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The diameter of callus in leg lengthening

28 tibial lengthenings in 14 patients with achondroplasia

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We investigated the relation between callus diameter during bone distraction and the occurrence of late fracture and deformity. We retrospectively reviewed 28 tibial lengthenings in 14 patients with achondroplasia. The minimal diameter of the lengthened zone was measured on radiographs, when the sliding mechanism of the lengthening device was released, and the callus diameter ratio in two planes (CDR; diameter of the callus/diameter of the tibia at the level of the osteotomy end) was calculated. The CDR correlated negatively with the distracted length. Late fracture or late angular deformity occurred in 6 of the 28 lengthenings. When the CDR was 85% or more in both planes, these complications did not occur, but when the CDR was 80% or less in either plane, they occurred in 6 of 20 bones. Careful attention should therefore be given not only to the continuity of the callus but also to its diameter.

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Although distraction osteogenesis using callotasis (De Bastiani et al. 1987, Ilizarov 1990) has improved the treatment of limb lengthening, late fracture still occurs (Franke et al. 1990, Paley 1990, Vade and Eissenstat 1990, Guidera et al. 1991).

The longer the bone the greater is the magnitude of the bending moment when force is applied, and the greater is the diameter required for a distracted bone to have the same strength as that before lengthening, if the bone quality is unchanged. Torsional strength is of even greater importance, as it is proportional to the 4th power of the diameter. Therefore, the diameter is one of the most important measurements for evaluating the callus. No previous reports, however, have referred to the diameter, except that by Fischgrund et al. (1994), which stated that late fracture occurred in 2 of 4 cases when the callus had an hourglass shape.

We investigated the influence of callus diameter during distraction on the late fracture and angular deformity rate.

Patients and methods

We retrospectively reviewed 28 tibial lengthenings in 14 patients with achondroplasia, who were treated between 1987 and 1993 at the University of Tokyo Hospital: 6 men and 8 women, aged 16 (8–26) years (Table 1).

The callotasis method was used for lengthening. Simultaneous operations were performed on both legs of each patient. The pins for fixation were inserted from anteromedial to posterolateral of the tibia. An osteotomy was performed, mean 75 (55–107) mm below the knee joint. One of two types of fixator was applied: a unilateral lengthener, the Dynamic Axial Fixator (Orthofix, Italy) (14 legs) or the Hifixator (a unilateral fixator with a clamp connected to a rod by linear ball bearings to achieve a low-friction sliding mechanism (Matsumoto Co., Japan) (14 legs). After an initial delay of 14 (7–15) days, gradual distraction was begun. The distraction rate was adjusted to avoid impairing the continuity of the callus on the radiographs. During and after the distraction, weight bearing was encouraged so much as possible, with two crutches. The criteria for fixator removal were completion of the corticalization of 3 of the 4 sides: medial and lateral cortices on the frontal radiograph, anterior and posterior ones on the lateral.

The minimum diameter of the callus and the diameter of the tibia at the proximal end of the osteotomy were measured with a ruler on frontal and lateral radiographs, taken when the sliding mechanism of the lengthening device was released, mean 88 (42–336) days, following completion of the distraction procedure (Figure 1). The callus diameter ratio (CDR) was calculated as the minimal callus diameter, divided by the tibia diameter.

Table 1. Summary of patient characteristics

Case	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	1	26	1	4.5	27	90	90	0.54	121	95	100	5	10	
			2	4.5	27	90	90	0.54	180	90	80	0	0	
2	1	10	1	8.5	59	80	70	0.44	42	80	80	0	0	1
			2	8.5	59	80	95	0.44	39	80	100	0	4	
3	2	21	1	9.0	55	80	90	0.46	59	75	85	9	9	
			2	9.0	56	75	85	0.46	63	80	85	10	10	
4	2	19	1	10.0	54	75	80	0.65	40	80	85	4	10	
			2	10.0	57	95	85	0.65	44	85	80	5	9	
5	2	12	1	10.0	63	95	90	0.89	29	85	85	7	12	
			2	10.5	66	100	100	0.94	36	95	100	5	12	
6	1	21	1	11.0	58	85	95	0.37	46	85	95	6	10	
			2	11.5	62	75	90	0.39	44	70	90	8	8	
7	2	13	1	12.0	75	80	100	0.71	28	75	95	5	11	
			2	12.5	78	85	100	0.74	36	80	95	6	10	
8	2	16	1	12.5	74	80	90	0.60	35	80	95	5	4	
			2	12.0	71	85	100	0.57	36	85	95	0	0	
9	1	8	1	12.5	89	60	70	0.66	43	55	70	2	16	
			2	12.5	89	55	65	0.66	45	55	65	3	10	
10	2	23	1	15.5	97	75	70	0.39	43	75	70	2	8	
			2	15.0	94	70	75	0.38	40	70	75	1	6	2
11	2	17	1	15.0	97	75	80	0.61	36	75	80	2	7	
			2	16.5	107	55	65	0.67	37	60	75	2	15	1
12	1	12	1	16.0	84	70	90	0.77	34	60	90	10	0	
			2	16.0	87	55	75	0.77	30	55	75	10	16	
13	1	16	1	16.0	100	60	75	0.71	36	65	70	6	2	2
			2	16.0	97	70	70	0.71	35	70	75	3	7	
14	2	10	1	17.5	109	55	80	0.87	35	45	65	7	12	1
			2	17.5	109	80	80	0.87	33	55	55	9	6	1

