

The increase in dose must then be justified on the basis of what information is required. The result is usually a compromise where the largest slice thickness is used which will allow the relevant pathology to be demonstrated.

The volume of data generated can lead to problems of its own. For example, a CT examination of the whole cervical spine using a 1.25 mm slice thickness will generate 180 images not including the reformats. If a slice thickness of 0.625 mm is used although the quality of data is substantially better, this results in 550 images.

Contrast Enhancement

All scans have natural contrast, however, difference between soft tissues can be very subtle (Fig. 2). This can be of particular problem when trying to differentiate acute haematoma from the liver and spleen (the most commonly injured solid organ with blunt trauma). Fortunately, there are a variety of ways in which the contrast can be enhanced:

1. Air—as air has a very low Hounsfield number, this is easily identifiable. Air in an abnormal location is pathognomonic for certain conditions, for instance, a pneumoperitoneum indicates a perforation. Air can also be introduced to enhance structure, for example, air per rectum is used to evaluate the large bowel.

2. Intravenous contrast—iodine containing preparations can be injected. The timing of the scan can then be tailored to assess different structures. An early scan will show arteries and arterial phase filling of solid structures. A slightly delayed scan will show venous anatomy, venous filling of solid structures and to a lesser extent the arteries. For general abdominal examination, the scans are timed to coincide with portal venous filling of the liver as this tends to demonstrate most abdominal organs well.

3. Oral contrast—iodine containing preparations can be taken to more clearly demonstrate the bowel. In the acute abdomen, this needs, ideally, to be an hour before the scan to clearly demonstrate the stomach, duodenum and as much of the small bowel as possible. For oncology scans, the patient takes further oral preparations on the day before to demonstrate the large bowel as well.

4. Rectal contrast—iodine containing preparations can be introduced per rectum to ensure high quality imaging of the large bowel. This is particularly useful where there is pelvic or large bowel pathology.

5. Bladder contrast—the bladder can be filled with contrast enhancing either by performing a delayed scan by which time iodine will have been excreted by the kidneys or by directly filling the bladder with very dilute contrast agent using a urinary catheter. This latter technique is particularly useful in the acute trauma case where there is clinical concern for bladder rupture.

6. Tampons—these are clearly visible and for pelvic pathology are routinely used to clearly define the location of the vagina.

Applications

CT has benefited greatly from the exponential development in computer software, and with the
advent of smaller slice thickness it is now possible to post-process the data in a multitude of ways.

The most widely used post-processing is Multi-Planar Reformats (MPRs) (Fig. 3). This is the reconstruction of the data into any plane desired although usually this is a sagittal and coronal reformat. Curved reformats are possible and are of particular use for spinal imaging in patients with scoliosis.

3D images (Fig. 4). There are multiple software packages available to produce these images. These either create surface-rendered images or true volumetric images. These used to be considered purely as a toy; however, careful selection of patients means that these can find a place in the interpretation of complex fractures or complex spinal abnormalities to give the surgeon an overview. The only potential problem with these is that there is an inevitable loss of definition associated with this form of post-processing which means that subtle fractures can "fade away" or alternatively be created.

A recent development of this principle is the ability to ghost out structures (Fig. 5). For

Figure 2 Post-contrast-enhanced axial abdominal image. The aorta (A), IVC (I), spleen (Sp), liver (L) and kidneys (K) are all seen to enhance due to vascular contrast media. Irregular vascular enhancement of the spleen is shown secondary to a Grade 4 splenic laceration. The stomach (St) is seen to contain oral contrast media. The free air in the tension pneumothorax is demonstrated displacing the spleen and stomach.

Figure 3 Sagittal reformat through the ankle demonstrating the distal end of an intra-medullary nail with a multi-segmental fracture of the distal tibia. Note: the lack of artefact secondary to the nail. Prior to multi-slice this imaging was not possible.
example, with acetabular fractures this allows a ghost outline of a femoral head to be maintained to show its relationship to the fracture but with full view of the fracture itself still possible.

Virtual endoscopy is a technique which is fast becoming popular as a non-invasive way of looking for luminal tumours. Multiple software packages are available and certainly in frail elderly patients this is far safer and a more patient friendly examination than endoscopy itself. The main downside to this technique remains the large radiation dose necessary for the investigation; although this is less of a problem in the older patient this does rather limit this application for the younger age group.

**Terminology**

There are a number of common misconceptions mainly because of the very fast development in CT technology.

Spiral—this describes the underlying technique used and now applies to most scans performed. Therefore, asking for a spiral scan will usually elicit a smile from the radiologist as virtually all scanners now used are these.

