Bone mineralization gradient at the callotasis site

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Abstract Thirteen patients (18 lengthenings; mean age at operation, 11.0 years) underwent dual-energy X-ray absorptiometry (DEXA) scanning weekly during the distraction phase, at 2-week intervals until removal of the fixator, and at the time of each outpatient visit after removal of the apparatus for a median of 353 days. The three transverse regions remained significantly different in the 7 achondroplastic patients throughout the study, but the difference among these regions became nonsignificant by fixator removal in the 11 limb length discrepancy (LLD) patients. The most proximal region was significantly more mineralized throughout the study in the achondroplastic patients. The central region became the region of highest mineralization in the LLD patients by week 16 after removal of the fixator. The three longitudinal regions showed significantly different mineralization at all time points except at fixator removal. The central and medial regions always showed the highest mineralization. The mechanical characteristics of the fixator and the biomechanical features of the lengthening site may account for the mineralization gradient reported in this study and should probably be taken into account when planning removal of the fixator and subsequent weight-bearing.

Key words Limb length discrepancy · Callotasis · External fixation · DEXA

Introduction

Gradual callus distraction (callotasis) has become a reliable and predictable technique for the correction of limb length inequality.4,13,17,18,23,29 The lengthening process is carefully monitored to ensure that the pin sites do not become infected, that bone alignment is correct, and that new bone formation takes place.23,29 Critical points in the process of callotasis lengthening are when to discontinue the distraction and when to remove the fixator.16,21

Many imaging techniques have been used to assess the process of lengthening.12,16,21,26 Plain radiography in two planes is the main tool used in clinical practice for qualitative assessment of the regenerate.16,21 Recently, more objective quantification of the mineralization process in the regenerate has been performed16,7,11,28 using quantitative computer tomography,27 quantitative technetium bone scanning,20 and dual-energy X-ray absorptiometry (DEXA).14

New bone formation during the early phases of callotasis predicts later mineralization,14 and bone mineralization of the regenerate continues well after lengthening has been concluded.15 In clinical practice, we had the impression that regenerate production did not proceed at the same rate in the medial and lateral and in the proximal and distal directions of the bone segment undergoing callotasis. We therefore hypothesized that mineralization proceeded at different rates in the medial and lateral regions and in the proximal and distal regions of the regenerate, and designed an investigation to determine, using DEXA, whether such differences were present in a group of patients undergoing callotasis lengthening.

Patients and methods

Approval for the study was granted by the Ethical Committee for Research on Human Subjects of the Chinese University of Hong Kong, Faculty of Medicine. Informed consent was obtained from patients and/or their parents.

Patients

Thirteen patients (18 lengthening procedures) (mean age at operation, 11.0 ± 3.72 years; range, 4–17 years)
underwent callotasis lengthening of the lower limb. In the achondroplastic patients, the aim of the surgery was to increase the overall stature of the patients. In the patients with leg length discrepancy (LLD) (4–13 cm at surgery), we aimed to equalize leg length.

The operative technique has been extensively described. Distraction was applied 7–10 days after corticotomy, at a planned distraction rate of 0.25 mm four times a day, varied according to clinical conditions and imaging results. All patients received regular physiotherapy and, when necessary, splinting to maintain mobility of the joints proximal and distal to the bone lengthened. The Ilizarov frame was used in ten cases (nine tibiae and one femur), and the Orthofix apparatus was used in the remaining eight cases (four femora and four tibiae). All achondroplasic patients underwent lengthening using the Orthofix apparatus only.

**Imaging**

DEXA scans were obtained in the anteroposterior plane using a Norland XR26 Bone Densitometer (Norland, Fort Atkinson, WI, USA) equipped with Bone Analysis Software 2.5 (Norland) according to the manufacturer’s instructions. For all scans, the resolution was 1 mm × 1 mm, at a scanning speed of 30 mm/s. For this study, we used bone mineral content (BMC) as the index of bone mineralization, as, given the likely volumetric changes that the regenerate undergoes during lengthening, spuriously high or low readings of dimension-related bone mineralization indices could have been produced. In the present investigation, BMC represents the total bone mineral content values of all pixels within the marked areas, i.e., the whole of the regenerate.

Patients were scanned weekly during the distraction phase, once every 2 weeks until removal of the fixator, and at the time of their outpatient visits thereafter. Plain antero-posterior and lateral radiographs were obtained at the same times. Patients were scanned while lying supine on a couch, with the bony segment(s) to be scanned adjusted to be horizontal and parallel to the couch, resting on a pillow. Both limbs were scanned in each session. BMC was expressed in grams. The preoperative BMC was considered 100%, and all postoperative and postlengthening BMC values were also expressed as a ratio to this value. In the patients in whom only one side was undergoing lengthening, a comparable site and area of the contralateral unoperated limb was also DEXA scanned. In these patients, the BMC of the contralateral unoperated limb after the beginning of the distraction was expressed as a percentage of the preoperative BMC.

Reproducibility of the DEXA scan results was evaluated by double measurements of the same area at each visit. Reproducibility varied between 2% and 4%, according to the mineralization of the area studied. Once the area to the analyzed was marked, the computer automatically detected the bone edges, and related the BMC of the newly formed bone in the distraction gap with the BMC of the area used as control. After lengthening had been completed and the fixator removed, the areas measured by DEXA scanning were carefully outlined and were scanned at subsequent visits.