A Sex
 1 male
 2 female
B Age (years)
C Side
 1 right
 2 left
D Lengthening achieved (cm)
E Lengthening (%)
F CDR on frontal radiograph at release of sliding mechanism (%)
G CDR on lateral radiograph at release (%)
H Mean distraction speed (mm/day)
I Healing index (days/cm)
J CDR on frontal radiograph at fixator removal(%)
K CDR on lateral radiograph at removal(%)
L Valgus deformity at time of fixator removal (°)
M Procurvatum deformity at removal (°)
N Deformity after device removal
 1 Angular deformity
 2 Late fracture

Each measurement was done independently by three observers and we recorded the mean of three CDRs in each case. Inter-observer differences were calculated, using the repeatability (95% confidence interval) among three series of data from different observers (4.8% on frontal, 5.8% on lateral) (Bland and Altman 1996).

To study the change of diameter in the period between release of the sliding mechanism and fixator removal, we compared CDR at fixator removal with CDR at release. CDR at removal should be calculated strictly by the minimal diameter of the callus at removal, divided by the tibia diameter at removal. Because the latter was hard to measure due to the bone remodeling, an alternative CDR was calculated by dividing by the value of the tibia diameter at release instead.

The relationship between CDRs in both planes was examined and between CDR and age, mean distraction rate, distracted length and healing index. Spearman's rank correlation was used for statistical analysis with $p<0.05$ set as significant. "Late fracture" and "late angular deformity" were defined as fracture that occurred and bowing deformity over 5° that progressed gradually for 3 months after fixator removal, respectively. The CDR was compared between the fracture group which was complicated by either of these and the no fracture group (Table 1). Mann-Whitney's U-test was employed with $p < 0.05$ set as significant.

Results

The average distraction rate (distracted length/days) was mean 0.65 (0.37–0.94) mm/day. Angular deformity existing at the time of fixator removal was 5 (0–10)° of valgus and 9 (0–16)° of procurvatum. The distracted length was mean 12 (4.5–17.5) cm, 75 (27–109)% of the original bone length. The healing index

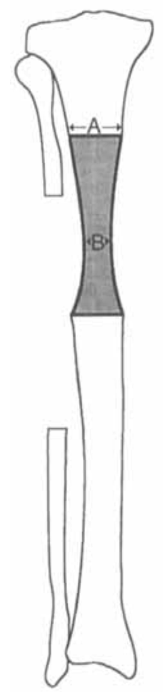

Figure 1. Callus diameter ratio (CDR) was calculated as B/A ×100. A is the diameter of the proximal osteotomy end and B is the minimal diameter of the callus.

was mean 38 (28–180) days in fixator/cm. Late fracture occurred in the left leg of patient 10 and the right of patient 13. Fractures were short oblique and transverse, and occurred at the level of the middle third of the regenerated bone 11 and 0 days after fixator removal, respectively. Late angular deformity developed gradually in 4 lengthenings in 3 cases. Degrees of bowing advancing after removal were 12° procurvatum in the right leg of patient 2, 10° procurvatum in patient 11 left, 9° valgus and 24° procurvatum in the right leg and 12° valgus and 17° procurvatum in the left leg of patient 14 (Table 1).

