A practical guide to bone densitometry in children

National Osteoporosis Society

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National Osteoporosis Society

Foreword

This document provides practical advice about the use of bone densitometry in children. It was developed jointly by the Bone Densitometry Forum of the National Osteoporosis Society and the British Paediatric and Adolescent Bone Group to guide healthcare professionals in the acquisition and interpretation of these measurements. I would strongly recommend that all healthcare professionals involved in clinical densitometry should read and make use of these guidelines.

Professor Richard Eastell, MD, FRCP, FRCPath, FMedSci Professor of Bone Metabolism, Research Dean for the Medical School, R&D Director for the Sheffield Teaching Hospital Trust, University of Sheffield Clinical Sciences Centre, Northern General Hospital

Contributors (in alphabetical order):

- **Professor JE Adams MBBS, FRCR, FRCR (Radiologist) University of Manchester**
- **Mrs C Alsop DCR (Radiographer) University of Manchester**
- **Professor N Bishop MBChB, MRCP, MD, FRCPCH (Paediatrician) University of Sheffield**
- **Ms N Crabtree BSc, MSc (Medical Physicist), Queen Elizabeth Hospital, Birmingham**
- **Dr SF Ahmed MBChB, MRCP (Paediatrician), Royal Hospital for Sick Children, Glasgow**
- **Dr M Fewtrell MD, BM BCh, FRCPCH, DCH, MA (Paediatrician) London**
- **Dr MZ Mughal MBChB, FRCP, FRCPCH (Paediatrician) St Mary's Hospital, Manchester**
- **Dr NJ Shaw MBChB, MRCP, DCH RCP, DRCOG, DTM &H (Paediatrician) The Children's Hospital, Birmingham**
- **Mr MR Stevens BSc, MPhil (Scientific Co-ordinator), National Osteoporosis Society, Camerton, Bath**
- **Dr K Ward BSc, PhD (Research Scientist) University of Manchester**

Introduction

There are now scanning methods available which allow for the study of bone density, size and shape with good reproducibility, low dose of ionising radiation and rapid acquisition. These make the methods suitable for clinical and research applications in children. However, such scanners are primarily designed for application in adults and some of the limitations, most importantly the size dependency of dual energy X-ray absorptiometry (DXA), have significant impact on measurements made in children.

This booklet is designed to give helpful advice to those who are performing, or requesting, bone densitometry in children on appropriate indications for scanning, how to scan and interpret results in children, the particular strengths and limitations of the different scanning techniques (DXA, QCT and QUS) as they apply to children and a two page questionnaire that can be photocopied for local use for children referred for scanning.

The aim is to raise the standard of scanning and interpretation of bone densitometry in children. The advice document will be reviewed in future (2006) and revised if required, in the light of new scientific evidence and technical developments in scanning methods. We would welcome comments and feedback on the contents of the document, and wish to express our gratitude to all those who have contributed. Comments should be sent to Mr Martin Stevens, Scientific Co-ordinator, National Osteoporosis Society, Camerton, Bath, BA2 0PJ (email: m.stevens@nos.org.uk).

Professor Judith Adams
Chairman
Bone Densitometry Forum
National Osteoporosis Society

Dr Nick Shaw
Secretary
British Paediatric and Adolescent Bone Group

Contents

Key points and/or recommendations:

(some adapted from International Society of Clinical Densitometry ISCD[1])

1. The most widely used bone density technique currently applied to children in clinical diagnosis is dual energy X-ray absorptiometry (DXA), and the following comments apply principally to this method.
2. T-scores must not be used in children; Z-scores should be used (in children who are normal in size for their age).
3. The diagnosis of osteoporosis in children should not be made on the basis of densitometric criteria alone. Terminology such as 'low bone density for chronological age' may be used if the Z-score is below –2.0.
4. Z-scores must be interpreted in the light of the best available paediatric reference databases of age-matched controls. The reference database used should be cited in the report.
5. Age related Z scores are unreliable in children who are small for their age and need to be adjusted to account for body size.
6. There are several methods suggested for adjusting BMD and bone mineral content (BMC) for factors such as body size, pubertal stage, skeletal maturity and body composition, but currently there is no consensus on the optimum method to use. If adjustments are made the method used should be clearly stated in the report.
7. Serial BMD studies should be performed on the same machine using the same scanning mode, software and analysis when appropriate.
8. Any deviation from standard adult acquisition protocols, such as the use of low-density software and manual adjustment of the region of interest, should be stated in the report.
9. It is recommended that bone density scans for 'clinical' indications should ideally be performed in centres with a clinical team which has a specific interest and expertise in bone densitometry in children.
10. The value of BMD to predict fractures in children is not yet determined.
11. Quantitative computed tomography QCT provides separate measures of cortical and trabecular bone, and volumetric BMD, so is not size dependent as is DXA.

Section 1
Bone densitometry in children

1.1. Introduction: why use bone densitometry in children?

Osteoporosis is a systemic skeletal disorder characterized in adults by low bone mass and micro-architectural deterioration of bone tissue with a consequent increase in bone fragility and susceptibility to fracture. It is a major and increasing cause of morbidity and mortality in older individuals in developed countries, and set to become so worldwide over the next 50 years. An individual's bone mass later in life is determined by the peak bone mass attained at skeletal maturity and the subsequent rate of bone loss. Historically, strategies to prevent osteoporosis concentrated on reducing bone loss, particularly in the post-menopausal period in women. However, over the past decade it has become clear that events operating during fetal life, infancy and childhood may affect peak bone mass and therefore potentially influence the development of osteoporosis[2]. Approximately 80% of peak bone mass is genetically determined and 20% by modifiable lifestyle factors, such as nutrition and exercise. The appreciation that infancy and childhood are important periods of life for bone development has led to a need for suitable methods for monitoring bone health, for clinical and research purposes, and hence to an increasing use of bone densitometry (and related techniques) in children.

Bone densitometry was introduced for use in adults to diagnose and monitor the course of osteoporosis, mainly in post-menopausal women. The most commonly used densitometric technique – Dual Energy X-ray Absorptiometry (DXA) – was developed in the late 1980s and is now widely available. Other methods include axial and peripheral Quantitative Computed Tomography (QCT), which can provide a three-dimensional assessment of the structural and geometric properties of the skeleton, plus a variety of methods using ultrasound to measure the speed and attenuation of sound through appendicular bone. Individual methods are discussed in greater detail in subsequent sections. Using these different techniques, measurements of bone density can be made of localised regions including the lumbar spine (L1-4), hip and distal radius and of the whole body (total and regional). The choice of site may be important due to differences in the proportions of trabecular and cortical bone, which may be differentially affected by disease processes.

1.2. Specific issues associated with bone densitometry in children

'Area' measurements of bone mass (areal Bone Mineral density or aBMD in g/cm^2) made using DXA in untreated adults have been shown to predict a useful clinical outcome, namely fracture risk. The WHO criteria for diagnosing osteoporosis in adults are based on DXA BMD measurements. Thus a T-score (defined as the standard deviation (SD) score of the observed BMD compared with that of a normal young adult) of < -1 SD indicates osteopenia, while a score < -2.5 SD defines osteoporosis[3]. The situation in children is very different. T-scores are completely meaningless, as they are the equivalent of comparing a child's height to that of an adult. Moreover, in children and younger adults, bone densitometry measurements have yet to be related to clinical outcome, and no fracture threshold has been defined. The use of these measurements therefore requires special care and consideration.

DXA BMD measurements are two-dimensional; they represent a composite of bone size and bone density and are highly related to body size. Children may have low bone mineral content (BMC) or aBMD either because they have smaller bones, and/or because they have less mineral than expected for the size of their bones (that is, reduced bone density). Current consensus is that it is worth distinguishing between these two factors, in terms of the underlying pathology and need for treatment[4].

The problem of size effects in DXA bone densitometry is now widely appreciated, and a number of different approaches have been proposed and are in use for interpreting and presenting bone densitometry data in children. All of the methods attempt to perform an adjustment for bone and/or body size in order to avoid perhaps the most worrying potential pitfall of diagnosing 'low bone mass' or 'osteoporosis' in a sick child who is merely very small for his or her age. These issues are discussed further in Section 5.

1.3. Use of bone densitometry in children

Notwithstanding the above issues, when used appropriately, bone densitometry can be a helpful tool in children. Its use falls into two categories:

1.3.1. **Clinical**
In a clinical setting, patients are generally scanned either because they are thought to be at risk of low bone density as a result of their underlying disease or treatment, or to monitor the effects of treatment. Patient selection issues are discussed further in Section 2. One of the major issues with bone densitometry in an individual child is that of presenting results in a clinically useful form, given the factors outlined above which are addressed in more detail in Section 5.

1.3.2. **Research**
In research studies, bone densitometry is commonly used to measure the effects of disease e.g. cystic fibrosis and thalassaemia, dietary or exercise interventions, often comparing randomised groups. There are fewer problems relating to the need to present the results for an individual in a clinically useful form. However, it is important to be able to interpret changes in bone density independent of those due to growth.

