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# Callotasis Mineralisation in Achondroplasia Tibial Lengthening-an individualised treatment process

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**Abstract** We have prospectively followed 8 selected patients with achondroplasia who underwent bilateral tibial lengthening using the Ilizarov hybrid advance fixator, between 1991-2000. One of these 8 patients underwent bilateral lengthening twice. We measured the callotasis and the stress-shielded original host bone mineral density (BMD) and the bone mineral content (BMC) changes during lengthening, and analysed these with respect to age, body weight, baseline pre-operative BMD of the tibia, and to rigidity of the frame construct. The mean age of the patients at the time of the operation was 12.15 (9.58～14.4) years. There were 5 girls and 3 boys. Preoperatively, the average BMD of the tibia was 0.796 (0.53～0.97) g/cm²; the average achieved lengthening was 9.48 (5.5～11.9) and 9.78 (5～11.8) cm; with an average Lengthening Index of 28.84 (22.65～37.44) and 28.05 (20.54～37.01) days/cm for the right and the left tibia respectively. The Lengthening Index (LI) showed a correlation with age, and with preoperative BMD of the tibia, and body weight, when the frame rigidity was normalised. The frame construct and dynamisation should be individualized to optimize mineralisation. Close BMC monitoring allows quantification of mineralisation to decide on the introduction of strategies to enhance mineralisation.

## Introduction

There have been only a few studies of callotasis mineralisation during distraction osteogenesis[5)6)9)10)]. The introduction of a hybrid advance fixation system has greatly improved patient comfort. These large diameter rigid half pins have replaced the fine original Ilizarov transosseous tensioned wires which greatly increase the frame rigidity and simplicity of the frame[3)]. The loading dynamics of the forces acting at the callotasis and the stress shielded host bone affect the rate of mineralisation. This study prospectively followed a group of achondroplasia patients who underwent tibial lengthening with a same Ilizarov hybrid fixator to discover clinically how different factors were related to new and original bone mineralisation during distraction and how mineralisation may be optimised.

## Materials and Methods

We have followed 8 achondroplasia patients who underwent bilateral tibial lengthening, with complete clinical records and X-rays. The age, body weight, preoperative BMD, fixation frame construct, rate of lengthening, and the BMD changes during distraction and other interventional procedures were recorded. Dual Energy X-ray Absorptiometry (DEXA) scans

**Key words**: Achondroplasia, Tibia, Lengthening, Callotasis, Mineralisation

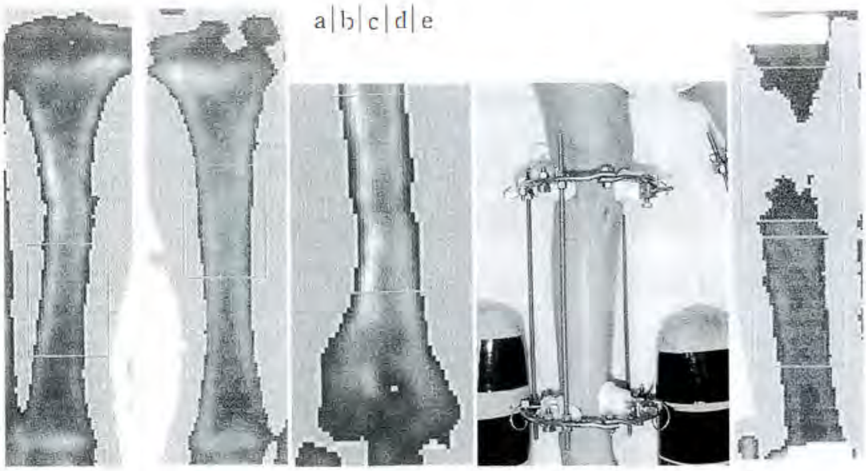


**Fig. 1.**

- a : Preoperative BMD scan of right tibia
- b : Preoperative BMD scan of left tibia
- c : Preoperative BMD scan of humerus as control
- d : Careful positioning of limb during lengthening ensures consistence of scan
- e : Measurement of bone segments according to fixed distance from fixation pin

were made preoperatively on the humerus as control, and on both tibiae at a marked site. The same sites were scanned serially with reference to a fixed distance from fixation pins to ensure consistency of the measured segment (Fig. 1 scan technique & graphs).

