THE RELATIONSHIP BETWEEN PERIOSTEAL DIVISION AND COMPRESSION OR DISTRACTION OF THE GROWTH PLATE

AN EXPERIMENTAL STUDY IN THE RABBIT

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We subjected the proximal tibial growth plates of six-week-old rabbits to either compression or distraction of 1 kg on both legs. On one side the proximal tibial periosteum was divided circumferentially and stripped for 1 cm. After six weeks, growth was measured at both proximal and distal growth plates.

Compression inhibited total tibial growth and distraction enhanced it. The compressed growth plate grew less and the distracted growth plate grew more, but there was a reciprocal change at the other end of the bone. Periosteal division enhanced growth at the adjacent growth plate but inhibited it distally; the effect of distraction was enhanced and that of compression reduced.

We found reciprocal growth rates at the proximal and distal growth plates. Relatively small amounts of compression or distraction did affect total bone growth. Periosteal division appeared to induce overgrowth at least partly by a mechanical effect; it may be useful as an adjunct to other methods of leg lengthening, though not to epiphyseolysis.

Ollier (1867) first recognised the connection between damage to the periosteum and overgrowth after fracture, suggesting that this might be due to periosteal irritation. It is now apparent that transverse division or stripping of the periosteum causes an increase in growth of a long bone (Crilly 1972; Harkness and Trotter 1978; Warrell and Taylor 1979; Rooker 1980; Carvell 1983; Lynch and Taylor 1987; Taylor, Warrell and Evans 1987); this has been used to correct leg discrepancy (Taillard and Morscher 1965; Chan and Hodgson 1970; Jenkins, Cheng and Hodgson 1975; Wilde and Baker 1987).

How periosteal division causes increased growth is not known. Crilly (1972) suggested that tension in the periosteum normally inhibits growth at the growth plate and that periosteal division releases the growth plate. Harkness and Trotter (1978) and Houghton and Dekel (1979) showed that transplanted bones or bones isolated in a diffusion chamber grew more than controls when the

periosteum was divided: this suggests that the effect is a purely mechanical one.

Hyperaemia is known to cause overgrowth in, for example, cases of arteriovenous fistula or after infection in the metaphysis (Hiertonn 1961), and there is some evidence that transverse division of the periosteum can cause an alteration in the vascularity of the bone (Warrell and Taylor 1976; Harkness and Trotter 1978; Houghton and Duriez 1980), and firm evidence that periosteal stripping alters the vasculature of bone (Foster, Kelly and Watts 1951; Trueta and Caladiaz 1964).

At the growth plate, distraction without epiphyseolysis causes an increase in bone growth (Sledge and Noble 1978; De Bastiani et al 1986a,b). Compression by forces well in excess of body-weight will eventually cause epiphyseodesis (Strobino, French and Colonna 1952; Trueta and Trias 1961; Sibrandij 1963), but little is known about the effect of lower forces of compression.

Our aim was to establish the mechanism by which periosteal division causes overgrowth of bone, with and without low levels of compression or distraction.

METHOD

A total of 16 six-week-old New Zealand white rabbits were anaesthetised with intravenous Hypnoval. Kirschner wires (1 mm) were passed through the epiphysis proximal to the growth plate of each tibia, and a guide was used to place a parallel wire through each diaphysis.

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On the left a transverse incision was made in the periosteum 1 cm distal to the growth plate and the periosteum stripped 0.5 cm proximally and distally (Fig. 1). On the right a control operation was performed where the tibia was exposed, but the periosteum was left intact (Fig. 2). The wounds were closed with dextron sutures, and external fixators applied (Fig. 3).

Eight animals then had a compression force of 1 kg applied across the proximal growth plate of both tibias using precalibrated springs, and the second group of eight had distraction applied in a similar way. Thus each animal had either compression or distraction bilaterally, with periosteal division on one side only.

Fig. 1

Fig. 2

Figure 1 – Placing of the pins, and division of the periosteum with stripping back for 5 mm. Figure 2 – Control operation with no division of the periosteum.

The springs were adjusted daily to ensure that a constant force of 1 kg was applied to the growth plate, and were recalibrated at the end of the experiment. Radiographs were taken on the day of operation and then at two-weekly intervals using a previously described technique (Houghton and Rooker 1979). Tibial length was measured from the serial radiographs using calipers. The animals were allowed to eat and drink freely, and were weighed at two-weekly intervals. At 48 hours and 24 hours before being killed the animals were given an intravenous dose of oxytetracycline (10 mg/kg).