Section 2
Indicators for BMD scanning in children

2.1. Introduction

The practitioner who authorises an assessment of bone density in a child must use appropriate selection criteria to avoid exposing that child to unnecessary ionizing radiation, even though the doses involved in the scanning techniques are small (Table 3.1 and 9). A key principle in the performance of any investigation in a child is that the result of the investigation should influence the child's clinical management. If it does not, then it is difficult to justify such a request on clinical grounds. It is also relevant to recognise requests for bone density scans which are essentially performed for research; such requests must have appropriate ethical approval and the informed consent of parent and child. It would not be appropriate to perform a bone density scan purely on the basis that a published study has shown that children with a certain condition have low bone density or 'osteopenia'. Published bone density studies in children with certain chronic disease have shown osteopenia to be present. However, many of these studies have not adjusted the DXA results for growth retardation. In selecting children appropriately for bone densitometry the disease should not only be known to be associated with osteopenia, but also with increased risk of fracture, and there should be effective intervention. The individual requesting the scan should have appropriate experience of the condition and of the child. In practice this is likely to be the consultant who is primarily responsible for the child's long-term care.

2.2. Clinical indications for scanning

The list of appropriate indications for bone densitometry in Table 2.1 refers primarily to the use of axial DXA, as this is the most widely available technique and the most studied in paediatric practice. It would be particularly appropriate to consider a scan in a child with any of these indications, if the additional following clinical features are present: back pain, spinal deformity, loss of height, decrease in mobility status, malnutrition.

Table 2.1. Appropriate clinical indications for bone densitometry

1. Systemic long-term corticosteroids
2. Chronic inflammatory disease
3. Hypogonadism – primary or secondary
4. Prolonged immobilisation
5. Osteogenesis imperfecta
6. Idiopathic juvenile osteoporosis
7. Recurrent low trauma fracture
8. Apparent osteopenia on radiographs

Table 2.2 indicates the clinical situations in which bone densitometry scanning is inappropriate in children.

Table 2.2. Inappropriate clinical indications for bone densitometry

1. Skeletal pain in absence of other factors e.g. fractures or another clinical indication listed in Table 2.1
2. Chronic disease in absence of other risk factors listed in Table 2.1
3. Traumatic fractures in absence of another factor in Table 2.1

2.3. Evidence for individual indications for bone densitometry

2.3.1. **Systemic long term corticosteroids**

In adults there are many studies which have demonstrated increased fracture risk as a consequence of long-term corticosteroid treatment. There are now national guidelines that define the risk and the indications for bone densitometry and use of prophylactic medication[5]. However, in paediatric practice there is insufficient evidence at present on which to base firm guidelines. It is therefore currently not possible to define the dosage and duration of corticosteroid treatment which would warrant a bone density scan in a child. It is also difficult to separate the impact of the corticosteroids on bone from the effects on the skeleton of the chronic inflammatory condition for which they are being used for therapy.

2.3.2. **Chronic Inflammatory disease**

There are a number of such conditions in which low bone density and a risk of fractures have been reported. These include rheumatological conditions such as juvenile idiopathic arthritis[6], systemic lupus erythematosis and dermatomyositis. Inflammatory bowel disease, particularly Crohn's disease, is also known to have adverse effects on bone[7]. Children with chronic liver disease, particularly cholestatic liver disease, are known to have abnormal bone density and may present with low trauma fractures[8]. These conditions may often be treated with corticosteroids which compound the adverse effects of the inflammatory condition on bone. However, there are several studies which have documented fractures occurring in these conditions in the absence of corticosteroid therapy e.g. juvenile idiopathic arthritis and Crohn's disease[9].

2.3.3. **Hypogonadism**

There are a number of paediatric conditions in which hypogonadism occurs, with a consequent failure to produce testosterone or oestrogen, which are both known to have important influences on bone density particularly in adolescence. This may either be primary hypogonadism e.g. ovarian or testicular failure, or secondary to a failure to secrete gonadotrophins from the pituitary gland. Examples of such conditions are hypopituitarism, galactosaemia in teenage girls, Klinefelter's Syndrome and Thalassaemia Major. There are a number of studies that have demonstrated low bone density in individuals with untreated hypogonadism[10] and improvement with appropriate sex steroid replacement[11]. Although there is limited information about fracture risk in these conditions the performance of a bone density scan can be useful in the assessment of the adequacy of replacement therapy.

2.3.4. **Prolonged Immobilisation**

Long term immobilisation is known to have adverse effects on the skeleton with evidence of increased bone resorption. The failure of appropriate weight bearing exercise is critical in the aetiology of osteopenia in this situation. There are several examples of conditions in children that can result in immobilisation such as severe cerebral palsy and spinal cord injuries. Low trauma fractures are well documented in children with severe cerebral palsy[12]. As some of these conditions are amenable to medical treatment with a bisphosphonate[13,14] it would seem appropriate to consider a bone density scan in such a child who has sustained a low trauma fracture.

2.3.5. **Osteogenesis Imperfecta**
Children with this condition have a primary abnormality in bone matrix composition which has adverse effects on bone mineralisation leading to low trauma fractures. This can vary in severity from recurrent fractures in infancy to infrequent fractures during childhood. As medical treatment with bisphosphonates has become available in this condition in recent years, with evidence of improved bone density and a reduction in fractures, it is appropriate to perform a bone density scan, particularly when treatment is being considered[15].

2.3.6. **Idiopathic Juvenile Osteoporosis**
This is a rare condition the precise aetiology of which is currently unclear. It characteristically appears during early puberty with evidence of back pain, difficulty walking and vertebral compression fractures. Although spontaneous resolution is reported to occur it is difficult to predict those individuals in whom this does not occur and who will go on to have a severe disabling condition and potentially lose the ability to walk. There are a number of documented reports of such children being treated with bisphosphonates[16] or active vitamin D analogues[17] with improvement in bone density and prevention of further fractures. It would therefore be appropriate in the investigation of such children that a bone density scan is performed.

2.3.7. **Recurrent low trauma fractures**
It is difficult to define precisely what constitutes a 'low trauma fracture' other than one where the degree of force involved appears inappropriate for the fracture. As children in this category may have a condition such as a mild form of osteogenesis imperfecta, in which the demonstration of abnormal bone density would be an important clue to the diagnosis, a bone density scan is appropriate.

2.3.8. **Apparent osteopenia on radiographs**
It is recognised that assessment of bone density using a radiograph is unreliable and it is usually quoted that a bone has to lose a third of its mineral content to appear osteopenic on radiographs. If osteopenia has been identified on radiographs, it is worth documenting if there are any additional features which may predict abnormal bone density such as fractures, back pain, skeletal deformity or malnutrition prior to a bone density scan.

2.4. Research indications for scanning

There is a continuing need to understand the impact of lifestyle and disease on bone density in growing children and adolescents, particularly as events in childhood are felt to have an influence on the risk of developing osteoporosis in later life. For example the impact of dietary (e.g. calcium supplements) or exercise (e.g. weight-bearing exercise) interventions on bone density in healthy children, or in those with chronic disease, is often examined in a randomised controlled manner. The impact of bone active agents (e.g. oestrogen or bisphosphonates) on bone density in a particular condition may be examined in longitudinal studies. There is a need for studies of agents administered for prophylaxis in conditions in which it is known that a significant fracture risk exists (e.g. in children with chronic inflammatory disease on long-term corticosteroids). Such studies must have appropriate ethical approval, and be appropriately designed and funded to ensure that an adequate number of children are studied to enable the hypotheses of the study to be answered.

2.5. Frequency of scans

In the majority of clinical indications a scan interval of at least one year is appropriate to measure a significant change in bone density. The need for further scans will be influenced by the result of the previous scan and any change in the disease or its management. Scan intervals of six months may be appropriate in a research study or to examine the impact of a pharmacological intervention. However, the interval between scans is dependant on the precision of the scanning technique. The least significant change (LSC) that can be detected will be 2.8 multiplied by the site specific precision error of the bone density technique[18]. In clinical practice generally an interval of at least 18 to 24 months should be made between scans.

2.6. Where scans should take place

At present scans being undertaken for 'clinical' indications should ideally be performed in centres which have a clinical team with specific interest and expertise in skeletal disorders and bone densitometry in children.

Section 3
Dual energy x-ray absorptiometry (DXA)

3.1. Introduction

Dual energy X-ray absorptiometry (DXA) has been available since the late 1980s. The fundamental principle of DXA is to measure the transmission of X-rays through the body at high and low energies. The use of two energies is to allow discrimination between soft tissue and bone. X-ray attenuation values are converted to bone mineral content (BMC in g). Bone area (BA in cm) is calculated by summing the pixels within the bone edges; software algorithms detect the bone edges. 'Areal' bone mineral density (aBMDin g/cm^2) is then calculated by dividing BMC/BA. DXA may be applied to the whole body or skeletal regions of interest, for example the spine, proximal femur, and radius. In pre-pubertal children the lumbar spine is the most useful site to scan in clinical practice. In older children the spine and hip are generally scanned. Whole body DXA remains, at present, a research scan.

3.2. Strengths and limitations of DXA

3.2.1. **Strengths**

3.2.1a. **Radiation Dose**

Consideration of radiation dose is of utmost importance in children, and DXA has the major advantage of only subjecting the patient to a low effective radiation dose (Table 3.1A). Some comparative radiation doses are presented in Table 3.1B. The most commonly measured sites are spine, then hip and total body; peripheral measurements may also be made, for example in the distal forearm. Radiation dose at all sites is appreciably less than that which we are exposed to from the natural environment (background radiation). The effective dose ranges from 0.4μSv for a lumbar spine scan to 5.4μSv for a total body scan. Radiation doses are machine and manufacturer specific.

3.2.1b. **Scan time**

Original DXA technology (pencil-beam scanners e.g. Lunar DPX-L) had a relatively long scan time, taking up to 15 minutes per site. With the advent of fan-beam scanners, the scan time is now reduced to approximately 2 to 3 minutes; this time is dependent upon the size of the child and region to be scanned. It is now possible to complete scans in a very short time – extremely important in children.