An Ilizarov Hybrid Advanced fixator was used with a combination of transsosseous tensioned wires and half pins. A detailed stiffness study was made on each patient's frame construct to categorise the frame rigidity. The choice of fixation was selected by the surgeon to be the best frame construct at the time according to the size and build of the patient. The frame rigidity can be classified into two categories of rigidity in terms of the number of rigid pins. All patients had two maximally intersection angle cross wires for each segment[11]. Six patients (category 1) had one rigid 6/5 mm Orthofix pin, and two patients (category 2) had two 6/5 mm Orthofix pins, per segment of fixation.

Each patient underwent a standard sequence of treatment. A syndesmosis screw was first placed across the ankle. A fibula osteotomy was performed by excision of a 1 cm segment. Fixation of the proximal and distal segments was then performed. Osteotomy was then performed either by multiple drill holes or through conventional corticotomy. Postoperative distraction was started after 10 days at 1 mm perday in four steps. Few patients had the rate changed due to soft tissue tightness, which responded to temporarily stopping distraction for a few days. All patients walked at full-weight bearing by two weeks when they had recovered from the initial wound pain and had become accustomed to the fixator. They each had intensive knee flexion extension, ankle dorsi- and plantar flexion exercises. Splinting at rest was used to keep knees in extension and ankles in plantigrade during distraction. close follow-up BMC studies of the callotasis and the original host bone were made using DEXA scans weekly during distraction and fortnightly during neutralization. Distraction was stopped if there was any increasing soft tissue tightness leading to joint motion reduction, or any progressive osteoporosis in the stress-shielded original bone segments with BMC at less than 20% of the starting level. Each patient then underwent a period of neutral fixation. The fixator was removed when the BMC of the callotasis had reached a plateau above 50～65% of the original bone, the callotasis was painfree on stress, and an X-ray showed a continuous well-formed bone column. After removal of the fixator, a well-moulded long leg dynacast was

**Table 1.** BMC Changes at Callotasis and Original Host Bone during Lengthening

| | Left(mean±sd) | Right (mean±sd) |
|---|---|---|
| Host bone BMD change during distraction (%/day) | −0.41±0.00128 | −0.36±0.0015 |
| Host bone BMD change during neutralization (%/day) | −0.01 | −0.01 |
| Callotasis BMC change during distraction (%/day) | 0.13±0.0007 | 0.12±0.0008 |
| Callotasis BMC change during neutralization (%/day) | 0.32±0.001 | 0.36±0.002 |

**Table 2.** Axial and AP Bending Rigidity Test Results of Different Wire and Pin Constructs

| Construct | Loading speed 20 mm/minute | | | | Loading speed 50 mm/minute | | | |
|---|---|---|---|---|---|---|---|---|
| | Axial Loading | | | | | | | |
| | Rod Pos. 5, 8, 10 | | Rod Pos. 3, 5, 10 | | Rod Pos. 5, 8, 10 | | Rod Pos. 3, 5, 10 | |
| | Max N | Displace | Max N | Displace | Max N | Displace | Max N | Displace |
| 2 W | 206 | 6 | 240 | 6 | 220 | 6 | 258 | 6 |
| 2 W+1 P | 414 | 6 | 428 | 6 | | | | |
| 2 W+2 P | 450 | 6 | 453 | 6 | | | 437 | 6 |
| | AP 4-Point bending rigidity | | | | | | | |
| 2 W | 16 | 1.856 | | | 18 | 1.02 | | |
| 2 W+1 P | 142 | 6 | 50 | 2.46 | 164 | 5.23 | 64 | 1.87 |
| 2 W+2 P | 246 | 6 | 114 | 3.1 | 226 | 6 | 126 | 4.45 |

