LIMB LENGTHENING BY DISTRACTION OF THE EPIPHYSEAL PLATE

A COMPARISON OF TWO TECHNIQUES IN THE RABBIT

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We have compared, in rabbits, two techniques of limb lengthening by distraction of the epiphyseal plate using a unilateral external fixation frame. In all cases, 14 mm of symmetrical lengthening without deviation was achieved.

With rapid distraction at rates of 1 mm per day (distractional epiphyseolysis) separation of the epiphysis from the metaphysis occurred by day 7, and by day 70 almost complete ossification of the cartilage and the elongated segment was evident.

In contrast, slow distraction at 0.25 mm every 12 hours (chondrodiatasis) produced hyperplasia of growth cartilage without any evidence of detachment at 28 days, the end of the distraction period. By day 70 the epiphyseal plate had returned to normal thickness with normal cellular morphology, while the lengthened segment was occupied by ossified tissue. The significance of these findings is discussed.

Limb lengthening, either for the correction of leg inequality or to achieve bilateral increased length in children with achondroplasia, may be achieved by distraction of the epiphyseal plate. Two different methods have been described: the first employs large forces and/or rapid rates of distraction which produce a fracture at the physis and separation of the epiphysis from the metaphysis. Lengthening is then obtained by progressive stretching of the gap produced.

In 1958 Ring demonstrated that, in dogs, separation takes place between the calcified and degenerative areas of the epiphyseal plate. Ilizarov and Soibelman (1969) repeated the experiment on sheep with a similar result. They compared the fracture to a Salter-Harris Type I traumatic epiphyseolysis (Salter and Harris 1963). Monticelli, Spinelli and Bonucci (1979, 1981a,b,c) repeated the sheep experiment with the same results and also calculated that the distractional force needed to effect a fracture in the proximal physis of the sheep tibia was 20 to 25 kg, and that separation took place within the first seven days when the rate of distraction was at

least 1 mm per day. Other authors have confirmed these results in animals (Fishbane and Riley 1978; Houghton and Duriez 1980). The first published work to describe the clinical application of this technique was by Zazjyalov and Plaksin (1967, 1968), who introduced the term distractional epiphyseolysis. In recent years other clinical results have been reported (Jani 1975; Hähnel 1977; Berchiche and Wittek 1983).

The second method of distracting the epiphyseal plate employs smaller forces and/or a slow rate of distraction with the intention of inducing an increase in the activity of the growth plate without causing either fracture or gap. Thus the functional integrity of the plate is maintained until the end of the physiological growth period (Sledge and Noble 1978; Noble et al. 1982; Wasserstein and Schewior 1983). In 1979 De Bastiani, Aldegheri and Renzi Brivio introduced the term chondrodiatasis to describe this slow, controlled and symmetrical distraction of the epiphyseal plate without fracture or rupture.

The mechanism by which lengthening is achieved and the possibility of the continued function of the growth plate after epiphyseal distraction have prompted further work. The present study was designed to compare the effect of distractional epiphyseolysis and chondrodiatasis on the growth plate of the rabbit, to determine whether elongation of the growth plate could be achieved without axial deviation using a unilateral external fixation frame, and to determine whether a lengthened growth plate retains its activity after the external fixator has been removed.

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Fig. 1

Radiograph of a prototype of the dynamic axial fixator fitted to the right femur of a rabbit for distraction of the distal epiphyseal plate.

MATERIALS AND METHODS

The study was carried out on 14 New Zealand white rabbits aged 12 weeks and weighing 2.2 kg. The growth of these rabbits is normally complete by 24 weeks. In each animal the distal growth plate of the right femur was subjected to distraction, the left femur serving as a control.