3.2.1c. **Precision**

The precision of DXA measurements (measure of the repeatability of the method) is extremely good, with the coefficient of variation ranging from 1 to 3% on modern scanners. Precision is machine and site specific. When interpreting longitudinal data it is relevant to take into account the precision of the technique when assessing the magnitude of change in bone measurements[18].

3.2.1d. **Reference data**

The interpretation of any bone densitometry measurement is reliant upon having good, robust data in normal, healthy children. As the most widely used technique throughout the world, DXA has the largest normal database of all of the bone density techniques[19,20]. The National Institute of Health in the USA is currently funding a national initiative for the collation of a normal database consisting of 1,400 children, which will be the largest paediatric database produced to date. Ideally, such reference data should be specific for sex, ethnic origin, pubertal status, and take into account height, weight and body mass index (BMI). There are important considerations to note regarding normative databases and these will be discussed in the limitations section.

Table 3.1a Effective dose and entrance surface doses for the commonly available bone densitometers (due to limited published data this table refers to adukIt radiation)

Machine	Beam	Spine		Whole Body	
		Effective Dose µSv)	Entrance Surface Dose (µGy)	Effective Dose (µSv)	Entrance Surface Dose (µGy)
Hologic QDR1000[21]	Pencil	0.5	60 *<43	4.6	18 *<13
Lunar DPX series[22]	Pencil	0.21	10.25 *11		*0.2
Norland	Pencil		*0.9-44.4		*0.4
Hologic QDR2000[21]	Fan	0.9	138 *192	3.6	11 *8
Hologic QDR4500 series[21]	Fan	5.4	*200	3.4 *2.7	*10
Lunar Expert[23]	Fan	31	895 *530		*50
Lunar Prodigy	Narrow Fan	*0.7	37	*<1.0	*0.4

Exposure [*manufacturers reported values]

Table 3.1b Some other radiation doses for comparison

	Effective Dose (µSv)
PERIPHERAL QCT (RADIUS/ TIBIA)	0.43 per slice
3D- QUANTITATIVE COMPUTER TOMOGRAPHY (SPINE)	55*
RETURN TRANSATLANTIC FLIGHT[24,25]	80
NATURALLY OCCURRING BACKGROUND RADIATION IN THE UK[23]	6 – 20** per day
HAND RADIOGRAPH[26]	0.17
CHEST RADIOGRAPH[27]	20
PLANAR LUMBAR SPINE RADIOGRAPH[27]	1000
RADIOISOTOPE BONE SCAN[28]	3000

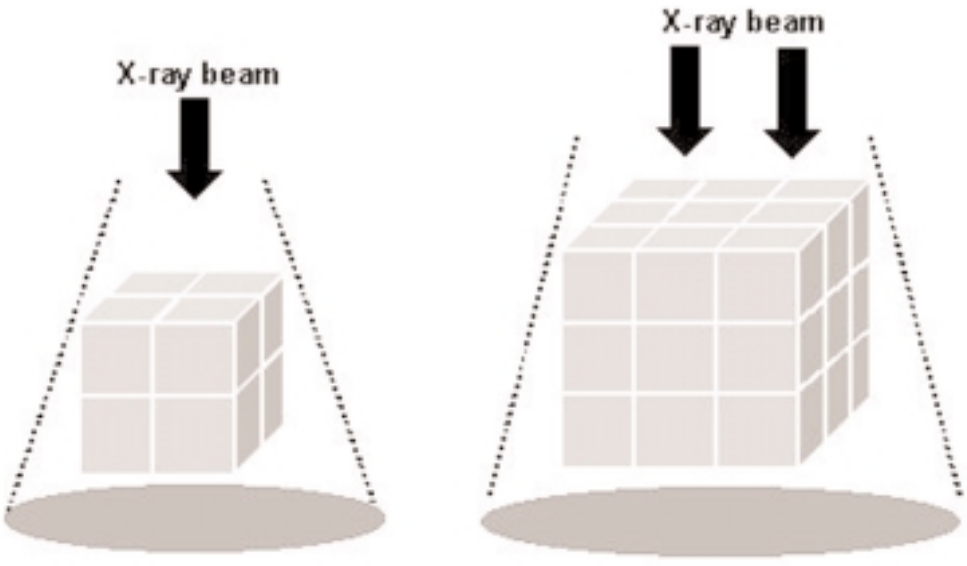
* Including the lateral scan, ** depending on location within UK

3.2.2 **Limitations**

3.2.2a. **Size dependence**

The most significant limitation of DXA is the size dependence of the measurement. DXA provides a bone mineral density (BMD) based on a two-dimensional projection of a three-dimensional structure. By doing this, it does not account for the depth of the bone being measured. The resultant BMD is called 'areal' BMD (aBMD) and is measured in g/cm^2. The net result of this is that the BMD of small bones is underestimated and in large bones BMD is overestimated (Figure 3.1). In a growing child this will cause inaccuracies and it is imperative that the size dependence of the technique is accounted for when interpreting results. Several methods have been proposed to adjust for the size dependence of the measurement and these are discussed in more detail in Section 5[29-36]. Each has its own advantages and disadvantages and when performing research studies it is often useful to use several approaches to adjust for, and investigate, the size related dependence of DXA.

Table 3.1 Size dependance of DXA: Each bone has exactly the same volumetric density, however, because DXA BMD does not take the depth of the bone into account, the smaller bone has an apparently lower ABMD than the larger one (adapted from Carter et al[30]).



MINERAL WEIGHT (G)	16	54
VOLUME (CM^3)	8	27
PROJECTED AREA (CM^2)	4	9
VOLUMETRIC BMD (G/ CM3)	2	2
AREAL BMD (G/ CM^2)	4	6

3.2.2b. **Changes in body composition**

In addition to the size dependence of DXA measurements, longitudinal studies may also be influenced by changes in body composition, i.e. the amount of fat/ lean mass overlying the scanned region of interest. DXA corrects for soft tissue around the bone by assuming a homogenous distribution, in a growing child the soft tissue will undoubtedly change and may cause some inaccuracies in measurement.

3.2.2c. **Software and reference data**

The algorithms that separate bone from soft tissue have been designed to optimise measurements in adults. Because of the changing body size and low mineralisation of the bones, especially in smaller children, this may cause problems with bone-edge detection and hence affect results. Manufacturers have tried to overcome this by producing specialist paediatric software programmes, which have low-density algorithms for the separation of tissues. The use of this software does significantly alter bone density results and cannot be automatically interchangeable with adult software[37] – an important factor to consider when analysing follow-up scans.

The interpretation of DXA results relies upon the source of reference data used; most often manufacturer specific data are used; other sources include locally derived data or that published in the literature. The reference database used can significantly affect the standard deviation scores (SDS) obtained from a scanner[38] and may therefore lead to misclassification of a child as osteopenic (a SDS score of -2SD from the age matched mean). While age, sex and ethnicity are known to affect BMD many of these databases combine gender and ethnic groups, were performed on previous releases of scanner models and software, or include insufficient subjects. Interpreting results based on these databases may cause inaccuracies when assessing an individual child's bone status. It is therefore essential to be aware of the software version which is being used, which reference database this includes and what will change when software or machine upgrades occur. These issues are highly relevant to ensure that the interpretation of paediatric DXA data is as accurate as possible.

3.2.2d. **Measurements obtained from DXA**

The measurement of bone mineral density obtained by DXA is a composite measurement of both trabecular and cortical bone (integral bone); it is not possible to discern whether a disease process affects predominantly cortical or trabecular bone.

A bone's strength is not just dependent upon its mineral density. While mineral density explains approximately 70% of bone strength other factors such as the shape, internal architecture and overall size also contribute to bone strength. Therefore a measurement of BMD alone may not discern whether a child is at high risk of fracture; for example children with osteopetrosis and pykynodyosostosis may have high BMD but still suffer fractures.

Section 4
How to perform DXA scans in children

4.1. Information prior to scan

It is important that the child is mentally prepared before coming to hospital for his/her scan. Where possible, information appropriate for the child's age and understanding should be used. In the letter sent out with the scan appointment it is helpful to include relevant pictures or diagrams of the scanning to reduce the fear of the unknown, and assist the parent or guardian to explain the procedure. The referring clinician should provide sufficient information for the operator to be aware of any potential problems, such as learning or physical difficulties, which will either prevent the scan being performed or require additional scanning support or modification of standard techniques.

4.2. Room preparation

As with any investigation involving children it is relevant to ensure the environment is child-friendly. The use of colourful pictures, soft toys, videos and music will make the scanning room more appealing to a young child and hence make it easier for them to relax and cooperate for the scan.

4.3. Patient preparation

Preparing a child for a DXA scan follows the same basic principles as that for an adult. The operator will need to record the child's height and weight (in light indoor clothes) and remove any metal objects which may cause image artifacts, such as clothes with zips or buckles. To achieve optimum scan quality it is recommended that the child is scanned in light indoor clothes or a hospital gown. The child should receive a clear explanation of the procedure, since the quality of the scan will depend as much on this as it will on the skill and patience of the operator. Throughout the scan the operator should keep the child informed of what is happening, what the scanner will do, the noises it will make and how long the scan will take.

4.4. Performing the scan

The ultimate goal is to achieve a perfect scan with the child correctly positioned, which can then be readily reproduced at follow-up examinations. However, this is not always achievable! Different age groups require different considerations and particular attention is necessary when scanning children with special needs. It is relevant to assess the child's cooperation before starting the scan to avoid any unnecessary radiation exposure by having to repeat an unusable scan.