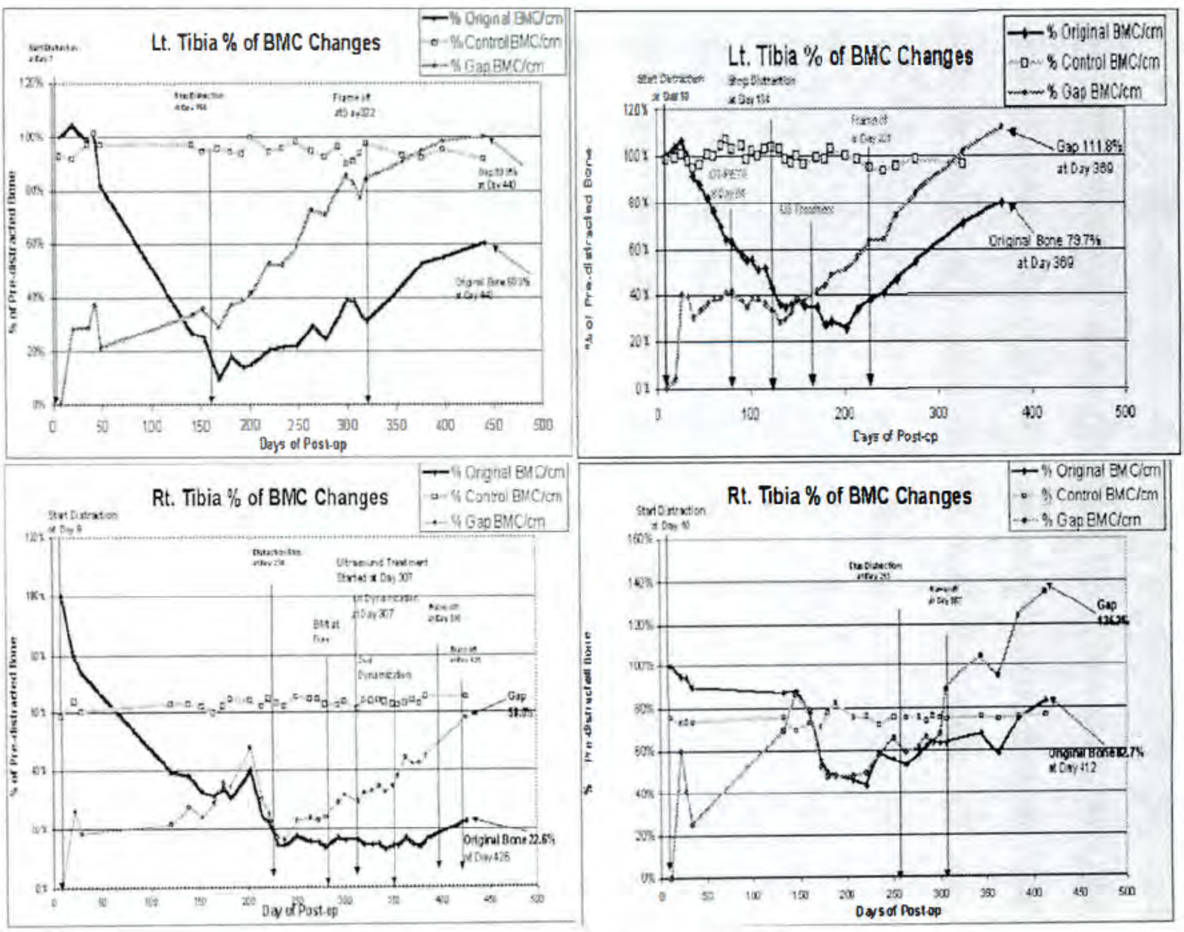


**Fig. 2.**

a|b
c|d

a : BMC changes in NCY low BMD pre-operation, 2 W 1 P construct
b : BMC changes in KYL good BMD pre-operation, 2 W 1 P construct
c : BMC changes in TWY good BMD pre-op. rigid frame 2 W 2 P construct
d : BMC changes in MHY good BMD pre-op. less rigid frame 2 W 1 P construct

