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BREAKING FORCE OF THE RABBIT GROWTH PLATE AND ITS APPLICATION TO EPIPHYSEAL DISTRACTION

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The *in vitro* breaking forces of the distal femoral growth plates of young rabbits were measured as a background to the design of a bone lengthening method, using epiphyseal distraction. The mean breaking force in 16 femora was 12.98 ± 3.48 kg and the mean strain was 0.91 ± 0.33 mm. The mean stress in 10 femora was 14.51 ± 3.88 kg/cm^2. The procedure was repeated, after applying a 1.0 kg dead weight to 6 femora for 24 hours and the breaking force was then 15.01 ± 4.70 kg, with a mean strain of 0.85 ± 0.62 mm. A further 8 rabbits then underwent epiphyseal distraction for 2 days *in vivo*, with 1 or 2 kg forces delivered to two parallel K wires by a pair of spring devices, whereupon the femora were removed and tested as before. The breaking force on the distracted side was now only 8.91 ± 3.71 kg, compared with 13.99 ± 3.40 kg on the control side. Although not fractured, these plates had obviously been weakened. The clinical implication of this is discussed.

Key words: epiphyseodesis; growth plate cartilage; limb-length equalisation

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There have been sporadic attempts, over three decades, to lengthen long bones by distraction forces across a growth plate. They all resulted, deliberately or otherwise, in a Salter-Harris type I juxta-metaphyseal fracture. The principle of lengthening by stimulating the growth plate (i.e. the reverse of epiphyseodesis), would be attractive, if the problem of fracturing could be overcome. The earlier work (Ring 1958, Marsh et al. 1961, Harsha 1962, Fishbane & Riley 1976) had employed rigidly applied forces, whose magnitude was apparently not measured. We have been able to achieve limb lengthening in young rabbits without epiphyseolysis (Noble et al. 1978, Sledge & Noble 1978), although problems with fracturing were still encountered. Consequently we have studied breaking forces and stresses across rabbits' distal femoral growth plates before and after experimental epiphyseal distraction.

MATERIAL AND METHODS

Experiment 1

Both femora were removed from six New Zealand white rabbits, aged 60 ± 2 days old. Care was taken to remove all soft tissues, although no special attempt was made to strip the periosteum/perichondrium from about the growth plate. The femora were then held in a vice and, using a jig (Sledge & Noble 1978), a pair of K wires were passed in parallel, either side of the distal growth plate. Two pairs of yokes, with holes to fit the 0.062 gauge K wires, were then used to mount the bone upon an Instron tension-compression machine (Figure 1). The bones were kept moist by surrounding them with gauze sponges, onto which normal saline dripped. Using a cross-head speed of 0.25 mm/s we measured both the breaking forces (acme) and the strain (horizontal distance from start of test to acme) from the load/deflection charts.

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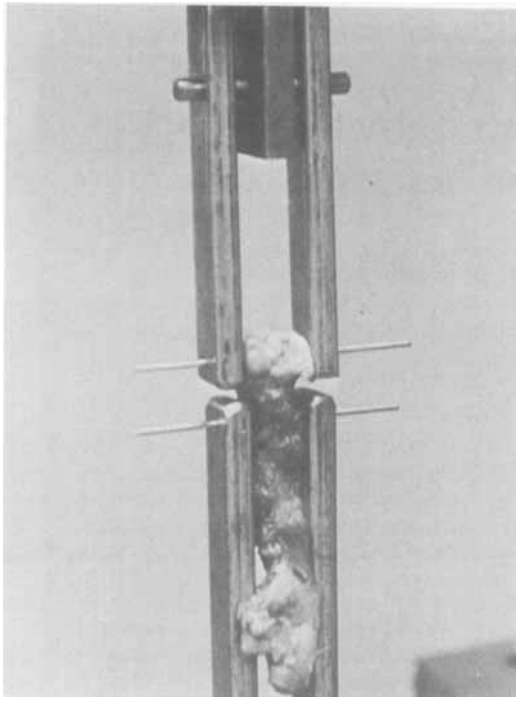

Figure 1. Separated distal femoral epiphysis with parallel K wires, mounted on Instron machine.