4.4.1. **Babies & Infants** (Figure A)
The easiest way to scan a new born infant is to ask the mother to feed and settle him/her, then place the infant on the scanning couch in a clean nappy. Usually at this age the child will be quite happy sleeping through the scan and will require little operator intervention. The child should be observed during the scan for any involuntary movement.

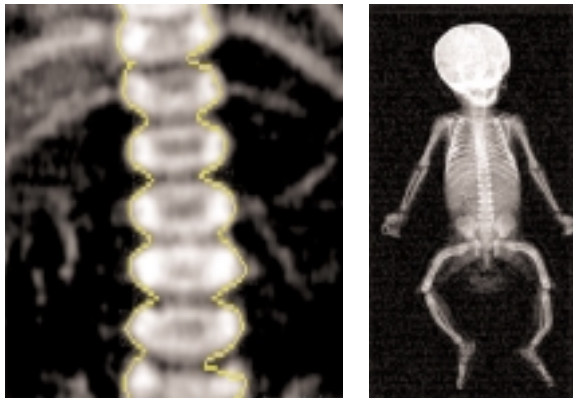


Figure A
Six-month-old boy with osteogenesis imperfecta

4.4.2. **Toddlers** (Figure B)
For toddlers the 'feed and sleep' method is unlikely to be successful as they will be more aware of their surroundings and find it difficult to settle, and are often quite apprehensive. The easiest way to scan this group of children is with light sedation. This makes it more time-consuming since the sedation may take time to take effect, but with patience, and an understanding parent or guardian, successful results can be obtained.

Commonly used medications include chloral hydrate 50mg/kg and Vallergan 1mg/kg. All staff involved in scanning sedated or unwell children should have received paediatric basic life support training.

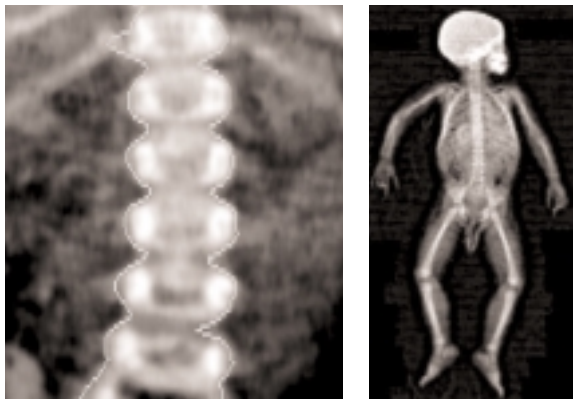


Figure B
2.5 year-old child post liver transplant

4.4.3. **Young children** (Figure C)
From age 3 years and above a clear explanation of what is going to happen, with some reward for the child for staying still will usually suffice. However, it is important to talk to the child constantly throughout the scan, reminding him/her to stay still, as concentration can easily be lost.

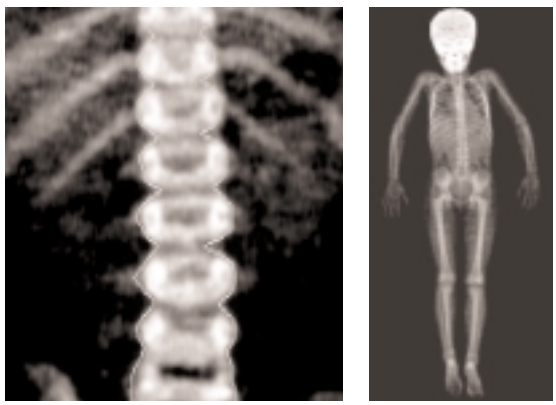


Figure C
5-year-old girl with congenital neutropenia

4.4.4. **Teenagers** (Figure D)
Teenagers are usually easier to scan as they have a greater understanding of the procedure. However, they often have more metal artefacts which they may be reluctant to remove, such as ear piercings, navel rings etc. Other issues become important, especially for girls, who have reached child bearing age. Local procedures should be applied regarding potential radiation exposure and pregnancy.

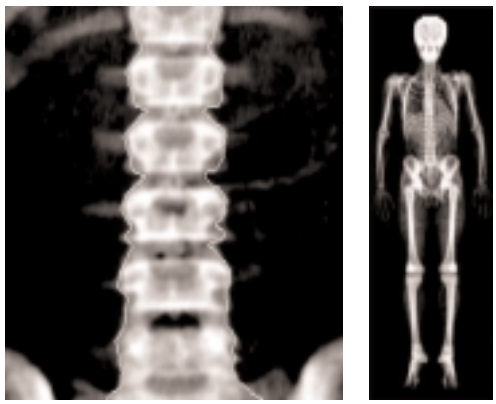


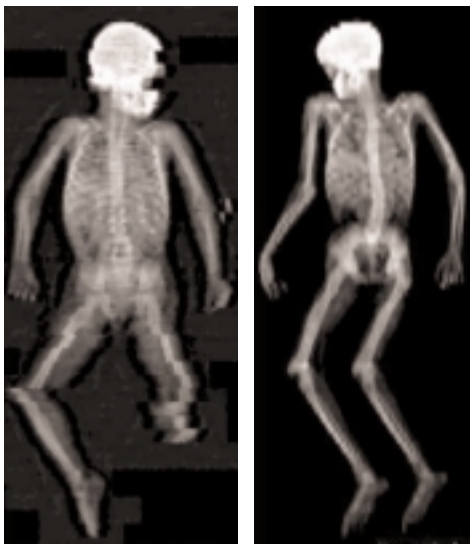
Figure D
13-year-old boy with low trauma fracture

4.5. Common Problems

4.5.1. **Movement**

The most common problem when scanning a child is movement. Although most analysis techniques can cope with a small amount of movement, any movement in the scan field will reduce the measurement precision and may give unreliable results. If the child is unable to stay still for the duration of the scan the following points need to be considered:

- how urgent is the scan? Can it be delayed until the child is older and able to understand and co-operate better?
- would practising staying still help? (Sometimes this can be done at home prior to scanning).
- is sedation necessary? It is not always young children who require sedation; sometimes older children with learning difficulties may require sedation to achieve a scan that can be analysed (Figure E).



A B

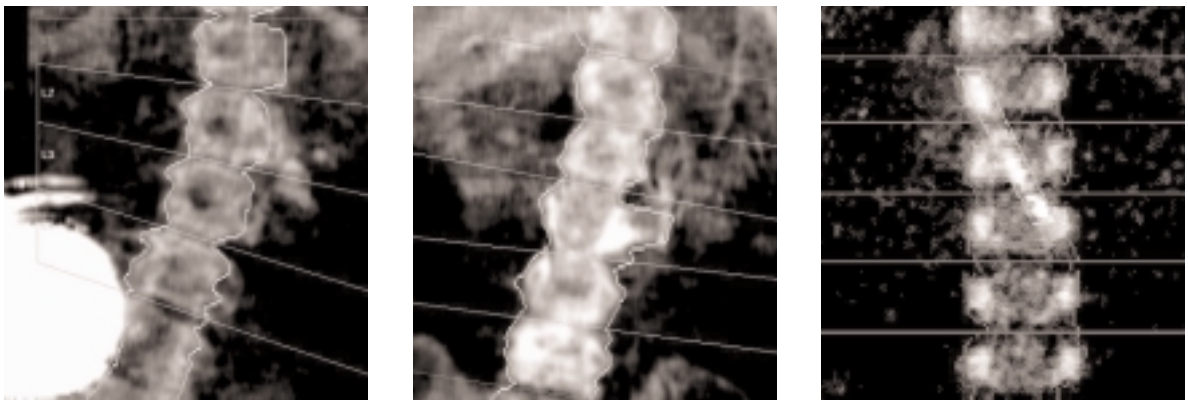
Figure E Two children with cerebral palsy (a) restrained but not sedated-scan degraded by movement artefact (b) with sedation scan quality is much improved

4.5.2. **Artefacts**

Other common problems are artefacts which cannot be removed, such as plaster casts, intra-medullary rods, feeding tubes etc (Figures F & G). Each case will need to be assessed on an individual basis.

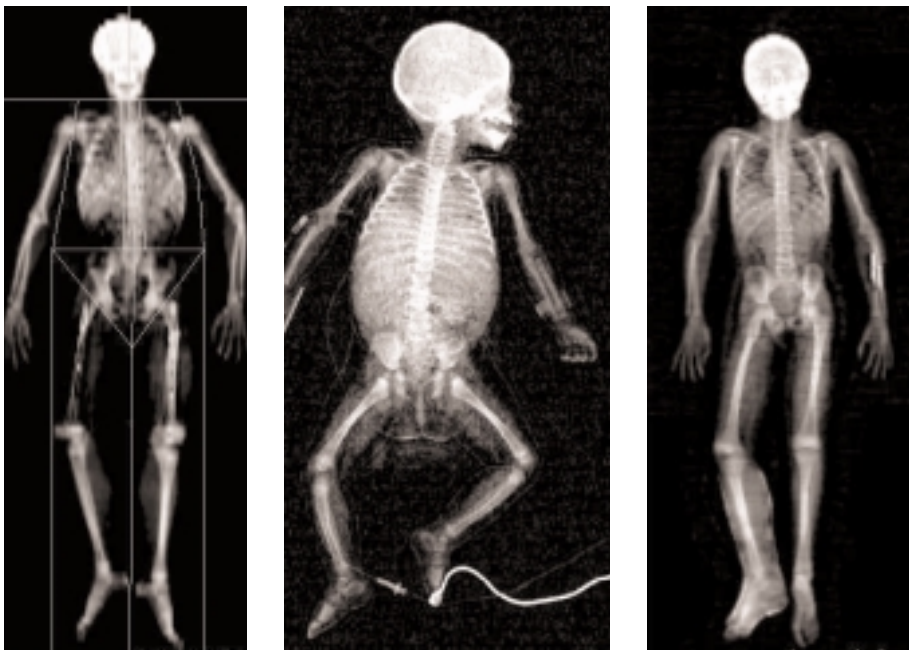
- Artefacts which will stay *in situ* for the foreseeable future, such as metal rods, are less troublesome. They may affect initial baseline results but have limited effect on long-term follow-up.
- Where the child has a temporary artefact, such as plaster cast, it is best to delay the scan until the artefact has been removed or only scan the unaffected area. For example if the child had a leg cast a spine measurement would be achievable while a total body scan would be unreliable and cause unnecessary radiation exposure.

