NEW BONE FORMATION DURING LEG LENGTHENING
EVALUATED BY DUAL ENERGY X-RAY ABSORPTIOMETRY

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We measured the extent and rate of new bone formation over an 18-month period before, during and after the lengthening of ten leg segments in six patients aged between 8 and 18 years, using dual-energy X-ray absorptiometry (DEXA).

New bone formation could be identified within one week of the start of distraction. As lengthening proceeded, the bone density of the gap fell, reaching minimum values at the time of maximal distraction. Consolidation of the regenerating bone was started 1 to 2 weeks later in the tibia, and 2.5 to 3.0 weeks later in the femur. The rate of mineral accretion in new bone was significantly greater in the tibia than in the femur (16 ± 1.86%/month, and 11 ± 1.1%/month respectively; mean ± SEM). There was significant osteoporosis distal to the osteotomy, more in the tibia than in the femur, particularly on the side of the fixator. The bone mineral density of the distal segment remained low at the time of fixator removal (44.2 ± 5.58% and 61.0 ± 4.2% of the control values at the tibia and femur respectively) and was only partially reversed by subsequent weight-bearing.

We conclude that dual-energy X-ray absorptiometry provides an objective and quantitative assessment of new bone formation during leg lengthening. The technique also allows the measurement of the distraction gap and the assessment of leg alignment from the high-resolution images. Its use may decrease the requirements for conventional radiography.

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A precise and accurate non-invasive method of quantifying new bone formation would be valuable in the assessment of bone healing after fracture. Plain radiography is relatively insensitive and does not detect new bone production until a considerable quantity has been laid down (Peretti et al 1988; Young et al 1990); it cannot be used to determine the rate of bone formation.

Other non-invasive techniques to monitor bone healing have been investigated such as the velocity of ultrasound in bone and the serial changes during fracture healing but this was found to be unreliable (Gill et al 1989). Ultrasound has been used effectively to identify new bone formation early in the course of limb lengthening (Young et al 1990), but although cortication of the regenerating bone can be readily identified, the quantity and rate of bone formation cannot be evaluated. Measurements of the bending rigidity of newly formed callus correlate closely with the mineral to matrix ratio of the repair tissue (Chakhalkalak et al 1990) and the calcium content of callus is a reliable indicator of the mechanical strength of healing fractures (Powell et al 1989). This suggests that an index of bone healing could be obtained from measurements of bone mineral content (BMC) or bone mineral density (BMD) using quantitative techniques.

Dual-energy X-ray absorptiometry (DEXA) is a relatively new densitometric technique which is widely used to investigate and monitor metabolic bone disease (Mazess 1983; Sartoris and Resnick 1989). It has some advantages over other densitometric techniques, being more reproducible than dual-photon absorptiometry and, unlike single-photon absorptiometry, avoids the need for the limb to be immersed. Dual-photon absorptiometry has been used during limb-lengthening procedures in man (Peretti et al 1988) but the resolution of the image is poor. The higher resolution of DEXA suggested that it might be a useful non-invasive and quantitative method for examining mineralisation during distraction osteogenesis. In this paper we describe the use of DEXA to quantitate changes in BMD during limb lengthening, both at the site of distraction and in the proximal and distal segments of the bone.

PATIENTS AND METHODS

We studied six patients, four male and two female, aged
NEW BONE FORMATION DURING LEG LENGTHENING

Table 1. Clinical details of the six patients and ten legs studied by dual-energy X-ray absorptiometry

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>Site</th>
<th>Lengthening (mm)</th>
<th>Duration of study (mth)</th>
<th>Lengthening index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>F</td>
<td>Achondroplasia</td>
<td>Left femur</td>
<td>80</td>
<td>12</td>
<td>42</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>M</td>
<td>Achondroplasia</td>
<td>Left femur</td>
<td>100</td>
<td>14</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right tibia</td>
<td>100</td>
<td>14</td>
<td>29</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>M</td>
<td>Pseudoachondroplasia</td>
<td>Left tibia</td>
<td>46</td>
<td>19</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right tibia</td>
<td>45</td>
<td>19</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>F</td>
<td>Achondroplasia</td>
<td>Left femur</td>
<td>115</td>
<td>15</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Left tibia</td>
<td>97</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>19</td>
<td>F</td>
<td>Achondroplasia</td>
<td>Left femur</td>
<td>92</td>
<td>13</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right tibia</td>
<td>90</td>
<td>13</td>
<td>41</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>M</td>
<td>Achondroplasia</td>
<td>Right tibia</td>
<td>55</td>
<td>12</td>
<td>30</td>
</tr>
</tbody>
</table>

