CHONDRODIATASIS – CONTROLLED SYMMETRICAL DISTRACTION OF THE EPIPHYSEAL PLATE

LIMB LENGTHENING IN CHILDREN

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We describe a technique for slow, progressive, symmetrical distraction of the growth plate using a lightweight dynamic axial fixation system. Results are given for the elongation of 40 bony segments in children with limb-length discrepancies and 60 segments in children with achondroplasia or hypochondroplasia.

Increases in limb length of up to 36% were obtained in non-achondroplastic and up to 64.5% in achondroplastic patients. There were no nerve or vascular lesions or bony infections and no case required a bone graft. Pin-track complications occurred in only 1.5%.

Limb lengthening in children by distraction of the growth plate was first described by Zazjyalov and Plaksin (1967, 1968) who used a technique they termed distractional epiphyseolysis, which invariably resulted in separation of the epiphysis from the metaphysis. Other authors have described the clinical application of this technique (Jani 1975; Hähnel 1977; Berchiche and Wittek 1983).

This method of distraction, which employs large forces or rapid rates of distraction or both, has the disadvantage that the integrity and the further functional viability of the growth plate are permanently impaired. It can therefore only be used shortly before physiological fusion of the epiphysis would occur.

We have employed an alternative technique in which lengthening is by slow, controlled and symmetrical distraction of the epiphyseal plate, without rupture or fracture, with the aim of preserving its function throughout the growth period (Sledge and Noble 1978; Noble et al. 1982; Wasserstein and Schewior 1983). De Bastiani, Aldegheri and Renzi Brivio (1979) introduced the term chondrodiatasis to describe this technique.

Initial studies in rabbits (De Bastiani et al. 1986) demonstrated that chondrodiatasis could be achieved symmetrically, and without axial deviation, using a uni-

lateral external fixation frame. Furthermore, the histological findings indicated that when distraction ceased the epiphyseal cartilage gradually returned to its initial thickness and retained its normal cellular morphology.

We have subsequently used this method to lengthen limbs in children with leg-length discrepancies or with achondroplasia. The animal studies suggested that the growth plate would retain its function after chondrodiatasis, but in the absence of definitive proof we used the technique clinically almost always during the last two years of the growth period.

Fig. 1

The Orthofix dynamic axial fixator.

MATERIAL AND METHODS

We have applied chondrodiatasis to 100 leg segments, 50 femora and 50 tibiae, in 58 patients. Of these, 40 lengthenings (20 femora and 20 tibiae) were in 33 patients with leg-length discrepancies of various aetiologies, and 60 lengthenings (30 femora and 30 tibiae) were in 25 achondroplastic patients. In seven patients with leg inequality

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0301 620X/86/4112 \$2.00

Fig. 2

Fig. 3

Fig. 4

Operation for chondrodiatasis of the right femur. Figure 2 – Locator template attached to the first (anterior) epiphyseal screw. Figure 3 – Body template with clamp for defining the position of the diaphyseal screws. Figure 4 – Fixator in place with the distractor unit attached to it.

and in all the achondroplastic or hypochondroplastic patients we undertook simultaneous lengthening of the femur and the tibia on the same side.

The average age of the children with length discrepancy was 12.2 years (range 6 to 16 years) six segments were in patients under 10 years of age, four in patients aged between 10 and 12, and 30 were in patients aged over 12 years. The average age of the achondroplastic patients was 13 years (range 10 to 16 years).

The cause of the discrepancy in the leg length was congenital in 32 patients; these included two with agenesis of the fibula, one with fibrous dysplasia, one with club foot and one with Silver–Russell syndrome. The other eight patients included five with hemi-hypertrophy due to arteriovenous aneurysm or angiomas, one case secondary to growth-plate injury, one after resection of an adamantinoma and one of poliomyelitis.

The Orthofix dynamic axial fixator (Fig. 1) was used because it offers the following special features and advantages (De Bastiani, Aldeghegi and Renzi Brivio 1984).