Figure F Immovable artefacts overlying the spine (a) internal drug dispenser overlying right lower abdomen (b) percutaneous gastrostomy tube overlying L3 (c) naso-gastric tube overlying L1-3.



A B C

Figure G Immovable artefacts within the whole body scan area (a) bilateral intra-medullary rods in femora (b) intra-venous lines and pulse-oximeter monitor right arm and left foot (c) plaster cast right calf.



A B C

4.6. After the scan

- Reward the child for staying still with a certificate or sticker, as appropriate.
- If possible show them the scan to assist in understanding of the procedure.
- If required complete any questionnaires or pubertal assessments **after** the scan, as both the child and the parent/guardian will be more relaxed and cooperative.
- Inform the parent or guardian of what will happen with the results, who will assess them and how long it will take for the scan to be reported.

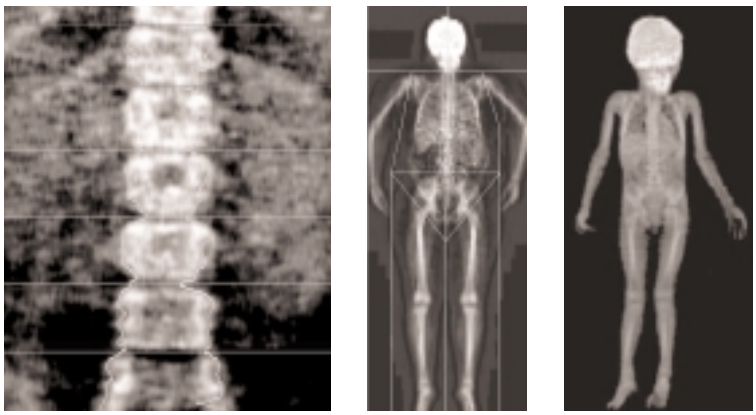
4.7. Analysis

Bone density evaluation should be performed following standard manufacturer procedures. However the operator should be aware of the following points:

4.7.1. **Edge detection and tissue differentiation**
In poor or under mineralised bone the analysis software may fail to detect the edges of the bone (Figure H).

4.7.1a. **Low Density Analysis Software**
Most densitometers have the facility to perform ‘low density’ analysis (see limitations). This may be **automatic** i.e. the machine will go into the most appropriate mode, or **manual** i.e. chosen by the operator. Although this ‘low density’ analysis can improve edge detection of the bone it can cause problems with longitudinal scanning if a different analysis technique is used as the bone becomes more mineralised. It is important to scrutinise the bone area, bone mineral content and the bone density, since a reduction in bone area can be indicative of a change in analysis mode or poor edge detection.

4.7.1b. **Acquisition Mode**
Tissue differentiation can be difficult in obese children due to insufficient X-rays penetrating the body. This may be helped by scanning the child in a more appropriate mode where counting statistics can be improved with a greater photon flux (Figure H)

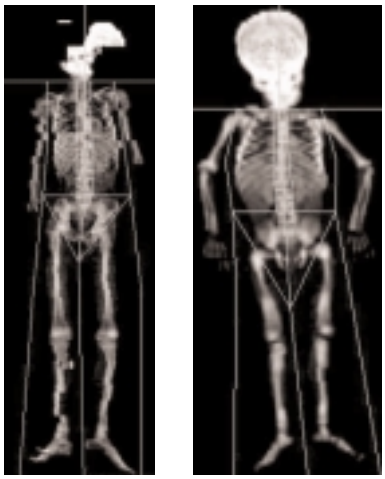


A B C

Figure H Poor bone detection affecting BMD analysis. (a) Incorrect edge detection due to poor mineralisation of the spine (b) obese patient scanned with insufficient photon flux (c) child with osteogenesis imperfecta and very low bone density and poor tissue differentiation.

4.7.2. **Movement (Figure I)**

Most analysis software can cope with a small amount of movement but the operator should be aware when excessive movement will adversely affect the analysis. For example one or two lateral movements in a total body scan is unlikely to affect the whole body result, while one movement at the wrong moment may have a great effect on the results of a localized scan e.g. of the spine.



A B

Figure I Example of movement affecting the quality of the scan. (a) Unusable whole body scan due to excessive movement (b) Movement artefact having only a limited effect on this scan in a patient with osteopetrosis.

4.7.3. **Artefacts**

As far as possible the scan should be artefact free. However, if this is not possible the artefact, or region containing the artefact, should be excluded from the analysis and a note made before the scan is interpreted. Caution should be taken in longitudinal studies in which the artefacts may change i.e. rods removed or added since a previous scan.

4.7.4. **Customised region of interest**

In some cases it is impossible to perform a standard analysis, for example if the child was unable to lie in the correct position or the spine curvature was too great for the regions of interest to be placed correctly. In these circumstances it may be better to use customised regions of interest i.e. where the operator can identify specific areas or adjust standard regions to be more appropriate for the image. This can be useful when following a child over time, but the operator should be aware that there will be no reference data for comparison.

4.7.5. **Longitudinal studies and growth**

In longitudinal studies growth, and its influence on BMD by DXA, is the most difficult factor for which to correct. As the child grows the bones will change in shape and size, and the body will also change in size and composition. This can make it difficult to compare recent to past scan results. Unfortunately it is not possible to adjust for all of these factors. However, the operator should always make note of any such changes that may affect the results in an individual child.

The most important factor when scanning children is that **they must not be considered as small adults**. They require explanations appropriate to their age and understanding, and reassurance of the whole scanning procedure. It is essential to allow sufficient time and have the patience to achieve the best scan results and avoid any unnecessary exposure to ionising radiation.

Section 5
Interpretation of bone mineral density measured by DXA

5.1. Introduction

DXA measures the total amount of BMC (g) contained within the skeletal region scanned and the two-dimensional projected bone area (BA; cm^2). DXA does not measure the bone thickness and therefore the volume (cm^3) that is required for estimation of volumetric bone mineral density (vBMD; g/cm^3). The vBMD can be measured using quantitative computed tomography techniques (see Section 6). The ratio of BMC and BA, expressed in units of g/cm^2, is referred to as the 'areal' bone mineral density (aBMD). DXA provides measures of the average amount of BMC or aBMD at a particular skeletal region but does not allow separate assessments of these parameters within the cortical and trabecular bone compartments. aBMD values are usually expressed as the number of standard deviations (SD) above or below the mean reference value for children of the same age, gender and ethnic origin.

5.2. Interpretation and reference databases

Some DXA scanners automatically provide a T-score, which expresses the patient's aBMD in relation to reference data for peak aBMD of a normal young adult. The T-score is completely meaningless in a growing child and **must not be used** for the interpretation of aBMD in children. The DXA manufacturer's software packages usually include paediatric aBMD reference databases which enable an individual patient's aBMD to be expressed as SDS. However, such databases should be used with caution as Leonard et al[38] have shown that the use of different published paediatric DXA reference databases for assessment of aBMD in children with chronic diseases leads to significant inconsistencies in the diagnosis of osteopenia, arbitrarily defined as an aBMD of less than 2 SDS below the mean for age. Many of the databases are not ethnic or gender specific, and are based on a small number of subjects, so may not reflect accurately normal variations in aBMD for each age and pubertal category. For example, the use of gender non-specific aBMD databases resulted in a significantly greater percentage of boys being misclassified as osteopenic[38]. Furthermore, Leonard et al[37] also showed that the use of different versions of analysis software (standard and low density) provided by DXA manufactures resulted in significantly different values for lumbar spine BMC, BA and aBMD in children. It is therefore crucial to use a large, gender-, ethnic-, densitometer- and software-specific paediatric reference database when interpreting DXA results in children and adolescents.

5.3. Methods of correcting DXA results for size

Areal BMD is a function of a bone's size and vBMD; aBMD increases with bone size, due to the greater thickness of larger bones. Thus, an increase in a child's aBMD might reflect an increase in bone size or vBMD, or a mixture of both. The interpretation of aBMD poses major challenges in healthy children, due to changes in bone size related to age and puberty, and in children with chronic diseases in whom poor growth and delayed puberty adversely affect bone size. A number of approaches have been proposed for reducing the influence of changes in bone size that accompany skeletal growth on DXA measurements:

5.3.1.
Bone mineral apparent density (BMAD): one approach involves the calculation of bone mineral apparent density (BMAD) by dividing BMC by the three-dimensional bone volume derived from its two-dimensional projected BA[29-31]. The BMAD of the lumbar spine (LS) is estimated by modelling it as a **cube**[30] ($BMAD_{LS} = BMC_{LS}/BA_{LS}^{1.5}$) or as a **cylinder**[31] ($BMAD_{LS} = BMC_{LS} \times [4/(\pi \times \text{bone width of LS})]$). At the mid-femoral shaft and the femoral neck, Lu et al[35] showed that the age and height dependence of aBMD at the mid-femoral shaft and the femoral neck disappeared when the data were expressed as BMAD. However, the BMAD at the lumbar spine, calculated by modelling the vertebrae as cylinders, continued to increase with age, presumably because the human vertebrae are not cylindrical in shape, and due to the continued increase in size of the posterior vertebral processes (lamina and pedicle). Nevill et al[34] have suggested that the spinal BMAD may not fully address bone size differences when comparing groups, which will differ in other factors that are known to affect BMC, such as body weight.

