Bone densitometry has become internationally accepted for in vivo bone mass measurements over a relatively short period of time. There are an estimated 5,000 plus DXA scanners in regular use world-wide, while increasing use is made of peripheral bone densitometry techniques. In addition there are centres performing quantitative computed tomography. The rapid growth of DXA has meant that technicians with varied experience are working with this technique, some after only minimal instruction. Operator training in different centres and countries is not standardised, and a lack of knowledge can lead to innocent mistakes both in acquiring the scan, its analysis and subsequent interpretation.

As in other clinical measurements, sources of error may be found in the following:

1. The instrument
2. The patient
3. The operator
4. The report

1. The Instrument.
Reliability of DXA systems has greatly improved, but calibration and quality assurance checks must be rigidly followed, and are the responsibility of the technical staff. Operators should be aware of the differences that exist between centres using the same machine and even greater differences found between manufacturer’s data. Algorithms and population reference data are not identical between manufacturers, or ethnic groups. For this reason caution is needed when a patient is referred to a centre having had a previous scan from a different machine or osteoporosis centre, because it is unlikely that the results will be directly comparable with the current report.

2. The Patient
The height and weight of the patient is normally required, and the technician should be aware of the effects of under or overweight on BMD. The manufacturer’s algorithms are based on a normal Body Mass Index. Fat distribution, which may be inhomogeneous and variable over time is known to affect bone densitometry.

The patient should be checked for metal objects in or on clothing, prostheses, and questioned about recent nuclear medicine investigations or an injection of contrast media. It is advisable to ask each patient about their recent investigations or previous surgery, which may reveal that a pacemaker, or radioactive seeds have been implanted.

Even by excluding interventional sources of artifacts, the unsuspecting operator may still encounter a number of problems which can include the following:
1 **Metal** associated with body piercing, pacemaker leads or implants. Fig.1.

2 **Surgical clips** (internal) These have been found even in a patient who denied surgery!

3 **Cannulae** e.g. Hickman drainage line Fig.2.

4 **Contrast medium.** Some patients who have had myelography in the past, may show the presence of the medium many years later. It may be located in different parts of the spine at different times. Fig 3.

5 **Buttons.** These are normally regarded as of little consequence unless they are obviously metal. In fact small pearl buttons can be very clearly recorded in a DXA scan. A useful experiment is to take a selection of buttons and place them on the phantom for scanning. Only all-plastic buttons will fail to record. Fig.4.

6 **Plastic materials** in a pocket may interfere, especially credit cards, so all pockets of clothing worn during the scan should be emptied.

7 Some **sticking plasters** using zinc oxide will show on a DXA scan, but unless it is overlaying the sites for measurement it may be ignored unless the location is likely to affect soft tissue readings. Large plasters should be removed before scanning.

A number of clinical artefacts affecting DXA have been described, including undiagnosed conditions that can affect the region being scanned. Anomalies can also be found in normal subjects, especially the presence of extra ribs and vertebrae which can confuse the selection of vertebral levels. In general, the only way to deal with this is to record the chosen levels for analysis so that further scans can be analysed from the same vertebrae. Other abnormalities may also be found, which are due to undiagnosed conditions such as spina bifida occulta.

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>EFFECT ON SCAN</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic calcification</td>
<td>elevated lumbar BMD</td>
<td>check for mysterious contrasts in BMD</td>
</tr>
<tr>
<td></td>
<td>see fig.7</td>
<td>lateral spine DXA? Lateral radiograph</td>
</tr>
<tr>
<td>Osteophyte formation</td>
<td>increased lumbar BMD</td>
<td>lateral DXA or exclude specific vertebrae</td>
</tr>
<tr>
<td>Myeloma</td>
<td>increased BMD one level</td>
<td>radiograph to confirm,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Check vertebral level BMD</td>
</tr>
<tr>
<td>Paget’s Disease</td>
<td>high BMD</td>
<td>check vertebral area increase</td>
</tr>
<tr>
<td>Ankylosing Spondylitis</td>
<td>vertebrae fused, high BMD</td>
<td>lateral DXA, exclude spinous processes</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>increased BMD hip or spine</td>
<td>exclude regions or scans affected</td>
</tr>
<tr>
<td>Dermatomyositis</td>
<td>high background, with calcific deposits</td>
<td>scan unusable? forearm scan</td>
</tr>
<tr>
<td>Fracture/kyphosis</td>
<td>high BMD, reduced vertebral area</td>
<td>exclude affected levels, spine result may be unusable</td>
</tr>
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</table>

**Table 1** summarises the result of one study of 100 control subjects and 400 clinical referrals for DXA. In the patient sample of 400, 22% of lumbar spine scans were found to be abnormal due to clinical artefacts. These included aortic calcification, osteophyte formation, myeloma, and undiagnosed Paget’s Disease or ankylosing spondylitis. The presence of osteophytes on the vertebrae is common in older patients, and may have a major effect on the BMD measurements, especially from an AP DXA scan.
3. The Operator

Hip scan analysis
Software procedures provide a degree of automatic image analysis, but subtle abnormalities in the scanned image or the result should be detected by the operator. Positioning the patient can be critical, especially for the measurement of the hip, where rotation of the femur affects the area of bone being imaged. Palmer has shown that in a normal subject by changing the angle of rotation from 40° internal, 20° internal rotation through 0°, and then 20 external and 40° external rotation significant changes in the BMD of the different regions of interest are found. The effect of different degrees of rotation of the foot compared to a standard positioning angle of 20° internal rotation on BMD is shown in Table 2.