1. It is a unilateral unit and it causes less trauma to the soft tissues than a bilateral device.
2. Its two articulated ball joints provide versatility, enabling the body of the fixator to be aligned with the shaft of the bone to avoid any axial deviation of the growth plate during lengthening.
3. Its telescopic facility permits the application of distraction or compression. This allows dynamic compression along the major axis of the bone after the end of the period of distraction, which stimulates corticalisation of the lengthened section of bone.
4. The grip of the screws on the bone is optimised by the shape of their thread.

Mechanical trials of this apparatus by Chao and Kasman (1984) have shown its excellent stability under load, which is better than that of some bilateral fixators.

In all cases the device was applied using, first, two epiphyseal screws of cancellous type designed to hold well in spongy bone. These were inserted under image intensification to ensure their correct position in the central part of the epiphysis, parallel to the line of the growth plate. Once the first screw had been introduced

into a predrilled track using screw and drill guides, a locator template was attached in order to define the position for the second screw (Fig. 2). Great care was taken to avoid damage to either the articular cartilage or the growth plate, and to ensure that screw thread was present throughout the width of the epiphysis, with 2 or 3 mm projecting beyond the medial and lateral cortices.

A further body template (Fig. 3), allowed two diaphyseal screws of cortical type to be introduced exactly perpendicular to the shaft of the bone with only a few millimetres of thread projecting beyond the second cortex. The template was then replaced by the fixator which was firmly positioned, taking care that its body was exactly parallel to the axis of the diaphysis (Fig. 4). Selection of a long or standard-bodied model was made according to the length of the bone and the ultimate amount of distraction required. The distractor unit was

Fig. 5

Radiograph to confirm the position of the screws and the parallel alignment of fixator and bone.

then fitted to the fixator. For the femur the fixator was always on the lateral side, and the anterior epiphyseal screw was placed first. Correct positioning of the screws and parallelism of the fixator was always confirmed by radiographs (Fig. 5).

The tibia was always lengthened at the distal epiphyseal cartilage, since functional problems are less frequent at the ankle than at the knee. The screws were introduced into the medial side of the tibia to avoid damage to the peroneal nerve and vessels (Fig. 6). The posterior epiphyseal screw was placed first, and always penetrated through into the fibula to ensure that its lower end descended with the tibial epiphysis. About 2 cm of the distal third of the fibular shaft was resected with a power saw to prevent early fusion, and an antero-posterior radiograph confirmed the correct position of all components.

Fig. 6

Fixator in place for chondrodiastasis of the left tibia.

Partial weight-bearing was permitted from the first day after operation and slow distraction was obtained by turning a screw on the distractor unit by one quarter turn ($90^\circ = 0.25 \text{ mm}$) every 12 hours, which gave lengthening of 0.5 mm each day. The patient was usually discharged from hospital on the fourth day, and distraction was then continued by the patient, or his parent or guardian. The "distraction period" extended from the time of operation until the desired increase in length had been achieved. The locking screw on the body of the fixator was then tightened and the distractor unit removed. There was then a "neutralisation period"; during this time full weight-bearing with the aid of crutches was encouraged until radiographs showed regular opacity of the cortices in the distracted segment. The locking screw was then loosened, allowing dynamic compression to take place by virtue of the telescopic facility of the fixator. This compression phase started as soon as possible, and in cases with increases in length of up to 15% this was generally within one month of the end of the distraction period. Once radiological and clinical consolidation was complete, the removal of the fixator was a simple outpatient procedure. The total period of time between loosening of the locking screw and the removal of the fixator was termed the "dynamic load period".

We recorded the amount of lengthening, the duration of the "distraction", "neutralisation" and "dynamic load" periods, and the overall treatment time. Treatment was considered to be completed when there was enough biological and mechanical consolidation to allow complete, free weight-bearing on the treated limb. We also expressed the results in terms of an average healing index (Aldegheri) which was obtained by dividing the overall treatment time in days by the total lengthening in centimetres. This provides a means of comparing the healing times associated with different techniques.

Complications were recorded as permanent when they compromised the final result and temporary when they did not.