DEXA image of the femur (case 2) to show the sites of bone density measurement. Measurements along the length of the bone used a 3 x 2 mm area of interest, in increments of 2 mm intervals, including ipsilateral and contralateral cortical regions (Ci and Cc) and medullary regions (Mi and Mc) in relation to the fixator. Measurements were also made across the limb at the mid-point of the distraction gap (line A) using a 2 x 2 mm area of interest in 1 mm increments, to include the total area in which callus was generated. All these sites were compared with similar sites in the control limb.

between 8 and 18 years, prospectively over an 18-month period before, during and after the lengthening of ten leg segments. Leg dysplasia was due to achondroplasia in five and to pseudoachondroplasia in the sixth. Leg lengthening was performed using the technique of De Bastiani et al (1987) with a unilateral external-fixator system (Orthofix: Biomet, Swindon, UK). Bilateral tibial lengthening was performed in one patient, femoral and tibial lengthening, either ipsi- or contralateral, in three, femoral lengthening only in one and tibial only in one (Table 1). The bones were lengthened at a rate of 1 mm/day starting five to seven days after surgery. Patients were mobilised weight-bearing when possible during lengthening. DEXA scans of the operated and non-operated legs were performed before surgery and at two-to four-weekly intervals afterwards.

Leg lengthening had been performed previously at three sites in two of the patients (two femora and one tibia) between one and three years before the present study. BMD measurements were also performed at these sites and compared with those of the leg to be lengthened before surgery was started.

**DEXA scanning technique.** BMD measurements were made using a Hologic QDR 1000 (Hologic Inc, Massachusetts, USA). A self-contained X-ray source is mounted beneath the patient to provide alternating pulses at 70 kVP and 140 kVP. An X-ray detector is mounted above the patient and both source and detector move across the patient under computer control in a serpentine pattern. The two energies of radiation are generated as collimated beams and are absorbed by the bone and soft tissues. Computer analysis of the absorption patterns allows the measurement of BMC in grams and BMD in grams/cm². It also provides an image.

With the patient lying on the couch of the scanner, a reproducible position is ensured by placing the foot of the leg to be examined against an angled board with the external fixator resting against a pillow. Scanning time was approximately 3.5 minutes for each leg and the radiation dose for each scan was estimated to be less than
Bone density measurements. The BMD was computed from the BMC within a fixed area (2 x 3 mm) at various sites. Density measurements were made at the latera1 and medial cortices and over two regions of the medullary cavity as they were identified from the DEXA image (Fig. 1). These are termed cortical and medullary bone density respectively, but it is important to note that the measured medullary density includes that of two layers of cortical bone, because of its tubular structure. Density measurements were computed in this way throughout the length of the leg (Fig. 2), including the site of distraction, and also across the diameter of the bone. To allow for changes in bone density resulting from immobilisation, the values for density were also expressed as a ratio of that of the non-operated leg at a comparable site, or of the preoperative values in those patients undergoing bilateral lengthening.

Reproducibility of the results was evaluated by repeated measurements from the total length of bone between the fixator pins, and also from standardised areas in the proximal and distal segments, the mid-gap region, and sites in the control leg. Two consecutive scans were performed at the same visit and, as expected, the coefficient of variation was inversely related to BMD measurement. For the total area between the pins, the reproducibility error (coefficient of variation) was 0.15%. With the smaller area of interest (2 x 3 mm) used throughout this study, reproducibility was poorer. At sites of BMD greater than 0.2 g/cm², the reproducibility error was 2.5%; at sites less than 0.2 g/cm², this error was 6%.

RESULTS

Preoperative bone density. In both the femur and tibia, the density of cortical and medullary bone increased from the metaphysis towards the isthmus of the shaft and then decreased again distally. This pattern was more obvious in the femur than in the tibia (Fig. 2). BMD values in the medullary zones, as expected, were consistently lower than those in the cortical zones in both the tibia and femur, and sequential transverse measurements of BMD showed shoulders of increased density over the cortical zones (Fig. 2).