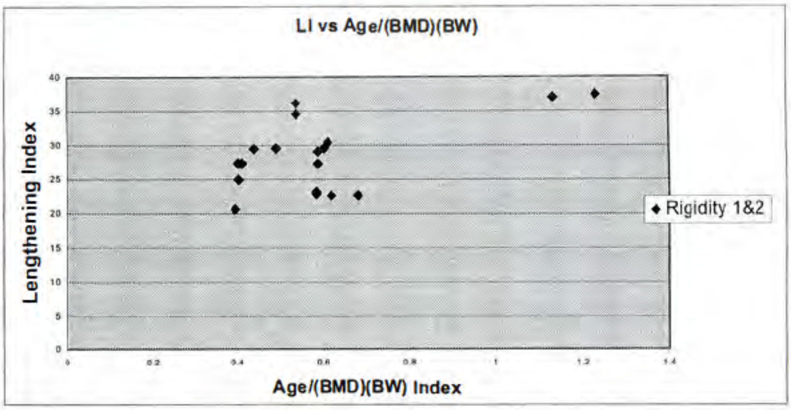


**Fig. 3.**
XY scatter plot of LI vs Age / BW/BMD Index

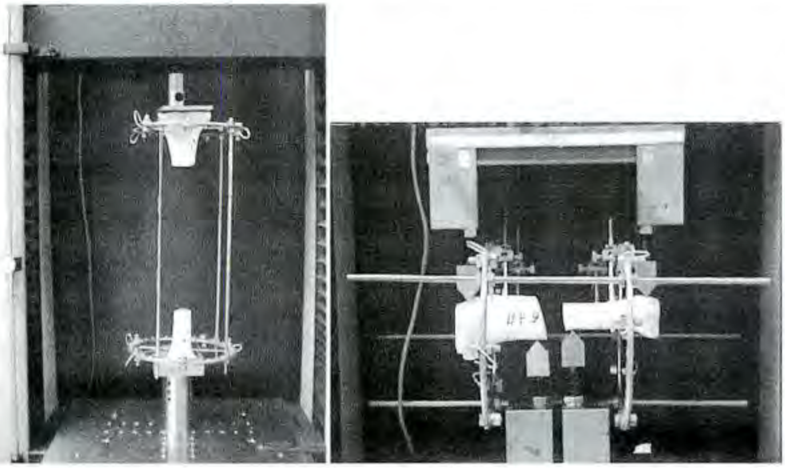

**Fig. 4.**
a : axial loading
b : 4-point bending

applied for six weeks, followed by a hinged Knee Ankle Foot Orthosis(KAFO) for approximately six weeks or a well-moulded KAFO for twelve weeks. Comparisons were made among these factors.

## Results

Bilateral tibial lengthening was performed for eight patients. In one of these 8 patients, the bilateral lengthening was performed twice. There were five girls and three boys, with an average age of 12.15(9.58~14.44) at the time of the operation. The BMD of tibia preoperatively was 0.79(0.49~0.97) $g/cm^2$ ; and the average lengthening was 9.48(5.5~11.9) cm and 9.78(5~11.8) cm ; the Lengthening Index were 28.84 and 28.05 days/cm for the right and left tibia respectively.

The BMC changes of the original host bone and the callotasis during distraction are shown in Table 1.

## Complications

Problems of pin tract infection occurred in all patients, which responded in each case to a short course of appropriate antibiotics and an increased frequency of pin tract cleansing. Obstacles, as defined by Paley[4], included one half pin required removal due to recurrent infection. Two patients required revision of the fixation, each at the proximal tibial segment. One patient had corticotomy cracked proximally towards one of the fixation wires. This was revised on the third day after a check by X-ray. There was delay in distraction due to the presence of pain in one patient. She had developed two episodes of premature fibular fusion requiring repeat callus osteotomy. She also required percutaneous Achilles' tendon lengthening, and manipulation of the knee under general anaesthesia. Another patient required placement of an additional half pin to control procurvatum deformity during lengthening. Two patients had ultrasonic therapy, and three patients had bone marrow injections to the callotasis site during the neutral fixation period when there appeared to be no progress in mineralisation. There was no incidence of fracture, and no vascular or neurological complication. All patients were satisfied with the achieved degree of lengthening.

## Discussion

Callotasis is a very complex process affected by a large number of factors from host factors to great variations in three-dimensional stability and stiffness from a different combination of fixation strategies. The variations in all these factors make studying the changes very difficult. The principles of distraction neo-osteogenesis is well accepted[7]. Ilizarov has stressed the importance of stability with the use of tensioned wires[1][2][7]. The use of tension wires has been associated with discomfort. Monolateral fixators are more rigid and comfortable, and the loading characteristics are different. It is much stiffer and of a cantilever nature. The ring fixator with tensioned wires has an isotropic property[8]-an elastic phase of axial stiffness before it finally behaves as a cantilever with linear response. The ideal rigidity for neo-osteogenesis is not entirely clear in terms of the frame construct for modern Hybrid Advance fixators. How stiff does it need to be for axial, antero-posterior and lateral bending? Dynamisation has remained the most important factor influencing the rate of mineralisation. A study of the fixator stiffness in axial and bending loading is therefore required to compare the differences.

An artificial tibial bone model was fixed with two different fixations using two rings with 1.8 mm wires tensioned to 110 kgF, and the wires were placed as they would be in a clinical situation. One of the proximal wires had an olive stopper. The normal anatomical corridor allowed for a convergence angle of 65 and 55 degrees for proximal and distal fixation rings respectively. Orthofix 6/5 mm screws were placed through Rancho cubes to simulate the clinical setting. Two wires only, two wires and one pin, and two wires and two pins combinations were tested using the Hounsfield MTS. The stress and displacement curves were obtained for speeds of 20 mm and 50 mm per minute at maximum displacement of 6 mm(Fig. 4).The results are summarized in Table 2.