RESULTS

The results have been assessed separately for the 40 segments treated for discrepancies in limb length and the 60 segments treated in achondroplastic patients.

Limb-length discrepancy. In 27 of the 40 segments the length discrepancy was eliminated; in 11 it was deliberately over-corrected, either on the basis of the final calculated length of the opposite limb in progressive lesions (Moseley 1978) or to compensate for uncorrected shortening of 1 cm in the other segment of the same limb in non-progressive lesions. In only two segments was the desired lengthening not achieved, because of complications during distraction.

Table I gives the lengthening obtained together with the duration of the various phases of treatment and Figures 7 to 11 show examples of the radiographic appearances in this group.

In children over the age of 12 years, eight segments have been assessed at the end of the growth period, 24 to 36 months after fixator removal. All had equal leg length (Figs 12 and 13). The other 22 segments in this age group showed satisfactory continuation of growth 6 to 23 months after fixator removal. The four segments lengthened in children aged 10 to 12 years have been followed for only 6 to 11 months and have not yet been studied in detail.

Table I. Results in 40 segments of 33 patients with limb-length discrepancy

	Mean	Range
Lengthening (cm)	3.3	1.5 to 7.0
Increase in length (per cent)	10	4.5 to 36
Distraction period (days)	68	30 to 160
Neutralisation period (days)	22	20 to 40
Dynamic load period (days)	21	10 to 30
Overall treatment time (days)	111	70 to 120
Healing index* (days per cm lengthening)	34	

* See text

Fig. 7

Fig. 8

Fig. 9

Radiographs of a 10-year-old girl who had congenital shortening of the left femur. This was lengthened by 3 cm (12%). Figure 7 – Lower end of left femur to show the elongated segment at the end of the distraction period. Figures 8 and 9 – Both knees three years after removal of the fixator showing preservation of the joint and remodelling of the metaphysis; the legs were now of equal length.

Examples of leg lengthening

Fig. 10

Fig. 11

Radiological appearances in chondrodiatasis of the tibia of a boy aged 13 who had 4 cm (11%) lengthening of the bone. Figure 10 – One week after application of the fixator. Figure 11 – Soon after removal of the fixator, 120 days after its application.

Fig. 12

Fig. 13

The clinical appearance of a 12-year-old hypochondroplastic patient after 18 cm lengthening of his right leg, and subsequent lengthening of his left leg.

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Long-term follow-up after leg lengthening. A boy operated upon at 9 years of age for shortening of the left femur of 4 cm (14%) and left tibia of 2 cm (9%), secondary to arthrogryposis. Figure 14 - Before treatment. Figure 15 - On the day of removal of the femoral fixator, 140 days after operation. The tibial fixator had been removed 80 days after operation. Length inequality was completely corrected. Figures 16 and 17 - One year after removal of femoral fixator, the left leg had continued to grow, but to a lesser extent than the normal side. The left femur had grown by 1 cm (right 2 cm); the left tibia had grown by 1 cm (right 1 cm). The lengthened segments of femur and tibia are shown. The presence of the epiphyseal lines suggests functional growth cartilage.

In all six segments in patients having their operation at under 10 years of age, radiographic assessment at 12 to 23 months after fixator removal has shown that the lengthened segment had continued to grow, but at a rate less than that of the contralateral limb (Figs 14 to 17).

Complications. Of the five complications in this group, only two were permanent; in one case, only the anterior part of the growth plate lengthened because of post-traumatic fusion of its posterior part. Chondrodiatasis was not appropriate for this case, but once consolidation had taken place, a re-alignment osteotomy was performed. In the second case, a patient with agenesis of the fibula, posterior subluxation of the tibia on the femur occurred during simultaneous chondrodiatasis of femur and tibia when femoral length had been increased by 15% and tibial length by 23%. The subluxation was reduced by shortening the femur by 2 cm at the same rate as the lengthening (0.25 mm every 12 hours) by turning the screw on the distractor unit in the opposite direction.