Distraction. The osteotomy site could be readily visualised from the DEXA images as a marked fall in bone density. New bone could be seen on the images within one or two weeks from the start of distraction, appearing from both ends of the corticotomy (Figs 3, 4). In contrast, no new bone could be detected on plain radiographs taken at three to six weeks of distraction.

As distraction progressed, the bone density at the distraction site increased, but was consistently lower than normal, and lowest at the centre of the gap. Both the distal and proximal bone ends contributed to new bone formation although by variable amounts (Fig. 5). The new bone was laid down in longitudinal streaks.

Sequential bone mineral density measurements (BMD) in the longitudinal and transverse axes of the femur and tibia (case 4) before osteotomy. The arrows mark the intended site of osteotomy and the corresponding transverse scans are shown in the right-hand panels. The bone density of the femur is greater than that of the tibia in the same patient, and the density of the medullary zone is lower than that of the cortical zone, thereby producing the bimodal transverse scan.
Sequential DEXA images of the femur (case 1) at 2 months (A), 3.5 months (B), 5 months (C) and 7 months (D). New bone appears from both ends of the corticotomy as two 'shoulders' which approximate near the mid-gap.

Sequential DEXA images of the tibia (case 4) at the time of osteotomy (A), at 2 months (B), 3 months (C) and at 5 months (D). New bone appears from each end of the corticotomy during distraction. These 'primary mineralisation fronts' approach each other and meet near the middle of the distraction gap, where they coalesce and consolidate.
Sequential BMD measurements (case 4) in the long axis of the femur during distraction at the time of osteotomy (July) and after 1 month (August) 2 months (September) and 4 months (October). Bone density fell at the site of the osteotomy then, as the limb was distracted, bone was generated from each end of the corticotomy and appeared as 'shoulders'. As distraction increased, bone density in the mid-gap fell further until two shoulders of bone approached each other to coalesce at the centre of the gap. The vertical bars represent the site of the fixator pins; the horizontal bars represent the bone proximal and distal to the distraction gap.

BMD measurements (mean ± SEM) of the various segments of the tibia and femur at the time of maximum distraction. There is relative osteopenia in the distal segment and greater osteopenia of the cortex on the same side as the body of the fixator (* = p < 0.05; † = p < 0.001).
Sequential DEXA images of the tibia (case 5) at 3 months (A), 4 months (B), 5.5 months (C) and 7 months (D) from the time of osteotomy. New bone in the distraction gap has formed eccentrically, predominantly on the opposite side of the bone to the fixator, at the time of maximal distraction (A). Consolidation on the same side as the fixator progressed over four months, but a small defect persisted after fixator removal. Osteoporosis of the distal segment is well shown (B,C) more obvious on the side of the fixator.

BMD measurements (mean ± SEM) during lengthening of the tibia and femur, as percentages of control values. The mid-gap density fell to minimum values towards the end of distraction and then increased during consolidation. The significant bone loss in the distal segments was greater in the tibia than the femur.
which were often eccentrically orientated in the gap, with significantly more bone in the gap in the cortical regions contralateral to the fixator than on the same side as the fixator (p < 0.001; Fig. 6). The mean increase in length was 6.2 cm in the tibia and 6.4 cm in the femur (Table I).

In the tibia, the minimum values of BMD were found in the mid-gap region at the end of the distraction phase: bone densities at the cortical and medullary bone sites were then 10\(^\%\) (0\% to 22\%) and 15\% (10\% to 25\%) of the control values respectively. Compared with the tibia, there was a more marked fall in bone density at the gap during the distraction of the femur (range 0\% to 18\% of the preoperative values; p < 0.001; Table II). In the oldest patient (case 5) undergoing both tibial and femoral lengthening, no bone mineral was detected by DEXA in the mid-gap of the femur or tibia for 2.5 months after starting distraction. New bone formed later; it was positioned eccentrically with more on the side opposite to the fixator. In this case, BMD values increased over the subsequent four months and although a small defect persisted on the same side as the fixator, this was removed without loss of length or fracture (Fig. 7).

During lengthening, the bone density of the proximal segment fell to reach minimum values (80 ± 1.4\% of control values) at the time of maximum distraction (Fig. 8). There was greater bone loss in the segment distal to the osteotomy site; this fell to 35 ± 3.6\% of the control values for the non-operated leg. Bone loss was again greater in the cortex nearest to the fixator, particularly in the tibia (see Fig. 6). An extreme example is shown in Figure 7.