From this preliminary testing, it showed a half pin greatly increased the axial stiffness by 2 times, as well as the AP bending stiffness[3]. The maximum axial stress sustained by 2 cross wires alone construct ranged from 206 to 258 Newtons while that of the 2 cross wires and 1 half pin construct ranged from 414 to 428 Newtons. The axial rigidity of 2 wires and 1 pin construct increased to 2 times. The bending rigidity increased even more between these two different constructs. The maximal stress was from 16 to 18 Newtons compared to 142 Newtons for 2 wires and 1 half pin, and 246 Newtons for 2 wires and 2 half pins. The addition of each pin increased the bending rigidity to almost 8 times the wire alone construct.

The tensioned wires showed good axial stiffness but almost no bending stiffness at all. Using two half pins did not increase axial stiffness but did increase the AP bending stiffness. Changing the rod position affected the AP 4-point bending stiffness.

Each influential factor can be analysed individually with others controlled. The effect of preoperative BMD on the BMC changes in stress-shielded host bone and callotasis of two male patients of similar age, body weight and frame construct can be compared. Patient A had a preoperative tibia BMD of 0.51 g/cm², and body weight of 20 kg. He underwent treatment with a frame of 2 wires and 1 pin per segment fixation. He showed a rapid drop in the stress-shielded host bone(−0.6%/day during distraction, −0.16%/day during neutralisation). Lengthening was stopped as the BMC dropped below 20% of the original bone. The healing during neutralization also took longer. He had a long Lengthening Index of 37.1 days/cm(Fig. 2-a). Patient B had a preoperative tibia BMD of 0.59 g/cm², and body weight of 21.2 kg. The frame construct was the same 2 wires and 1 pin per segment fixation. The drop in the stress-shielded host bone was less severe at −0.58%/day during distraction, and at −0.03%/day during neutralization. It did not drop below 20%. He had a Lengthening Index of 22.65 days/cm(Fig. 2-b).

With the body weight, BMD, and age all controlled, the effect of the fixator rigidity could be determined in a further two patients with different frame constructs. A third patient-Patient C-had 2 wires and 2 pins per segment fixation construct, and a fourth patient-Patient D-had 2 wires and 1 pin per segment construct.

Patient C showed a rapid drop in stress-shielded original bone at −0.31%/day during distraction and at −0.01%/day during neutralization. Her Lengthening Index was 36.11 days/cm(Fig. 2-c). Patient 4 showed a slower drop in stress-shielded original bone at −0.22%/day during distraction and at −0.25%/day during neutralization. Her Lengthening Index was 29.52 days/cm(Fig. 2-d). The Lengthening Index is a measure of the rate of healing. We have postulated that the Lengthening Index was proportional to age, and inversely proportional to body weight, and preoperative BMD of the tibia(BMDob), with the rigidity controlled. The age, body weight and BMDob can be expressed as an index for analysis, together with the Lengthening Index. This simplified relationship can be expressed as LI=c(Age)/[(BMDob)(BW)] where c is a constant of proportion, BMDob is the BMD of the original bone, BW is the body weight. The Age/(Body Weight and BMD) Index was a simple postulate of a mathematical relationship between the Lengthening Index and the three potential influential factors. The correlation coefficient was derived from this simple postulation. It may be that the linear relationship was related better with other mathematical modifications such as through using the log of age, BW, and BMD. For this very small sample, we just assessed if there was possibly any relation between these factors. The time when to remove the frame was the same for all the patients in this series. The XY scatter plot of the Lengthening Index and the Age/[(Body Weight)(BMD ob)] Index of all 18 limb lengthenings has been plotted and showed that the L. I. had a correlation with age, body weight, and the BMD index(Fig. 3). The correlation coefficient for all limbs and rigidity categories 1 and 2, rigidity category 1, and rigidity category 2 were 0.57, 0.72, and 0.44, respectively.

The increased stiffness appeared to be related to the clinical reduction in rate of mineralisation of the callotasis and increase in the osteoporosis of the stress-shielded bone. Two wires and 1 pin per segment fixation seemed to be the best combination in terms of elasticity. Two wires and two pins per segment fixation at maximal intersection angles was best for stability of fixation but may have been too rigid. Early dynamisation is therefore advisable to maximize the rate of mineralisation particularly during neutral fixation when mineralisation has reached a plateau. DEXA scans can allow monitoring of this quantitative change and determine the timing of dynamisation and timely frame removal.

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