5.3.2.
Size adjusted BMC: another approach involves the estimation of a 'size adjusted, BMC', which is calculated using a regression, or a multivariate, statistical model[32,36] to adjust BMC for cofounders, such as projected BA, overall body height and weight (surrogates for bone size) and Tanner stages of sexual development[39]. 'Size adjusted BMC' is often used in research studies, for example when comparing BMC in a group of children with a disease to healthy controls[40]. However, it should be borne in mind that body height and weight might not completely control for all relevant differences in size and shape of the skeletal region of interest. Furthermore, differences in bone size and shape may have important implications for bone strength, independently of adjusted or unadjusted BMC/aBMD.

5.3.3.
Molgaard method: Mølgaard et al[33] have proposed a three-step approach for the evaluation of whole body BMC in children, which seek to determine the following: (1) Is the child's height appropriate for age? ('short bones'); (2) Is the bone size (bone area) appropriate for height? ('narrow bones'); (3) Is the BMC appropriate for bone area? ('light bones'). Once these analyses have been performed they are used to calculate SDS by reference to local gender and ethnic specific reference data for these parameters. This pragmatic approach allows the clinician to separately determine if the child's skeletal fragility is due to reduction in the size of the bones or the amount of BMC within the periosteal envelope, or both these factors.

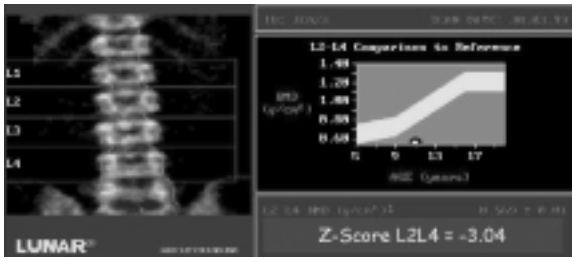
5.3.4.
Correction using lean tissue mass (LTM): an alternative approach is to interpret bone mineral content (BMC) in relation to lean tissue mass (LTM) which is a major predictor of BMC. Hogler et al[41] have proposed an algorithm for interpreting whole body DXA scans using a four step approach: 1) BMD or BMC for age 2) Height for age 3) LTM for height 4) BMC/LTM ratio for height. They provide normative data for this using a Lunar DPX-L scanner. A similar approach is proposed by Crabtree et al[42].

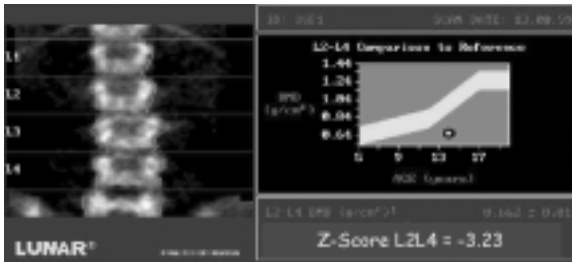
An example of one of these methods is illustrated in Figure 5.1. Each of the above approaches has particular advantages and disadvantages, when used for interpretation of DXA data in an individual child, or for group comparisons in research studies. In research studies it may be necessary to use several of the above-mentioned strategies in order to address the confounding effects of bone size differences between groups.

5.4. Summary

In addition to the use of reference data that are gender, race, puberty and software specific, it is crucially important to adjust BMC and aBMD for differences in bone size when interpreting DXA data in children. The correction for bone size is particularly important when disease, or its treatment, is associated with impaired growth. Finally, results should always be interpreted in the context of the individual child's medical condition and associated therapy.

Figure 5.1 Examples of the effect of body size on BMD. *BMAD was calculated using the method of Kroger et al[31]. BMAD Z scores were calculated as follows. **Case 1:** BMAD Z score = (0.234-0.312)/0.035 = -2.2, where the mean (SD) value for an 11-yea- old Caucasian female is 0.312 (0.035). **Case 2:** BMAD Z score = (0.300-0.320)/0.030 = -0.7, where the mean (SD) value for a 14-yea- old Asian boy is 0.320 (0.030). Reference population from the same geographical area as the subjects, and matched for age, gender, and ethnic group. Note that BMAD in boys lags behind that of girls during adolescence because of the later onset of puberty; thus the values for an 11-year-old girl and 14-yea- old boy are very similar.





Case 1	
Diagnosis	Juvenile arthritis with fragility fractures
Sex	Female
Age	11.5 years
BMD Z score	**-3.0**
Height Z score	-5.2
Weight Z score	-2.7
BMC (g)	10.96
BA (cm^2)	17.54
Bone width (cm)	3.1
BMAD Z score*	-2.2

Case 2	
Diagnosis	Growth hormone insensitivity syndrome, no bone symptoms
Sex	Male
Age	14.7 years
BMD Z score	**-3.2**
Height Z score	-5.0
Weight Z score	-4.7
BMC (g)	13.50
BA (cm^2)	20.38
Bone width (cm)	2.8
BMAD Z score*	-0.7

Section 6
Quantitative computed tomography

6.1. Introduction

Axial quantitative computed tomography (QCT) was first described in the late 1970s, and became more widely used during the 1980s[43,44]. With the introduction of DXA in 1988 the use of QCT declined. However, with the development of interest in bone size and geometry, particularly in research studies, technical developments (spiral and multi-slice CT) and QCT's particular advantages in children (true volumetric bone density, so not size dependent) use of the technique will probably increase in the future, particularly in research studies[45-47].

6.2. Strengths and limitations

6.2.1. **Strengths**

Whereas DXA measures integral (cortical and trabecular) bone density, QCT uniquely provides separate measures of cortical and trabecular BMD, the latter being eight times more metabolically active that cortical bone, so more sensitive to change in BMD. The BMD provided by QCT is a true volumetric density (mg/cm^3) so not size dependent, in contrast to DXA which provides an 'areal' density (g/cm^2). CT also provides true morphometric dimensions of bones, and in the shafts can give information of cross-sectional area of muscle and bone, from which biomechanical properties can be derived (stress-strain index; moment of inertia), together with measures of cortical thickness and density, periosteal and endosteal circumference.

6.2.2. Limitations

As with other bone densitometry techniques QCT requires a few skilled and dedicated staff to optimise precision (axial QCT CV = 1-3%); it is not suitable to have numerous staff rotating to perform the scans for a short period, as may be the custom in radiology departments with responsibilities to train radiographers in different imaging methods. With the range of diagnostic capabilities of CT it is much in demand and it may be difficult to obtain time on the scanner for axial QCT to be performed. Currently there is a dearth of commercial analysis packages for analysis of QCT that can be 'bought off the shelf' (Geanie, BonAlyse, Jyvaskyla, Finland; Mindways, San Fransisco CA, USA), so some units have developed their own analysis software[48].

6.3. Axial quantative computed tomography (QCT)

6.3.1. **Scanning -2D mode**

6.3.1a.

Scan details: the essential actions outlined in Section 4 for DXA (clear explanation of what the procedure involves, reassurance of the child and parents/guardian) also applies to QCT scanning to ensure optimisation of scan and results. The method can be applied to axial and peripheral (see Section 6.4) sites. For QCT of the spine the patient lies supine on the scanner table with the legs flexed and supported on a pad to flatten the natural lumbar lordosis. A bone mineral equivalent phantom (section 6.3.1b) is placed under the patient in the site to be scanned (Figure 6.1a). A water, or soft tissue equivalent, pad is placed between the patient and the phantom if there is a significant air gap. The height of the scanner table should be kept constant to ensure the vertebrae are in the centre of the scan field. An initial lateral scan projection radiograph is performed (Figure 6.1b and c). Sections (10mm, or 5mm in a small child) are then performed through the mid plane of the vertebrae to be measured (T12-L3 or L1 to L4 in adults; L1-3 in children), and parallel to the vertebral endplates. The section is in the correct plane when the area of reduced attenuation of the basi-vertebral vein is identified (Figure 6.1d). The results are expressed as a mean bone mineral density in mg/cm^3.

6.3.1b.

QCT bone equivalent calibration phantoms: the original phantoms were filled with variable concentrations (0, 50,100 and 200mg/cm^3) of fluid K2HPO4, which enables the bone region of interest, measured in Hounsfield units (HU), to be transformed into bone mineral equivalents. As the fluid transpired through the perspex with time, air bubbles developed in the phantom which made it difficult to position, and could potentially alter the concentrations of K_2HPO_4. As a consequent solid hydroxyapatite phantoms are now favoured. For comparable results in longitudinal studies the same phantom (and scanner) should be used. Some CT manufacturers provide their own software and phantoms (e.g. Siemens, Erlangen, Germany) or software and phantoms can be purchased (e.g. Mindways, San Francisco, CA, USA). If scanners or phantoms have to be changed during longitudinal studies then cross-calibration with patients and a phantom, such as the European Spine Phantom (ESP)[49], will have to be undertaken to make results comparable, as with DXA[50].