Experiment 2

Observing a considerable standard deviation (see Results) from the breaking forces in Experiment 1, we decided to ascertain if it was due to variations in plate surface area, and therefore tensile stress was computed. Five rabbits, who were 60-day-old litter mates, were sacrificed and their ten femora were drilled, mounted and pulled apart as before. Then the metaphyseal ends were pushed into wet acrylic cement and after it had set the bones with the acrylic cement were put into concentrated nitric acid. Within 48 hours the bone had entirely dissolved, leaving a negative mould of the metaphyseal surface of the growth plate. These moulds were then cut into multiple 1 mm sections, which were in turn placed on graph paper, from which the plate surface contour could be traced and then measured. As the thickness and number of slices were known, the surface area could be calculated. The cement was known, from previous work by Walker & Erkman (1975), to have an insignificant amount of shrinkage, which meant it could be used with accuracy.

Experiment 3

Six femora from six rabbits all 60 ± 4 days old were mounted on the Instron machine. A 1 kg dead weight load was then applied for 24 hours, with zero cross-head speed, after which the elongation was measured. Then four of the femora were treated exactly as before, in that they were taken up to a breaking force with a cross-head speed of 0.25 mm/s. The other two femora were decalcified and sectioned for histological examination, after haematoxylin and eosin staining.

Experiment 4

Finally, the breaking force and distension were measured after *in vivo* distraction. Eight rabbits aged 60 ± 2 days old who weighed 1.47 ± 0.11 kg were anaesthetised and K wires were placed on either side of the distal femoral growth plate of the right and left femora, as described by Sledge & Noble (1978). One kg paired devices were applied on the right femur to four animals, and 2 kg distraction devices were applied to a further four, after which the rabbits were sacrified. The femora were carefully dissected out, with the K wires remaining *in situ.* Thus we were able to mount the femora on the Instron as before and measure breaking force and longitudinal strain, comparing the distracted (right) side with the unstimulated control side (left).

RESULTS

Experiment 1. The mean breaking force was 12.30 ± 3.01 kgf. The mean elongation, prior to breaking, was 0.85 ± 0.32 mm.

Experiment 2. The mean breaking force was 13.66 ± 3.95 kgf and the mean plate surface area was 0.95 ± 0.17 cm^2. This gave a mean stress of 14.51 ± 3.88 kg/cm^2.

Experiment 3. The mean stretch with 1 kg dead weight was 0.85 ± 0.62 mm. The breaking force was 15.01 ± 4.70 kgf. There was no statistical difference between these breaking forces and those in Experiments 1 and 2. In the other two similarly treated femora, histological examination revealed micro-fractures (Figure 2).

Experiment 4. The mean breaking force for the control left femora in this experiment was 13.99 ± 3.40 kgf and there is no statistical difference between this and other breaking forces in Experiments 1, 2 and 3. The mean breaking force of those femora already distracted, by 1 or 2 kg forces *in vivo,* was 8.91 ± 3.71 kgf and this was significantly lower than mean values for the control side ($P < 0.001$). Similarly the pre-break