Table 2

<table>
<thead>
<tr>
<th>ANGLE OF ROTATION</th>
<th>% CHANGE F NECK</th>
<th>% CHANGE TROCHIL</th>
<th>% CHANGE WARD’S A</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>+4.75</td>
<td>+0.55</td>
<td>+8.05</td>
</tr>
<tr>
<td>20° external</td>
<td>+6.06</td>
<td>+2.36</td>
<td>+0.78</td>
</tr>
<tr>
<td>40° external</td>
<td>+9.23</td>
<td>+0.69</td>
<td>+3.79</td>
</tr>
<tr>
<td>40° internal</td>
<td>+2.77</td>
<td>+0.69</td>
<td>+6.16</td>
</tr>
</tbody>
</table>

In practice, differences in the angles of rotation will be smaller than those cited in this experiment. However, it serves to demonstrate that positioning of the leg by fixing the foot is subject to variables, and contributes to the experimental error in this method. Where there are knee joint problems, positioning the foot to a fixed angle, which is normal technique, cannot guarantee the relevant angle at the femoral neck. The scan should be carefully examined before analysis, and may need repeating after some repositioning to achieve the full length of the femoral neck in the scan.

Lumbar Vertebral analysis
The selection of regions of interest can be a source of error for even experienced operators, especially in a degenerate spine. In the normal spine the vertebrae are distinct, and the image analysis software is may be able to determine the separate levels for the regions of interest in the lumbar region. However, many patients and those with deformities, osteophytes etc. can present more difficult images, making the individual regions more difficult to define. The data for vertebral areas and BMD are important clues to the status of each separate vertebra, for certain disease states may yield inconsistent findings. For example a crushed vertebra may be obvious in the scan, but only a small decrease in area may be shown with vertebral fracture. In healthy subjects there is usually a gradual increase in vertebral area progressing from L2 to L4, which may be of the order of 10% per level. If this is not evident in the table of results, it is necessary to question whether the level selection for the ROI is wrong, or whether there is some pathological change affecting the BMD result (see figures 7 & 8). In many cases where abnormality is found in one level, it is usual to exclude this vertebra from the calculation of mean lumbar BMD. Three examples of artefacts found in children are shown in Figure 9.

Larger and denser than average vertebrae can be found in Paget’s disease of bone. A haemangioma, however, may present with a normal size, but an abnormal density, and a calcified aorta may raise vertebral density if overlying the spine in the posterior-anterior view. (see Table 1 and figure 8.)
Multiple operators
Where there are several operators working with the same machine, it is necessary to discuss and compare reasons for manually selecting the regions of interest in difficult cases, to minimize subjective variables. After initial training given with a new machine, there is often little further training given, and technicians may pass on their ideas to other new operators. Unless all operators work together to achieve standardization in both patient positioning and image analysis, there will be an increased inter-operator error within a given centre.

4. The Report
This topic is covered in more detail in the next section, but the technician should be aware of the potential for misunderstanding in the large amount of information often printed. Every item produced on the standard report should be identifiable by the technician. The printed scan image may not reproduce all the subtleties in density and anatomy which is seen on the screen image. Abnormalities which have an influence on the result should therefore be noted in the report to the physician. Great clinical reliance is often placed on the reference plot of the BMD status, using the T and Z scores. However, these reference data are compiled from cross sectional and not longitudinal values for the age groups. There appear to be local variations in reference populations, and individual reference population values can vary according to the inclusion and exclusion criteria for the controls recruited. Most software packages for BMD carry a serial number of the version in use. The manufacturer or research group whose reference data is being used should have recorded the population numbers and the exclusion criteria, and the relevant data should be kept by the centre for reference. The time to reach peak bone mass is assumed from averaged data since few patients have been measured for BMD over a significant number of years. The criteria for “normal” is also difficult to define after the sixth decade; care is therefore required not to over interpret the T score or Z score values from a single scan. It is not uncommon to find a patient with a T score indicating osteopenia, but in whom the Z scores are in the normal range. This may be confusing to the physician who is not familiar with the reference data systems. Perimenopausal data in women can also be influenced by the proportion of controls who reach the menopause at the sample age groups. For these reasons it may be advisable to perform two or more scans at intervals in borderline or suspiciously low results to determine bone loss over time. When the physician has the full clinical picture, with the additional information such as biochemical bone markers, if available, the risks of misinterpretation of the BMD measurement are reduced.

Conclusion
Methods for bone mineral measurement have been in use for over 15 years, but operating protocols are still improving. Clinical and technical awareness of potential sources of error and artefact is an important issue. Clinical cases do not always prove to be as straightforward as expected, so the dependence on careful and critical technique is significant. It is good technique and informed clinical interpretation in combination that ultimately determines the true value of a densitometry service.
References


FIGURES
Errors and Artefacts in Dual X-ray Absorptiometry (DXA)

Figure 1
DXA image of the lumbar spine, a metal stud by the navel can be seen over L5.

Figure 2
A drainage cannula (Hickman Line) shown on a DXA scan of the spine.

Figure 3a +b
Old contrast medium showing on a P-A and Lateral DXA spine scan resulting from a myelogram several years previously.

Figure 4
Test scan of a phantom on which 14 buttons have been placed. Metal, metal covered plastic and pearl buttons show clearly in the image. All-plastic buttons are not visible.
Errors and Artefacts in Dual X-ray Absorptiometry (DXA)

Figure 5
Soft tissue calcific deposits around the hip DXA scan in a patient with dermatomyositis. (Scleroderma in advanced stages may present a similar image.)

Figure 6
Undiagnosed Paget's Disease of Bone, with increased area and density at L1, L2-4 are unaffected in this example.

Figure 7
Calcified aorta, overlying L3, high BMD but vertebral size is normal.

Figure 8
Haemangioma over L3, raised BMD at that level but size normal.

Figure 9
Some artefacts found in children. A drug dispenser, B gastrostomy tube, C naso-gastric tube.