High resolution—this is limited to a specific type of chest CT examination (Fig. 6). A very thin slice is obtained specifically to look at the lung parenchyma. Only a small number of slices are taken through the lung at 10 mm intervals. This technique is limited to assessing diffuse parenchymal lung disease. The usual misconception is that this provides a detailed look at all of the lungs. If the examination is performed to look for small lung deposits then a more general scan is indicated, as large volumes of lung are not assessed by the high-resolution technique.

"A Contrast scan"—all scans have natural contrast and it is not always necessary to give contrast-enhancing agents to make the diagnosis. Part of a radiologist’s job is to understand how to tailor examinations for each patient.

A scan is always necessary—the quality of the imaging is so good now that few surgeons are willing to perform a blind operation. It is, however, essential that the patient is not forgotten in this and if they are unstable or if they still need an operation regardless of the scan results, then they should not be delayed just to get a pre-op scan. Every year, patients die in the CT department when they should have been on the operating table and hence the other name for CT Scanners is “The doughnut of death.”

**Radiation protection**

CT is a tremendously versatile modality with a wide range of applications and an almost limitless variety of ways in which the data can be manipulated. It is also, by dint of its speed with the new
multi-slice technology, very quick and is now very much the modality of choice for trauma patients.

The major drawback of CT is that it uses ionising radiation to generate the images. This means that it is a legal requirement to justify all investigations as there is the potential to cause harm to the patient.

CT unfortunately not only uses ionising radiation but the actual amounts are very high\(^3\) (Table 1).

In acute life-threatening trauma, this is easy to justify as for a patient to be at risk of a cancer, they must first survive the life threatening state that they are in. By the same argument, it is easy to justify the initial diagnostic examination in patients undergoing oncological investigation. However, it can be seen that this becomes more difficult to justify when repeat CTs are requested or alterna-

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**Figure 6** High-resolution CT scan of the lungs. This gives high-quality information about the lung parenchyma but provides little information about the mediastinum or bones.

**Table 1**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Typical effective dose (mSv)</th>
<th>Equivalent number of chest radiographs</th>
<th>Equivalent period of natural background radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CXR</td>
<td>0.02</td>
<td>1</td>
<td>3 days</td>
</tr>
<tr>
<td>Pelvic X-ray</td>
<td>0.7</td>
<td>35</td>
<td>4 months</td>
</tr>
<tr>
<td>CT head</td>
<td>2.0</td>
<td>100</td>
<td>10 months</td>
</tr>
<tr>
<td>CT chest</td>
<td>8.0</td>
<td>400</td>
<td>3.6 years</td>
</tr>
<tr>
<td>CT abdomen/pelvis</td>
<td>10.0</td>
<td>500</td>
<td>4.5 years</td>
</tr>
</tbody>
</table>
tively whole body CT for minor trauma. This is a particular problem with oncology where a significant number of patients are entered into clinical trials which rely upon regular CT follow-up.

Careful choice of areas to scan is important, the pelvis (reproductive organs), the neck (thyroid gland) and the face (orbits) are very radiosensitive and where possible these areas should be avoided.

The other factor to balance is the scan parameters. Multi-slice technology now means that there is no real limit on the volume scanned and down to 0.4 mm slices are possible. Unfortunately, the thinner the slice thickness and the greater the volume of tissue scanned, then the greater the dose the patient is subjected to.

### Availability

A cursory read through of this article will lead the reader to correctly assume that this is one of the key investigations available to the clinician. However, for any diagnostic investigation to be of major benefit, the waiting times for the test needs to be as short as possible. In North America, this is certainly the case with in-patient waiting times measured in hours and out-patient times in days. This is certainly not the case in the majority of UK centres.

The US centres achieve this as they operate on fee per service agreements and so the greater the demand the greater the revenue allowing for appropriate increases in staffing and equipment. In the UK, most radiology departments receive a lump sum to provide all their services and although this has steadily increased, few centres have taken account of the massive increase in demand for imaging associated with the technological advances.

This leaves most radiology departments now with too few CT scanners and too few staff to operate them and interpret the results. To put this into context, most UK hospitals will have one or two CT scanners, in North America similar size institutions will usually have between six and ten scanners! Until such time, as proper service led agreements become commonplace in the UK, it is difficult to see this changing. The end result is that waiting times in the UK are more usually measured in days for in-patients and months for out-patients.

### Summary

CT scanning has made dramatic improvements since its inception in the 1970s. It is now the modality of choice for the acute trauma patient with a wide range of software packages available. The challenges, in the UK, are to improve its availability and to address the increasing concern over the dose associated with this technique.

### References