Radiographs of the hind limbs were taken, and operations were performed under alphadone/alphaxolone anaesthesia. A prototype of the dynamic axial fixator (Orthofix – De Bastiani, Aldegheri and Renzi Brivio 1984) was used. Two screws were placed in the distal femoral epiphysis, parallel to the articular plane, but avoiding injury to the growth plate. Two proximal screws were then placed in the diaphysis of the femur in a plane perpendicular to the distal screws. The screws were clamped to the external fixation device, care being taken that it was parallel to the axis of the femur (Fig. 1). Prophylactic antibiotic therapy (cephalexin i.m.) was given for one week after the operation. The animals were allocated to one of two experimental groups:

Group 1 (4 animals). Distraction was performed according to the technique of distractional epiphyseolysis by 1 mm on a single occasion each 24 hours for 14 days until a 14 mm increase in length had been achieved (16.5%). Histological studies were made on two animals after seven days of distraction, and on the other two 70 days after distraction started, that is just before the time at which physiological closure of the normal growth plate would be expected.

Group 2 (10 animals). Distraction was performed by 0.25 mm every 12 hours, until the same 14 mm increase in length had been achieved (16.5%) after 28 days. Histo-

logical studies, on two animals on each occasion were made after seven and after 14 days of distraction, and then after lengthening was complete on days 28, 50 and 70 from the start of distraction. The smaller number of animals in Group 1 was justified by the fact that the histological changes associated with distractional epiphyseolysis had already been described by other authors.

From each animal both femora were dissected out, fixed in buffered formalin at pH 7.0 for 120 hours, and subjected to electrolytic decalcification with the DECA II apparatus. From each distal metaphyseo-epiphyseal zone, longitudinal samples were taken in a coronal plane. After embedding in paraffin, 5 µm sections were prepared and stained with H&E, with PAS and with Azan-Mallory.

RESULTS

In all 14 limbs subjected to distraction, symmetrical lengthening of the epiphyseal plate without deviation of the epiphyseo-diaphyseal axis was obtained. The histological results were as follows:

Group 1: distractional epiphyseolysis. At day 7, the epiphysis had separated from the metaphysis at a level between the degenerative zone and the zone of calcification, the growth cartilage remaining as part of the epiphysis. Haemorrhage was seen at the level of detachment (Fig. 2), while the appearance of the contralateral femur was normal (Fig. 3). At day 70 the cartilage appeared to be completely ossified though small isolated nests of cartilaginous cells remained (Fig. 4). In the control limbs the growth plate was of normal structure and thickness (Fig. 5).

Group 2: chondrodiastasis. After 7 and 14 days of distraction, an increase in the height of the growth plate was observed, but the line of the growth cartilage was regular (Fig. 6). The bridging cartilage appeared to be slightly hyperplastic with modest changes in the columnar architecture limited to a few points in the epiphyseal plate. There was no evidence of detachment of the epiphyseal nucleus, nor of any haemorrhage (Fig. 7).

By day 28, at the end of the period of distraction, the lengthened portion was occupied by ossification tissue similar in appearance to that of the metaphyseal bone of the control femur. The appearance was not uniform, because of brownish zones which were areas of tissue undergoing ossification. The line of the cartilage showed normal morphology, but at some points it was markedly thicker. At the periphery of the plate there was an increase in the thickness of the periosteum without gaps in the perichondrium.

The bridging cartilage in the zones of increased thickness displayed marked hyperplasia and hypertrophy, with some disorganisation of the columnar structure but no evidence of cellular damage (Figs 8 to 11).

Histological specimens taken on day 50 and day 70 showed an active epiphyseal plate which had returned to

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Histology of the distal femoral epiphysis in the rabbit during and after distractional epiphyseolysis (H & E, PAS, Azan-Mallory). Figure 2 - Seven days after starting distractional epiphyseolysis, there is separation of the epiphysis from the metaphysis with some haemorrhage ($\times 40$). Figure 3 - The control femur after 7 days, showing the normal histological pattern ($\times 16$). Figure 4 - Seventy days after starting the 14-day period of distractional epiphyseolysis the cartilage is ossified with only isolated nests of cartilaginous cells ($\times 40$). Figure 5 - Control femur at 70 days shows a normal histological pattern ($\times 16$).

normal thickness (Fig. 12). Cellular morphology confirmed the normal organisation of the growth plate and adjacent elements, matching that of the control limb.