Distal loss of bone in the femur was also seen but was less than that in the tibia. BMD fell to 48.2 ± 3.3\% of the control value; this was significantly less than that at the distal site in the tibia (p < 0.05). Again, there was more bone loss in the cortical region on the same side as the fixator (p < 0.001; see Fig. 6).

Consolidation. After a delay of one to two weeks after maximal distraction, consolidation of the regenerating tibial bone progressed rapidly in most cases (Fig. 8). BMD increased by approximately 16 ± 1.86\% per month, equivalent to a gain in mineral density of 0.6 ± 0.07 g/cm\(^2\)/month (Table II). The rate of increase was linear for the first three months after maximal distraction, then slowed progressively towards the end of consolidation. These changes in bone density were evident before any were obvious on conventional radiography.

A significantly greater mass of bone was laid down in the distraction gap in the region contralateral to the body of the fixator (p < 0.001). The BMD of the regenerating bone did not reach control values during our study (Table II), except in the youngest patient (case 3) with the shortest lengthening (tibia by 45 mm). In this patient, the bone density of the regenerating bone approached 140\% of the control value (Fig. 9).

Although cortication of the new tibial bone appeared to be complete from the longitudinal DEXA scan and the plain radiographs, the normal pattern of BMD measurements across the diameter of the bone was not regained until three to four months later, depending on the length achieved (Fig. 10). The distal loss of tibial bone recovered slightly with weight-bearing but remained low (mean 44.2 ± 5.58\% of control) at the time of fixator removal.

In the femur, the rate of mineralisation of the regenerating bone was slower than in the tibia (p < 0.005; Fig. 8 and Table II). BMD increased by approximately 11 ± 1.1\% per month, equivalent to 0.8 ± 0.08 g/cm\(^2\)/month). As in the tibia, a significantly greater mass of bone was generated in the region of the distraction gap opposite to the fixator (p < 0.05; Fig. 6). Normal cortication of the regenerating bone (as judged by the BMD measurements across the midpoint of the regenerate) was not regained until at least four to six months after surgery in most cases. As in the tibia, the distal loss of bone recovered with weight-bearing but remained at 61.0 ± 4.18\% of control values at the time of removal of the fixator (see Fig. 5). The mean lengthening index (days until fixator removed/length achieved) for the tibia was 37 days/cm, and for the femur 42 days/cm.

Table II. Sequential bone density measurements (mean ± SEM) of the cortical regions at the mid-point of the distraction gap throughout the study. Values are given at monthly intervals after the start of distraction and the achievement of maximal distraction

<table>
<thead>
<tr>
<th>Stage</th>
<th>BMD (g/cm(^2))</th>
<th>BMD (% of control value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tibia</td>
<td>Femur</td>
</tr>
<tr>
<td>Preoperative</td>
<td>0.91 (0.08)</td>
<td>1.41 (0.12)</td>
</tr>
<tr>
<td>Distraction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.50 (0.02)</td>
<td>0.62 (0.06)</td>
</tr>
<tr>
<td>2</td>
<td>0.30 (0.02)</td>
<td>0.11 (0.04)</td>
</tr>
<tr>
<td>3</td>
<td>0.21 (0.02)</td>
<td>0.10 (0.04)</td>
</tr>
<tr>
<td>Consolodation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.25 (0.01)</td>
<td>0.30 (0.03)</td>
</tr>
<tr>
<td>5</td>
<td>0.31 (0.01)</td>
<td>0.31 (0.04)</td>
</tr>
<tr>
<td>6</td>
<td>0.44 (0.01)</td>
<td>0.48 (0.04)</td>
</tr>
<tr>
<td>7</td>
<td>0.64 (0.01)</td>
<td>0.67 (0.04)</td>
</tr>
<tr>
<td>8</td>
<td>0.69 (0.02)</td>
<td>0.86 (0.05)</td>
</tr>
<tr>
<td>9</td>
<td>0.82 (0.02)</td>
<td>1.05 (0.08)</td>
</tr>
<tr>
<td>12</td>
<td>0.88 (0.02)</td>
<td>1.08 (0.12)</td>
</tr>
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</table>