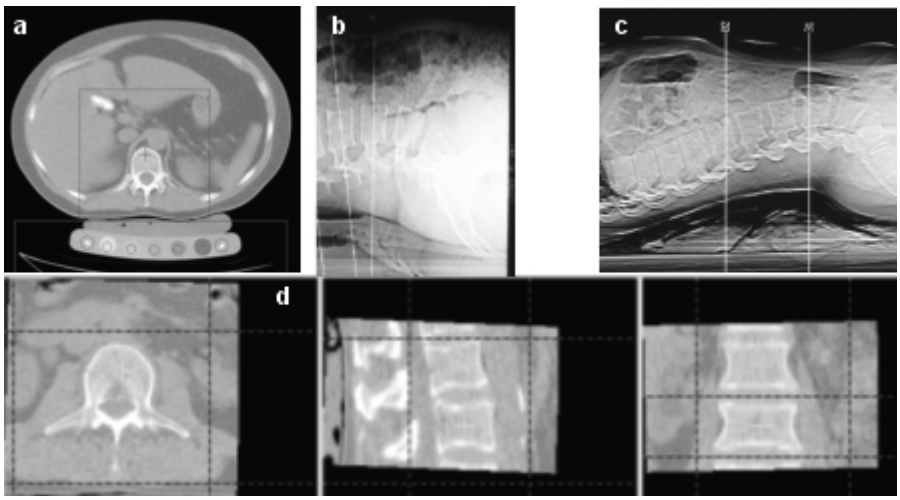
6.3.1c.

Interpretation and radiation dose: the results are expressed as standard deviations (SD) from the mean of appropriate age-, ethnic- and sex-matched reference data (Z score). As with other bone densitometry techniques there is a paucity of children's reference data required for interpretation of results; that which is generally used for spinal QCT has been gathered by Gilsanz and colleagues[51,52]. QCT also has the potential to be applied to novel sites (e.g. tibia, mid femur)[53]. As quantitative skeletal assessment does not require optimisation of image quality as in conventional CT, a low dose technique can be employed to minimise radiation dose[54,55], which is approximately 55µSv in the spine (Table 3.1b), equivalent to 2 to 3 chest radiographs, and quite acceptable in patients.

6.3.1d.

CT technological developments – QCT 3D mode: original CT scanners used rotate-translate technology which permitted only 2D images and took about 15 minutes to perform. Over the past decade there have been continuous technical developments in CT, with the introduction of continuous spiral rotation of the X-ray tube and multiple rows of detectors. This permits very rapid (less than a minute), 3D volume scanning. The 2D section for analysis can be selected from the 3D block of tissue (Figure 6.1c and d). These developments improve precision (better that CV 1%) and have advantages in children by reducing movement artefacts. 3D QCT can be applied to axial (spine and hip) and peripheral (upper and lower limbs).

Figure 6.1 Axial QCT: 2D method a) Patient positioned on calibration phantom for spinal scan b) mid plane sections, parallel to vertebral endplates, selected for 2D QCT measurement. In children generally L1-3 are scanned; 3D method c) a lateral scan projection radiograph for 3D QCT scan; d) reconstructed images in the transverse axial, sagittal and coronal planes.

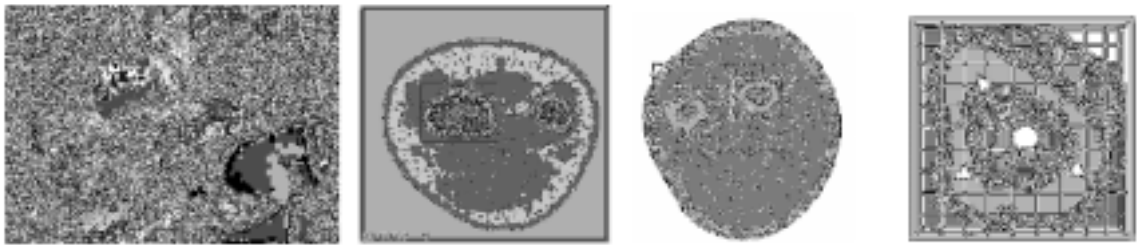


6.4. Peripheral quantitative computed tomography (pQCT)

6.4.1. **Introduction:**
Peripheral quantitative computed tomography (pQCT) (Figure 6.2a) first became commercially available in the early 1990s[56-58]. The method uses a traditional rotate-translate CT technology, and only single slices can be obtained (1 to 2mm thick). Peripheral QCT offers the same advantages as axial QCT (volumetric BMD [vBMD, mg/cm^3] so size independent; separate measures of trabecular and cortical bone). The technique is only applicable to the peripheral skeleton (the radius, tibia and femur) so is obtained at lower cost and radiation exposure (Table 3.1b) than axial QCT.

6.4.2.
Scan sites, precision and reference data: in children the distal 4% site in the forearm is most commonly used (Figure 6.2b); this is at a distance of 4% forearm length proximal to the growth plate. The paediatric reference database is from Germany and consists of 371 children, aged 6 to 18 years[59]. The most commonly used scanner is the Stratec XCT-2000 (Stratec Inc., Pforzheim, Germany) which measures the radius and tibia. The precision (in adults) is reported to be 0.8 to 1.5%[60]. Scan time can take between 2 to 3 minutes per slice and so the technique is better in older children who are able to keep still. As pQCT is not size-dependent it is not influenced by growth of a child; measurements of trabecular vBMD by pQCT remain consistent with age[59,60]. Measurements obtained include: integral, cortical and trabecular vBMD, assessment of bone geometry, parameters related to bone strength and muscle cross-sectional area (related to muscle force). For these measurements scanning sites are optimised. The 4% site measures total and trabecular vBMD in the distal end of the radius and tibia. In the mid-diaphyseal of the bone, measures include cortical vBMD, bone area, cortical thickness, periosteal circumference, endosteal circumference and muscle cross-sectional area (Figure 6.2c). Parameters related to bone strength are derived at the mid-diaphyseal site; axial moment of inertia (AMI) and the stress-strain index (SSI). The AMI is the distribution of bone material around the centre of the bone and the SSI is a combination of AMI and the vBMD of the cortex (Figure 6.2d); both relate well to the fracture load[61,62]. The study of the adaptation of bone to loading from muscle is possible using pQCT. Whether the bones have adapted efficiently to mechanical stress, and whether this contributes to bone strength/fragility can be assessed by calculating the ratio of bone to muscle. A model for the assessment of clinical conditions has been proposed[63], which would also be applicable to DXA measures of lean mass and BA or BMC. Peripheral QCT has been used in studies investigating clinical populations[64], bone development in healthy children[59, 65-67] and effects of exercise and calcium upon the skeleton[68,69].

Figure 6.2 pQCT: a) Child positioned for forearm scan b) an example of a distal forearm 4% scan from which trabecular and total vBMD are measured c) mid-diaphyseal radius for measurements of bone geometry, cortical vBMD, muscle area; d) measurement of stress strain index, bending and torsional strength of the bone



Section 7
Quantative ultrasound (QUS)

7.1. Introduction

Quantitative ultrasound (QUS) was first introduced in 1984[70], when a calcaneal ultrasound scanner was developed for assessment of bone status in adults. Measurements obtained from QUS are based upon the attenuation of the ultrasound beam as it passes through the specified region of interest in peripheral skeletal sites, most commonly broadband ultrasound attenuation (BUA, dB/MHz) or speed of sound (SOS, VOS, m/s). These are thought to be related not only to the mineral density of bone but also reflect parameters of bone quality and strength. The majority of ultrasound scanners to date are designed to transmit the ultrasound wave through the bone, most commonly the calcaneus, with receiver measuring the attenuated wave at the other side of the bone. Most such scanners have fixed emitting/receiving transducers; some systems provide an image of the calcaneus and the position of the region of interest (ROI) analysed. However, a more recently developed device (Omnisense, Sunlight Medical Limited, Te Aviv, Israel) is based upon just one probe being used, the ultrasonic wave travelling along the cortical bone, and this reflected wave being measured; this technique is called ultrasound critical angle reflectometry.

Ultrasound can only be applied to the peripheral skeleton and sites for measurement are the phalanges, radius, calcaneus, patella and tibia. Axial sites cannot be measured by QUS due to the large amount of soft tissue and muscle that overlie these sites and attenuate the ultrasonic beam. The most commonly measured site is the calcaneus which is rich (95%) in metabolically active trabecular bone, weight bearing, with little surrounding soft tissue, making it ideal for ultrasound measurements[71-73]. The method has been applied in children and neonates, measuring the properties of the cortical bone of the tibia, radius and phalanges[74-77].

7.2 Strengths and limitations of QUS

7.2.1. **Strengths**

QUS is based on the interaction of sound waves and bone, and does not use ionizing radiation, so is not covered by any ionizing regulation regulations, as are DXA and QCT. This use of ultrasound technology, rather than photon absorption, has potential advantages for use in children. Ultrasound devices are generally fairly compact and portable, with the potential to be used in a community, rather than a hospital or clinic, setting. Several studies have shown the ability of QUS parameters to predict hip, wrist or any fracture in post menopausal women[78-80]; in the most recent QUS predictive ability was also demonstrated in men[78].