DISCUSSION

Our study has confirmed that distraction of the rabbit growth plate without deviation of the epiphyseo-diaphyseal axis may be achieved with a rigid unilateral external fixation device. In addition, it has provided some information on the basic mechanisms involved when lengthening is obtained in this way. Histology indicates that controlled distraction of the cartilage at a slow rate of 0.25 mm per 12 hours produces lengthening by cellular hyperplasia without substantial morphological or structural changes. Slow distraction of the epiphyseal plate causes an increase in its thickness (or height) which is not comparable to the effect of distraction on a solid inert body, which would tend to decrease in diameter in response to this stress. We observed no modification in diameter of the growth plate.

In our view, the elongation is a result of the biological effect of the mechanical forces of distraction. It seems that traction applied in this manner may accelerate the rate of turnover of the cellular component of the growth plate, and influence particularly the maturation of the chondrocyte. This increased rate of turnover appears to occur equally in the transition layers between the germinal zone and the columnar zone and between the columnar zone and the hypertrophic and degenerate cells. The rate of primary calcification also increases, but to a lesser extent.

Histology has shown that the germinative and columnar zones after chondrodiasis have almost the same thickness as those of the control femur, whilst the relative thickness of the hypertrophic zone had been increased in an irregular manner. Furthermore, the increase in intercellular matrix which was regularly seen is indicative of enhanced cellular metabolic activity. It is possible that these phenomena are favoured by the lower mechanical resistance of the transitional zone between cortical tissue and perichondrium (Hunter's zone of modelling resorption), where detachment usually occurs when forcible distraction overcomes the resistance of the perichondrium. The irregular zones of cellular hypertrophy and hyperplasia may be a consequence of the phenomenon described by Trueta and Amato (1960) which follows interruption of metaphyseal circulation. The accumulation of cells may result from temporary local ischaemia caused by stretching of the lateral metaphyseal arteries where they penetrate into the growth plate through the periosteum (Téot et al. 1982). It will therefore be of interest in future studies to observe the anatomical and histological modifications which occur in the perichondrium and periosteum, since these tissues have an important role in both the development and the mechanical stability of the growth plate.

Once distraction has been discontinued, the growth

cartilage appears to return gradually to the rate of turnover that existed before distraction started, and to retain this rate until the end of the normal growth period. Long-term follow-up of animals subjected to chondrodiasis indicated that activity of the cartilage continued during the remaining period of growth, thus preserving the elongation obtained.

The results obtained in this study provided, in our opinion, ample justification for the application of this technique to leg lengthening in children.

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Fig. 6

Fig. 7 ▶

Histology of the distal femoral epiphysis in the rabbit during and after chondrodiastasis (H & E, PAS, Azan-Mallory).

Figures 6 and 7 - Fourteen days after starting chondrodiastasis. The metaphyseal zone shows increased height with slight hyperplasia of bridging cartilage, but no evidence of detachment of the epiphysis or of any haemorrhage (Fig. 6, $\times 4$; Fig. 7, $\times 40$).

Fig. 8

Fig. 9 ▶

Figures 8 and 9 At 28 days, the end of the distraction period, the treated femur shows ossification tissue of normal appearance in the lengthened portion. There is increased thickness of the bridging cartilage with hyperplasia, hypertrophy and some loss of columnar structure, but no cellular damage (Fig. 8, $\times 4$; Fig. 9, $\times 16$). Figures 10 and 11 The control femur on day 28, to show the normal histological pattern (Fig. 10, $\times 4$; Fig. 11, $\times 16$).

Fig. 10

Fig. 11 ▶

Figure 12 Seventy days after starting the 28-day period of chondrodiastasis. There is an active epiphyseal plate which has recovered its normal thickness. The cellular morphology is comparable to that of the control shown in Figure 5 ($\times 40$).

Fig. 12