Later changes. Three of the patients had previously undergone lengthening of the contralateral leg at least one year before the present study; plain radiographs and DEXA scans of these legs were performed. Even taking into account the underlying bone disease, the two tibiae and one femur did not have a ‘normal’ appearance. The new bone could be readily identified as a relatively sclerotic area and the cortices of the distal parts of the leg remained thin. The bone density of the cortical and medullary bone throughout the length of the regenerated segment was consistently higher than that of the non-operated leg (on average by about 20\% in both areas) although it was not possible to assess a precisely
BMD measurements along the length of the tibia for cortical and medullary zones during consolidation 4.5 months (top), 6 months (middle) and 7.5 months (bottom) from the time of osteotomy (case 1). At the time of maximum distraction (top), the bone density in the gap reached minimum values. Consolidation was established at 1.5 months (centre), particularly in the medullary zones. The significant late bone loss in the distal segment is shown in the lower panels.

BMD measurements across the width of the tibia at the mid-point of the regenerating bone (case 1) at 2, 3, 7.5 and 10 months after osteotomy. The dotted line shows the density values of the control limb. Evidence for corticization is seen in the 10-month scan, with development of the characteristic transverse profile of the control tibia.
equivalent area. The bone density of the distal shafts of femora and tibiae was also reduced compared with the non-operated side (mean 78%; range 65% to 85%) consistent with our findings described later.

**Non-operated leg.** In all patients there was a reduction in bone density in the non-operated leg during the lengthening procedures. This ranged from 5% to 10% of preoperative values with a distribution of bone loss similar to that in the operated legs in that it affected predominantly the distal tibia and femur.

**DISCUSSION**

We believe that this is the first description of the use of DEXA to quantify and monitor new bone formation during leg lengthening. The high resolution of the images that we obtained with DEXA gave a clear representation of the changes in bone density during lengthening, and was adequate for the assessment of leg alignment. In addition, with a pixel size of 1 mm, we were able to measure accurately the length of distraction achieved. We also found that DEXA was a highly reproducible technique for the measurement of BMC and BMD. This high accuracy has been assessed experimentally in cadaver studies (Wahner et al 1988; Devogelaer, Baudoux and Nagent de Deuxchaisnes 1990; Imai et al 1990); changes in bone density measured by this technique have been shown to correlate strongly with the torsional properties, calcium content and indentation stiffness of healing tibial osteotomies in dogs (Markel et al 1990).

It was particularly interesting that DEXA could be used to monitor the rate of new bone formation in a quantitative manner. We were able to determine the rate of mineralisation of the regenerating bone and found that this was more rapid in the tibia than in the femur in our group of patients. There was a short delay in consolidation after maximal distraction had been achieved, but accelerated mineralisation then occurred in most cases for the next three months, and this was followed by a slower rate of bone formation in the later stages. These changes are similar to those found in healing tibial fractures (Kenwright and Goodship 1989), although over longer periods of time. If further studies show that the normal rates of bone formation are sufficiently consistent, then DEXA could be used to assess other lengthening techniques and also the influence of pharmacological, mechanical or electromagnetic methods on mineralisation. There are few quantitative clinical methods of assessing bone repair after injury, and it is possible that DEXA could be used to monitor fracture healing.

During the distraction phase of lengthening one problem is to determine the correct rate. If it is too slow it will cause premature fusion, and if too fast, mineralisation defects (White and Kenwright 1990). We found that DEXA could detect changes in new bone formation earlier than plain radiographs; this may enable the surgeon to adjust the rate of distraction to prevent either of these complications. A fusiform appearance of the regenerating bone during lengthening would indicate proliferative new bone formation. Transverse scans were also helpful in monitoring the organisation and cortication of the new bone in the distraction gap.

DEXA has several advantages over other non-invasive techniques. Single-photon absorptiometry has been used to study fracture healing in animal experiments (Svesnikov and Oficerova 1985; Klug 1988), but the limb must be surrounded by a soft-tissue-equivalent medium, usually water; this is not practical in the presence of an external fixator. Quantitative computerised tomography (QCT) does not require limb immersion and has been used to study bone regeneration in animal limb lengthening (Aronson et al 1990; Markel et al 1990; van Roermund et al 1987, 1991), but despite technical advances this is a less precise and accurate technique than photon absorptiometry (Christiansen, Riis and Rodbro 1987). In addition, QCT for densitometry is not widely available and the radiation exposure required is 10 to 100 times greater than for photon absorptiometry. These features limit its clinical use, particularly in children. DEXA uses low radiation, and provides high accuracy with high-resolution images; our technique appears to be superior to those previously assessed.