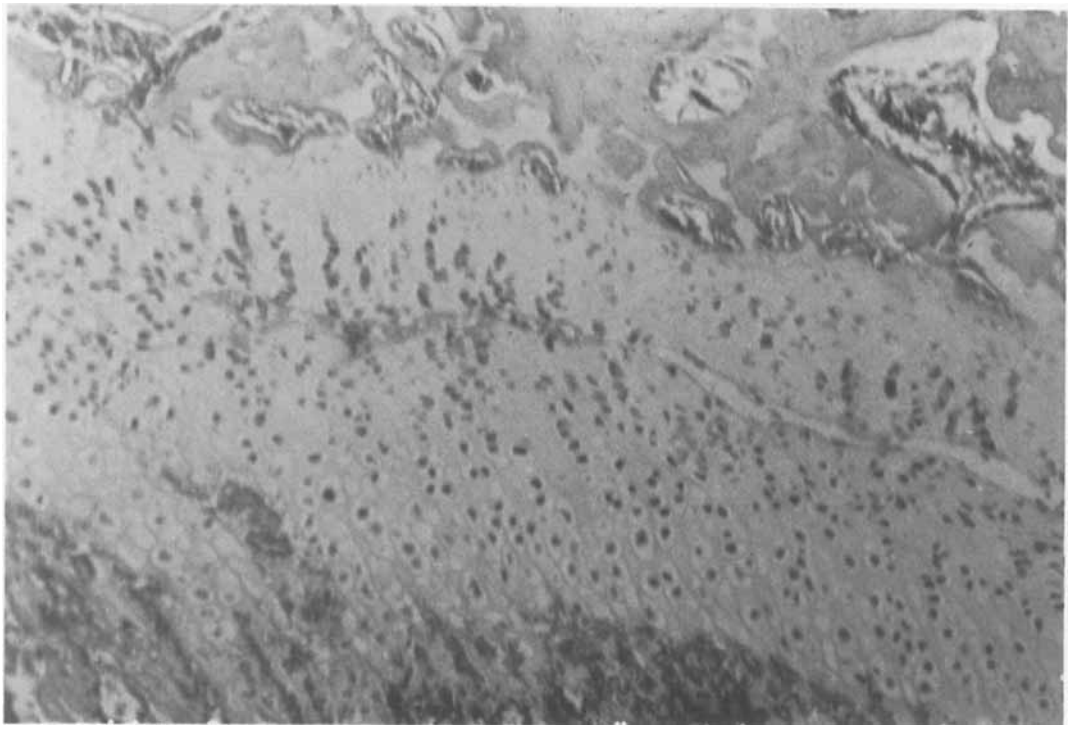

Figure 2. Micro-fracture, after application of 1 kg dead weight for 24 hours.

stretch for the controls was 0.94 ± 0.34 mm, with no significant difference from the data in Experiment 1, whereas the mean stretch for the right distal femora was 1.75 ± 0.54 mm. This is significantly higher than the stretch on the control side ($P < 0.001$). There had been a mean growth increase on the right of 1.05 ± 0.16 mm in excess of that on the control left side.

DISCUSSION

The technique described is a simple one, not previously reported. It differs from that described by Bright et al. (1974) insomuch as the force applied was vertical and not shearing. This is of direct application to the assessment of plate strength before devising epiphyseal distraction techniques. As the *in vivo* technique (Sledge & Noble 1978) is developed towards human application, we propose to repeat this work with paediatric autopsy specimens. The strain or distension data show that plastic deformation of growth plate cartilage is possible *in vitro* without any fracturing. Comparing this *in vitro* work with the *in vivo* work described elsewhere (Sledge & Noble 1978), it seems that the forces likely to be effective and safe for clinical distraction will be only 5 or 10 per cent of the *in vitro* breaking forces. We found that devices loaded with greater force springs almost invariably caused Salter-Harris type I fractures *in vivo*. Knowledge of a plate's approximate breaking force would be essential information, prior to the design of a spring-tension device for human use. It is noteworthy in this respect that clinical applications of such techniques in Eastern Europe (Eydelshtyn et al. 1973) have been termed epiphyseolysis. Lysis of the plate has also occurred in a number of other experimental studies, in none of which was the spring force reported (Ring 1958, Marsh et al. 1961, Harsha 1962, Fishbane & Riley 1976).

Despite the fact that we used male rabbits which were very similar to one another in size and

age, there was an approximately 25 per cent standard deviation in breaking forces and this was not decreased by calculating the plate surface area and therefore calculating stress. Application of a 1 kg dead weight for 24 hours had no influence on the subsequent breaking force, despite the appearance of a micro-fracture in one plate cartilage. Alternatively, application of 1 or 2 kg distraction forces, for 48 hours *in vivo,* caused a significantly lower breaking force. We suggest that this sharp contrast indicates a change in *visco-elastic* properties of the plate after *in vivo* distraction, probably due to growth plate hypertrophy. Alexander (1976) has recently re-emphasised the weakness of the hypertrophic zone when it thickens, in conditions such as rickets. We have shown *in vivo* (Noble et al. 1978, Sledge & Noble 1978) that there is a significant increase in the quantity of growth plate cartilage on the distracted side. We conclude that, in any future clinical application of epiphyseal distraction, the growth plate itself is likely to go through a phase of potential weakness, during which support and protection will be necessary.

CONCLUSIONS

1. For a similar group of animals there is an approximately 25 per cent standard deviation in the *in vitro* breaking force across the growth plate. This is not minimised by measuring the plate surface area and therefore calculating stress.

2. After the application of 1 or 2 kg forces *in vivo* for 48 hours not only is the strain greater but the *in vitro* breaking force is significantly decreased, suggesting altered visco-elastic properties of the growth plate cartilage and the need for added protection in any further clinical application.

3. Before the clinical application of distraction to a growth plate, a background knowledge of its breaking force, *in vitro,* would be a wise safeguard and we would suggest using 5 to 10 per cent of that *in vitro* force, *in vivo.*

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