Three cases suffered temporary complications. In one, only the lateral part of the growth plate responded to distraction. This was attributed to bending of the epiphyseal screws because of an excess length of screw thread outside the cortex nearest to the fixator (Fig. 18). The epiphyseal screws were replaced, and symmetrical distraction resumed. In two cases repeated fibular osteotomy was needed for premature union of the bone.

There were no nerve or vascular lesions, no articular damage, and no bone grafts were needed. No cases were complicated by either bone or pin-track infection.

Achondroplastic patients. Of the 25 patients in this group,

five have so far had lengthening of both legs while the remaining 20 have completed chondrodiatasis of both segments of one of their legs, and some are already undergoing lengthening of the second leg. Because of the extensive lengthening planned for this group, in all cases the fixator frames had the ball-joints encircled with a small amount of methylmethacrylate before distraction in order to help prevent any possible axial deviation during lengthening.

Table II illustrates the degree of lengthening

Fig. 18

Lower end of the femur of a girl aged 11 years after two weeks of distraction. Only the lateral part of the growth plate has opened because there was an excess of screw thread between fixator and cortex, which allowed bending. The screws were replaced and distraction started again.

obtained and the duration of the phases of treatment in achondroplastic patients, while Figures 19 and 20 show an example of the clinical results achieved. Follow-up after removal of the fixator in patients with achondroplasia was 6 to 11 months for 30 segments, 12 to 23 months for 20 and between 24 and 36 months for 10 segments.

All these children were operated on towards the end of the growth period; studies of growth-plate activity in achondroplastic patients is less relevant because of the nature of the disease.

Complications. Of a total of 18 complications in this group, three were due to the instability of a fixator and were corrected by adjustment of the ball joints to re-establish correct alignment. Complications associated with the screws were seen five times in three segments (2.1%). Two cases of local osteolysis were controlled by commencing dynamic loading, and one case of osteitis in a tibial diaphysis cleared after screw replacement. In the other two cases the anterior epiphyseal screw in the tibia migrated and required replacing.

There were four cases of premature fusion of the fibula, each requiring resection of a larger portion of the bone. In six cases fracture with angulation followed fixator removal; five tibiae were successfully treated in plaster and one femur, also treated in plaster, healed with angulation and required a corrective osteotomy.

Four of these 18 complications had permanent

Table II. Results in 60 segments of 25 achondroplastic patients

	Mean	Range
Lengthening (cm)	7.1	3 to 10.5
Increase in length (per cent)	32.5	13 to 64.5
Distraction period (days)	170	62 to 240
Neutralisation period (days)	57	16 to 131
Dynamic load period (days)	56	20 to 150
Overall treatment time (days)	290	105 to 519
Healing index* (days per cm lengthening)	42	

* See text

effects: three had residual tibiotalar valgus deformity of over 10° as a result of premature fibular union and one was the case of femoral angulation.

There were no nerve or vascular lesions and no case required a bone graft. There was no bony infection.

DISCUSSION

Our clinical experience with chondrodiatasis followed studies in rabbits (De Bastiani et al, 1986) which confirmed that a rigid unilateral external fixation device permitted symmetrical distraction of the growth plate within the epiphyseo-diaphyseal axis.

In 100 lengthenings by chondrodiatasis, between 1.5 cm and 10.5 cm was gained with maximum increases over initial bone length of 36% in cases with leg inequality and 64.5% for achondroplastics. In all cases regeneration was spontaneous and uniform, producing radiographs which showed relatively dense bony radiopacity.

The distraction period occupied about 60% of the total treatment time, the neutralisation period about 20% and the dynamic load period about 20%. The slow rate of distraction, twice 0.25 mm per day, means that the period of distraction is longer than that needed for epiphyseolysis, though the subsequent period of corticalisation is shorter.

Of possible complications, subluxation at the knee and retraction of the calcaneal tendon are common to all lengthening procedures. The low incidence of these problems in the present series is, in our opinion, ample justification for the use of slow distraction. Premature union of the fibula could be ascribed to inadequate resection. The cases of axial deviation after removal of the fixator were always related to minimal direct trauma. Of 100 applications of the dynamic axial fixator involving 400 screws, osteolysis was seen around only four screws (1%) and osteitis around two (0.5%).