The pattern of new bone regeneration that we found with DEXA is similar to that previously reported using standard radiographic techniques. We found, however, that the bone density in the mid-gap region fell much lower (mean 15%; range 0% to 40%) than that recorded by other densitometric techniques. Aronson et al (1990), for example, using QCT to monitor the mineralisation of the canine tibia lengthened by the Ilizarov technique, described a fall in bone density of the mid-gap region to 37% of the contralateral limb and a reduction of the calcium content at these sites to approximately 30% of control values. This difference may be related to the method of fixation used or to differences in accuracy. New bone formation using the uniplanar technique of De Bastiani has been shown to be less homogeneous than that with multiplanar fixator systems such as the Ilizarov frame (Aronson et al 1989). The significantly greater bone formation on the side of the bone opposite to the body of the fixator may result from the form of fixator device that we have used. Further DEXA studies are needed to assess new bone formation with uniplanar and biplanar fixator systems.

The marked loss of bone in the distal tibia, and to a less extent in the distal femur, has not been described in leg-lengthening procedures. The reason for this loss of bone is not clear. It is probably related, in part, to stress protection produced by the rigidity of the fixator device, since the cortex on the same side as the fixator body was predominantly affected. This distal osteoporosis may also be due to the effect of surgery on bone metabolism: an
increase in bone turnover has been documented after fractures due to trauma (Ulivi et al 1983; 1990). It has been postulated that distal osteoporosis represents a general response to local injury; changes in serum alkaline phosphatase activity and parathyroid hormone levels have been identified during fracture healing (Ulivi et al 1983). Injury to the medullary and periosteal vascular systems supplying the new callus may occur during lengthening (Delloye et al 1990), but the radiographic and densitometric changes in the distal segment do not indicate that the osteoporosis was related to vascular injury, since the characteristic appearance of bone ischaemia or infarction is that of relative sclerosis rather than porosis.

The distal osteopenia appeared to improve with progressive weight-bearing, but a significant reduction in bone density persisted for at least two years after surgery. This suggests that, although bone loss ceases, recovery is very slow and likely to be incomplete. Similar changes have been described after adult tibial (Andersson and Nilsson 1979; Ulivi et al 1990) and forearm fractures (Bickerstaff, O'Doherty and Kanis 1991), and in lengthened canine forelimbs (Delloye et al 1990). The significance of this bone loss after injury and immobilisation in children is unknown, but in adults there is some evidence that persistent regional osteopenia may increase the risk of recurrent fracture. Finsen and Benum (1987) identified 2744 past fractures in a series of 1659 present fractures and found that femoral, patellar and tibial fractures were more often seen in the same limb as previous lower-extremity fractures. They concluded that there was a fourfold increase in the risk of refracturing a previously fractured tibia compared with the risk for the contralateral tibia.

The macrostructure and microstructure of regenerating bone after lengthening have been described as being indistinguishable from those of normal bone, both radiographically and histologically (Ilizarov, Lediaev and Shitin 1969; Ilizarov and Soibelman 1969). We found, however, that there was relative sclerosis of the regenerated region when measured several years after previous lengthening procedures and that although the new bone appeared to be fully corticated on radiographs BMD measurements across the diameter of the bone did not approach control values for several months after consolidation. This may contribute to the pathogenesis of refractures after lengthening procedures (Aldegheri et al 1988).

In most of our patients, the fixator systems were removed when density measurements had reached about 75% of control values. There may be an optimal time for fixator removal when the regenerate is adequately mineralised; after this, removal avoids further stress protection effects. DEXA scanning is, however, a two-dimensional technique; it is possible to miss defects in mineralisation unless they lie directly in the path of the collimated beam. We therefore recommend its use in conjunction with ultrasound, so that these areas can be identified. In addition, the higher resolution of standard radiographs is still valuable to exclude small cortical fractures which may not be identifiable on DEXA images.

We conclude that DEXA can provide an objective and non-invasive method for assessing the rate of new bone formation during limb lengthening. The technique also allows measurement of the distraction gap and assessment of limb alignment. Its use may decrease the requirement for conventional radiography.

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REFERENCES