7.2.2. **Limitations**

Most QUS devices applied to the calcaneus are devised for adults, and may not be adaptable to the smaller and narrower feet of children, unless inserts are available. Imaging devices (UBIS 5000) may confer some advantages over fixed transducer scanners in that the ROI in which the analysis has been made can be identified and altered in position, if required. Although QUS may have a role in fracture risk prediction in postmenopausal women, its role in younger women and men, and in children in clinical practice is still to be defined[81]. QUS results are temperature dependent[82], and can be adversely affected by inadequate coupling with gel between

transducer and skin, poor positioning of hand-held transducers, by variations in foot size and shape, and by the presence of subcutaneous oedema in the site of measurement. QUS has limited application in monitoring change in skeletal status in both adults and children, because precision of QUS in the calcanues (standardize sCV%) tends to be less good that either DXA or QCT (SOS = 4.3 to 8.4%; BUA = 2.8 to 6.9%)[83], or sites of measurement are predominantly composed of cortical bone with slow turnover (tibia, phalanx, distal radius).

7.3. Application in children

The application of calcaneal ultrasound in children is problematic. Scanners have all been designed for adults, with moulded foot wells and fixed transducers, which makes assessment of the correct region of interest difficult in children. Commercially available imaging ultrasound devices do overcome this problem to some extent by allowing manual adjustment of the position and size of the region of interest. The newer devices, which measure the phalanges, radius and tibia, are more suitable for application in children. Some devices have been specifically designed for children and neonates, with age and gestational specific reference data.

Although QUS shows potential for use in adults, children and neonates[84], currently the clinical utility of ultrasound in children is yet to be determined. However, it has been used in various clinical populations to detect differences between bone status in children with disease compared to normals[74,75,77]. At present it is a research tool in paediatric practice and should be used to complement other bone densitometry techniques. All QUS devices should be operated by trained staff who are able to demonstrate precision of measurement within the manufacturer's specification.

Section 8
Neonates and infants

8.1. Introduction and summary

Bone densitometry has been undertaken since the early 1990s in neonates and infants, initially using pencil beam and subsequently, fan beam instruments[85-87]. Both modalities have been validated for use in infants up to the age of two years and regional DXA has been used and compared to whole body DXA in one study[88]. Groups of infant studies include those born prematurely, at term, and small and large for gestational age[89]. Associations have been sought between parental attributes, cord blood, biochemical measurements in infancy and genetic variations with bone mass and body composition either at birth or during the first year of life[90]. The sites investigated have been the whole body and lumbar spine, although forearm has been used in one study. Technical issues, such as the use of phantoms appropriate to size, and software/data acquisition issues have been discussed[91,92]. Normative data exists for apparently healthy infants from birth up to two years of age. Animal models have been used, largely pig bone, to investigate the predictive value of DXA for fracture load in long bones. The wealth of research data available has not, however, led to the introduction of DXA as a modality for routine clinical assessment of skeletal health in infancy. Bone densitometry has not been shown to be of clinical value in the investigation of unexplained fractures in infancy, for example. While DXA has a clear place in the assessment of bone mass and body composition in infancy in both cross-sectional and longitudinal observational and interventional research studies, its broader application in assessing clinical bone health in infancy is not yet established.

Section 9

Table 9. Summary overview of bone densitometry techniques including precision, radiation dose and time taken for scanning (including positioning).

Technique	Sites	Radiation dose (microsieverts µSV)	Precision (CV %)	Time for scan (minutes)	Application (In priority order)
DXA	Lumbar spine	0.4 – 4	2-3	5	1) Clinical 2) Research
	Total body	0.02 – 5	1-2	5	1) Research 2) Clinical
	Proximal femur	0.15-5.4*	0.15 –5.4	5	1) Research 2) Clinical
Axial QCT	Spine	30 – 60[55]	0.8 –1.5[93]	10 – 15	Research
Peripheral QCT	Radius	< 1.5 – 4 per scan	0.8-1.5	10	1) Research 2) Clinical
	Tibia	< 1.5 – 4 per scan	3.6 – 7.8 3-5 yr olds[67] 1.3 –1.8 12 yr olds[94]	10	Research Research
	Femur	< 1.5 – 4 per scan	1.2 – 495	10	Research
QUS	Calcaneus	N/A		5	Research
	Phalanges	N/A	BUA 1.6 – 5[96,97]	<5	Research
	Radius		SOS 0.5 –1.2[98-101]	5 – 10	Research
	Tibia	5 – 10			Research

*The quoted radiation dose does not include the Lunar Expert

Section 10

Bone Density Questionnaire (to copy for local use)

Patient Information

Name DOB ID

Primary Disease

Time since diagnosis

Any Other Health Problems

Height Weight BMI

Original Referral	**DXA Referral**
Consultant	Consultant
Speciality	Speciality
Hospital	Hospital

Fractures

Have you ever fractured any bones ☐ Yes ☐ No

If yes, when, which bone, & how?

Have you had any persistent back pain in the last 12 months? ☐ Yes ☐ No

Has a family member suffered from Osteoporosis ☐ Yes ☐ No

If yes, who?

Mobility & Physical Activity – Mobile Patients

How much physical Activity do you do per week?

Less than 3 hours (School activity only) ☐

3 – 5 hours (School + organised activities) ☐

More than 5 hours (Sports clubs) ☐

Have you had any periods of prolonged immobility? ☐ Yes ☐ No

If yes when and for how long?

Mobility & Physical Activity – Immobile Patients

How do you usually get around?

	Never	Occasionally	Frequently	Always
Walk	☐	☐	☐	☐
Walk with crutches	☐	☐	☐	☐
Chair	☐	☐	☐	☐
Bed	☐	☐	☐	☐

Do you use a standing frame? ☐ Yes ☐ No

If yes, how often?

Do you have regular hydrotherapy? ☐ Yes ☐ No

If yes, how often?

Do you have any other physical therapy? ☐ Yes ☐ No

If yes, how often?

Diet

Do you have any feeding or nutritional problems? ☐ Yes ☐ No

If yes, please give details?

If no,

How much milk do you drink daily?

- None ☐
- 0 – 1/4pt. (150ml) ☐
- 1/4 – 1/2pt. (300ml) ☐
- 1/2 – 3/4pt. (450ml) ☐
- 3/4 – 1pt. (600ml) ☐
- more than 1pt. (600ml) ☐

How often do you eat the following foods?

	Occasionally	1 –3 times weekly	most days
Cheese	☐	☐	☐
Yoghurt	☐	☐	☐
Fromage Frais	☐	☐	☐
Ice Cream	☐	☐	☐
Milk Chocolate	☐	☐	☐
Milk Pudding	☐	☐	☐

Do you take a calcium supplement? ☐ Yes ☐ No

Do you take a vitamin supplement? ☐ Yes ☐ No

Medication

Do you or have you ever taken oral steroids (e.g. Prednisolone)? ☐ Yes ☐ No

If YES, How much and for how long

Do you take any medication for your bones (e.g. Pamidronate)? ☐ Yes ☐ No

If YES, for how long

Have you ever taken hormone replacement therapy (HRT) or the oral contraceptive pill? ☐ Yes ☐ No

If YES, for how long

Do you take any other medication? ☐ Yes ☐ No

If YES, for how long

Puberty

Do you have any signs of puberty? ☐ Yes ☐ No

If yes please fill in the appropriate pubertal self assessment form[17]

(From the Form) – reference 102 Duke and Litt (1980)

Girls

Age of Menarche

Regular YES NO

Pubic Hair 1 2 3 4 5

Breast Development 1 2 3 4 5

Boys

Age of voice breaking

Testicular Volume

Pubic Hair 1 2 3 4 5

Section 11a
Pubertal Staging Self Assessment – Girls

(from: National Institute of Child and Human Development [NICHD] Research Triangle Institute – with permission, based on references 103 and 104)

http://secc.rti.org/display.cfm?t=f&i=FPD04G5

This is a self examination which will help us to know which stage of puberty you are in. The examination will be carried out in a private room. You can do this by yourself, or you may wish to have your Mum or Dad, or one of them, present. Before you start please make sure the door is locked.

Pubic hair

First you need to look at the area between your tummy and the top of your legs. This is the pubic area. The pictures below show you how your pubic hair will grow in this area. Look at the pictures and put a tick underneath the picture that looks most like your own pubic area.

Breasts

The pictures below show the growth of the breasts. Look at your own breasts and put a tick in the box under the picture which looks most like your own breasts.

Can you supply images?

Section 11b
Pubertal Staging Self Assessment – boys

(from National Institute of Child and Human Development [NICHD] Research Triangle Institute – with permission, based on references 103 and 104)

http://secc.rti.org/display.cfm?t=f&i=FPD05G5

This is a self examination which will help us to know which stage of puberty you are in. The examination will be carried out in a private room. You can do this by yourself, or you may wish to have your Mum or Dad, or one of them, present. Before you start please make sure the door is locked.

Pubic hair

First you need to look at the area between your tummy and the top of your legs. This is the pubic area. The pictures below show you how your pubic hair will grow in this area. Look at the pictures and put a tick underneath the picture that looks most like your own pubic area.

Testes

The pictures below represent the growth of the testes. You need to feel your own testes, on at a time, and compare the size of each testicle to the beads you have been given. Decide which bead feels most like your testicle in size. On each bead there is a number. The numbers are the same as those shown on the beads in the picture. Put a tick on the picture of the bead with the same number as the one which feels most like your own testicle. Do this first for your left testicle and than again for your right testicle. The number may or may not be the same for both sides.

The size of your Left testicle

The size of your Right testicle

Can you supply images?

Section 12
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National
Osteoporosis
Society

National Osteoporosis Society
Camerton
Bath BA2 0PJ

tel: 01761 471771
fax: 01761 471104
helpline: 0845 450 0230
website: www.nos.org.uk
e-mail: info@nos.org.uk

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