There is evidence that the lengthened segment continues to grow in children with limb-length discrepancies

Fig. 19

Fig. 20

An achondroplastic patient aged 13 years 2 months at the beginning of treatment. Clinical appearance before and after 16.5 cm lengthening of both legs.

operated upon under the age of 10 years but, as might be expected, at a slower rate than the unaffected limb. The radiographic evidence that the growth plate persists encourages the belief that its activity also continues; the reduced growth rate of the operated segment may be within that expected for the abnormal cartilage, and the pre-existing growth rate may, in the last resort, be the only valid means of assessing growth after lengthening. In the patients with leg inequality who were operated upon close to the end of the growth period, and in the achondroplastic patients, the effect of chondrodiastasis on subsequent growth is of no material significance.

We conclude that chondrodiastasis is currently the least traumatic method available for limb lengthening in children. Slow and regular distraction may stimulate metaphyseal ossification without causing the fissures

between epiphysis and metaphysis or the separation of the growth plate which are seen during distractional epiphyseolysis. It is essential for this technique, however, that the fixation device used should be capable of controlling the entire procedure from its inception to the resumption of full function.

The dynamic axial fixator is simple in construction and is easy to apply by a closed procedure which causes minimal tissue trauma. This is important in children where a painless technique is highly desirable. Only one operation and no bone grafts are needed. Complications are minimal and the risk of bony infection is negligible. The treatment period is acceptable and, perhaps most important of all, the child is able to walk, attend school and enjoy many normal activities while the fixator is in place.

REFERENCES

- Berchiche R, Wittek F.** Allongement du squelette jambier par épiphysiolyse-distraction: traitement des inégalités des membres inférieurs. *Acta Orthop Belg* 1983;49:321-31.
- De Bastiani G, Aldegheri R, Renzi Brivio L.** Indicazioni particolari dei fissatori esterni. *G Ital Fissatore Esterno*, 1979;501-31.
- De Bastiani G, Aldegheri R, Renzi Brivio L.** The treatment of fractures with a dynamic axial fixator. *J Bone Joint Surg [Br]* 1984;66 B: 538-45.
- De Bastiani G, Aldegheri R, Renzi Brivio L, Trivella G.** Limb lengthening by distraction of the epiphyseal plate: a comparison of two techniques in the rabbit. *J Bone Joint Surg [Br]* 1986;68 B: 545-9.
- Chao EYS, Kasman RA.** The mechanical performance of the Orthofix axial external fixator. Symposium on Recent Advances in Traumatology held at Venice, April 1984.
- Hähnel H.** Die Distractionsepiphysiolyse erste Erfahrungen bei der operativen Beinverlängerung nach Ilizarow. *Beitr Orthop Traumatol* 1977;24:594-603.
- Jani L.** Die Distractionsepiphysiolyse: Tier Experimentelle Studie zum Problem der Beinverlängerung. *Z Orthop* 1975;113:189-98 [Eng. Abstr.].
- Moseley CF.** A straight line graph for leg length discrepancies. *Clin Orthop* 1978;136:33-40.
- Noble J, Diamond R, Stirrat CR, Sledge CB.** Breaking force of the rabbit growth plate and its application to epiphyseal distraction. *Acta Orthop Scand* 1982;53:13-6.
- Sledge CB, Noble J.** Experimental limb lengthening by epiphyseal distraction. *Clin Orthop* 1978;136:111-9.
- Wasserstein I, Schewior Th.** L'allongement des membres inférieurs par épiphysiolyse au moyen d'un fixateur externe. *Méd et Hyg* 1983; 41:1629-34.
- Zazjyalov PV, Plaksin IT.** Elongation of crural bones in children using a method of distraction epiphysiolyse. *Vestn Khir Grekov* 1967; 103:67-70.
- Zazjyalov PV, Plaksin IT.** Distraction epiphysiolyse for lengthening of the lower limbs in children. *Khirurgiia (Mosk)* 1968;7:121-3.