After an overdose of thiopentone, the femurs and tibias were measured directly using calipers, photographed and fixed in 70% alcohol. Coronal sections were taken of the growth plates of the proximal and distal tibias at 1 mm intervals using a fine power saw; these were directly examined under ultraviolet light using a Zeiss incident light microscope. The distance between the tetracycline lines was measured using a graticule. From four animals the coronal sections were embedded in 2-hydroxyethylmethacrylate, 7 μ m sections were cut using a microtome and re-examined under ultraviolet light as above. The remainder of the sections were fixed, decalcified, sectioned as above, stained with haematoxylin and eosin, and examined with a Zeiss transmission

microscope, using a graticule to measure the thickness of the growth plates. This was done at 10 points across each section to compensate for irregularities in the growth plate.

The results were stored on a computer and assessed using a Statview program. The Mann-Whitney, Wilcoxon signed-rank, *t*-test and Kendall correlation coefficient statistical tests were used as appropriate.

RESULTS

Periosteal division caused increased growth in all except one animal ($p < 0.01$), but this represented only a 0.73% average increase in length (9.56 cm to 9.63 cm). Radiological assessment appeared to show no significant difference between group I (compression) and group II (distraction) in total tibial length, but direct measurement of the bones revealed a 5.78% difference in length (9.34 cm and 9.88 cm respectively) as compared with a normal tibial length of 9.68 cm at 12 weeks of age (Masoud et al 1986). The difference in tibial length between the two groups of animals was more significant statistically on the side where the periosteum had been divided ($p = 0.005$), than on the control side ($p = 0.02$). The increase in tibial length was related to weight gain (average 1.12 kg), but the correlation between the two was not significant ($p = 0.086$).

Fig. 3

Application of the external fixator in compression (left), and in distraction (right).

There was no difference in the length of the femora. There was an increase in the width of the tibia at the site of periosteal division compared to the control side (1.12 cm to 1.05 cm, difference $p = 0.047$), but there were no other differences in the dimensions of the bones.

Analysis of the radiographs to assess the relative contribution of each growth plate gave the following findings (Figs 4 and 5):

Fig. 4

Fig. 5

Growth at the proximal and distal growth plates after six weeks, without (Fig. 4) and with periosteal division (Fig. 5).

Fig. 6

Fig. 7

Growth at the proximal and distal growth plates, measured radiographically over six weeks. Figure 6 – Compression of the proximal growth plate, with and without division of the periosteum. Figure 7 – Distraction of the proximal growth plate, with and without division of the periosteum.

1. Compression reduced growth at the compressed growth plate, whereas distraction stimulated it. This effect was more marked on the control side ($p = 0.016$) than on the side where the periosteum had been divided ($p = 0.058$).
2. Compression proximally increased growth at the distal growth plate, whereas distraction inhibited it. This difference was more marked on the side where the periosteum had been divided ($p = 0.031$) than on the control side ($p = 0.058$).
3. Thus, periosteal division enhanced the effects of distraction, whereas it reversed to some extent the effects of compression.
4. The effects of compression, distraction and periosteal division were most marked during the first two weeks, and became less with time (Figs 6 and 7), but the changes were not statistically significant.

5. Compared to a normal population (Masoud et al 1986), growth at the proximal growth plate was reduced by compression alone. Growth at the distal growth plate was greater than normal where compression was applied proximally, whereas it was decreased in the animals subjected to proximal distraction.

Measurements of the tetracycline bands (Figs 8 and 9) and the thickness of the growth plates showed an almost identical pattern of stimulation or inhibition of the growth plates as that measured from the radiographs during the last two weeks of the experiment. The differences between distracted and compressed growth plates was significant both on the side of the periosteal release ($p = 0.049$ for tetracycline, $p = 0.56$ for growth plate thickness) and on the control side, where the differences were more marked ($p = 0.004$ for tetracy-

Fig. 8

Fig. 9

Average growth per day at the proximal (Fig. 8) and distal (Fig. 9) growth plates during the last week of the experiment, as measured by tetracycline bone staining.

cline, $p = 0.015$ for growth plate thickness). Thus periosteal release tended to reduce the effects of both compression and distraction at the growth plate by the end of the experiment. Although there were some differences at the distal growth plates, these did not approach significance. The moderate correlation between the tetracycline/histological measurements and the radiological measurements did not reach statistical significance.

The morphology of the growth plates showed marked changes, with great variation in thickness of the growth plate in any single specimen (Figs 10 and 11). These changes were more marked in the specimens where the periosteum had been divided, particularly after compression.