The CDR at removal of the sliding mechanism was 78 (55–100)% on the frontal radiograph and 85 (65–100)% on the lateral and the two CDRs were correlated ($r = 0.72$, $p < 0.001$). The change in CDR between release and removal was 0 (–25 to 5)% on the frontal radiograph and 0 (–25 to 10)% on the lateral (Table 1).

The CDR was not significantly correlated with patient age, mean distraction rate or healing index, but it was negatively correlated with the length of distraction: the greater the distracted length, the smaller was the callus diameter (frontal radiograph: $r = -0.67$,

Figure 2. Frontal and lateral radiographs at the time of release of the sliding mechanism of the lengthening device (left leg of patient 3). Note large callus diameter in relatively short distracted length.

Figure 3. Frontal and lateral radiographs at the time of release of the sliding mechanism of the lengthening device (left leg of patient 11). Note small callus diameter in relatively great distracted length (A, B), and angular deformity at 17 weeks after fixator removal (C, D).

Table 2. Comparison of CDRs (%) between fracture and no fracture groups, median (range)

Radiograph	No fracture group (n 22)	Fracture group (n 6)	P-value
Frontal	80 (55–100)	65 (55–80)	0.058
Lateral	90 (65–100)	75 (65–80)	0.017

$p < 0.001$; lateral radiograph: $r = -0.44$, $p = 0.02$; Figures 2 and 3).

CDRs in the no fracture group and fracture group were 80 (55–100)% and 65 (55–80)% on the frontal radiograph, and 90 (65–100)% and 75 (65–80)% on the lateral radiograph, respectively. The difference was not significant on the frontal ($p = 0.06$), but was on the lateral ($p = 0.02$) (Table 2).

Late fracture or angular deformity did not occur in the 8 legs, where the CDR was 85% or more on both frontal and lateral radiographs, but did occur in 6 of 20 lengthenings, where CDR was 80% or less in either plane. Of the 10 bones with distracted length over 15 cm, these complications occurred in 5 (Table 1).

Discussion

In this series, the healing index of 38 days/cm is rather high. These were our early cases and osteotomy levels were rather low. In addition, lengthening gains were rather large and callus diameters were small, and so we removed the fixators, after confirming there was sufficient corticalization of the regenerated bone. This is apparently the reason for the high value of the healing index.

We found that the diameter of callus at the distraction gap was smaller than that of the original bone. The callus diameter was negatively correlated with the distracted length. The smaller diameter was confirmed by both frontal and lateral radiographs; the distracted bone had an hourglass-like morphology. The reason for this phenomenon is not clear. However, when a viscoelastic material is continuously stretched, it is known to take on such a morphology; the structure lengthens and narrows (Nordin and Frankel 1980). With the callotasis method, a delay before elongation and slow distraction allows some early callus to form. Although the osteogenic tissue, the callus, is distracted slowly enough to maintain the tissue continuity, it is not fully mineralized during distraction; it contains the mesenchymal tissue prior to mineral deposition, which could give the callus viscoelastic property.

Under the conditions we adopted, where the distraction rate was adjusted so that it did not impair the continuity of the callus on the radiographs, there was no relationship between callus diameter and patient age, mean distraction rate or healing index. Since distraction rate, which probably can influence the healing index and the callus diameter, is somewhat arbitrary, the relationship between such factors could be different from our findings, if different conditions were used.

Since true CDR at fixator removal could not be calculated, a comparison was made using alternative CDR. The increase in CDR in the period between release and removal was not great and in some lengthenings there was a decrease. In patient 14, the decrease was 10% in the frontal and 15% in the lateral plane in the right leg and 25% in both planes in the left leg. The reason for this amount of decrease is not clear. Since the patient did not walk much in spite of our encouragement to do so, the mechanical environment of the regenerated bone might not have been appropriate.

The CDR at release of the sliding mechanism in the fractured group was smaller than that in the no fracture group and this was especially significant on the lateral radiograph. Fracture and angular deformity did not occur when the CDR was 85% or more in both planes, but did occur at a high rate when it was 80% or less in either plane. A fracture generally involves a combination of bone strength and the force used. Bone strength is determined by bone quality and geometry. As fracture occurrence depends on these all factors, one cannot set an entirely reliable lower limit for CDR that will avoid a late fracture. This is shown by the fact that 14 of the 20 tibiae with CDR below 80% had none of these complications. It is true that the force used is an important factor, but in this series these complications occurred without any unusual force or accident. Thus, a CDR value of less than 80% may be of practical use as an alarm signal for these complications.

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