DISCUSSION

The periosteum is very strong; Sebek, Skálová and Heřt (1972) showed that its mean longitudinal strength is as high as 26.7 kg/cm in the tibial shaft of calves. Forces of between 3.7 and 8 kg/cm² applied continuously are required to prevent growth at the tibial growth plate (Strobino et al 1952; Trueta and Trias 1961; Sijbrandij 1963; Christensen 1973; Peruchon et al 1980). This suggests that the periosteum subjects the growth plate to significant forces. Simple transverse incision of the periosteum will induce overgrowth (Crilly 1972; Houghton and Dekel 1979; Warrell and Taylor 1979; Rooker 1980; Taylor et al 1987), whereas longitudinal incision appears to induce no overgrowth (Crilly 1972; Rooker 1980; Warrell and Taylor 1979): this suggests a purely mechanical effect.

It is however possible that transverse incision interferes with the blood supply of the growth plate, although Houghton and Dekel (1979) found that bones isolated in a diffusion chamber overgrew when the periosteum was divided. Our study has shown that periosteal division stimulates growth, and that this is

Fig. 10

Growth plate after compression only.

Fig. 11

Growth plate after compression and division of the periosteum. Marked irregularity is shown.

moderated by pressure applied to the growth plate. Compression reduces the effect of division whereas distraction enhances it; periosteal division enhances the effect of distraction and inhibits that of compression. This suggests that the effect of periosteal division is largely mechanical in origin.

Although the amount of force needed to stop growth is known (approximately 3 kg in the rabbit), the effect of lower compression forces on the growth plate is uncertain. Some authors do not believe that lower pressures inhibit growth (Haas 1945; Blount and Clarke 1949; Strobino et al 1952), but Peruchon et al (1980), studying the effect of low compression forces on the growth plate, found that as the pressure was increased growth diminished. Our study confirmed that compressive forces of 1 kg (40% to 66% of body weight) did slow growth in the bone. The effect at the compressed growth plate was much more marked, but partially compensated by increased growth at the distal growth plate. Under normal circumstances the growth plate is subjected to forces well in excess of the experimental load, but continuous compression will inhibit normal growth. The effect appears to be one of disruption of the normal morphology of the growth plate, but exactly how this occurs is not known.

Distraction of a growth plate will cause epiphyseolysis if the force is great enough (Jani 1975; Monticelli and Spinelli 1981; De Bastiani et al 1986a); this is one method of treatment for leg length discrepancy. However, distraction may cause premature fusion of the growth plate, presumably due to vascular damage. It is possible that the use of lower forces may limit the amount of damage (Jani 1975; Penneçot, Herman and Pouliquen 1983; De Bastiani et al 1986a; Pablos, Villas and Canadell 1986). Sledge and Noble (1976) found that forces of 1 kg in the rabbit never caused epiphyseolysis, and yet produced significant overgrowth; De Bastiani et al (1986a,b) have demonstrated large gains in length both experimentally and clinically using the technique of 'chondrodiastasis'. Houghton and Duriez (1980) found that periosteal division combined with epiphyseolysis did not induce any overgrowth at all; histology showed infarction of the metaphysis a few days after the epiphyseolysis. The evidence we have now presented shows that overgrowth does occur with relatively low levels of distraction without epiphyseolysis, but that periosteal division enhances the amount of overgrowth which occurs. It is possible that the combination of chondrodiastasis and periosteal division could become a useful method of leg lengthening.

In 1951 Lacroix proposed that there was a neutral point on the bone, and that the relative amount of growth at each growth plate was dependent on this. Under normal circumstances in the rabbit tibia about 53% of growth is contributed by the proximal growth plate (Hansson 1967). Normally proximal periosteal division induces distal overgrowth (Brodin 1955; Taylor et al 1987); this suggests that the neutral point of Lacroix is

altered. Our study has shown the importance of the interrelationship between the growth plates. Growth at one growth plate cannot be altered by force across the growth plate or by periosteal division, without changing that at the other growth plate. This relationship is reciprocal, but it is changed by periosteal division, which enhances growth at the compressed growth plate, and diminishes distal growth. Similarly, compression and distraction alter the relationship, compression causing increased growth distally and distraction decreasing it. The effect of periosteal division in inducing distal overgrowth was reversed by distraction on the proximal growth plate. The local effects of force on the growth plate are moderated by interdependence between the growth plates, which limits the changes obtainable. It would seem sensible to try to stimulate both growth plates simultaneously, perhaps by distracting at one end of the bone and dividing the periosteum at the other end. Periosteal release could thus be combined with other methods of treatment, although periosteal release adjacent to the site of epiphyseolysis appears to be contraindicated (Houghton and Duriez 1980).

A better understanding of the biomechanics of the growth plate should help in developing new methods of leg lengthening. However, there may be a finite limit to the amount of lengthening which can be obtained without epiphyseolysis or operations on the diaphysis.

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