EXPERIMENTAL EPhipsYCal DISTRACTION PRODUCING AND CORRECTING ANGULAR DEFORMITIES

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Angular deformities of the distal radius of 15 sheep were induced by asymmetrical epiphysial distraction. Eleven sheep were between 10 and 20 weeks old; four were older than 24 weeks. Gradual distraction on the medial side of the limb caused partial separation of the epiphysis from the metaphysis, resulting in a valgus deformity.

The distraction device was removed three to six weeks after insertion. Spontaneous correction of angulation with growth occurred in the younger sheep; but when the induced valgus angle exceeded 20° correction was poor. In two sheep further distraction was applied on the lateral side and this produced complete correction. Premature closure of epiphyses did not occur after distraction and longitudinal growth of the bone remained normal. In the older sheep asymmetrical distraction succeeded in inducing angulation in only one case, and correction was poor.

Angular deformity in the growing skeleton may be caused by trauma, infection, metabolic or neurovascular disorder, as well as by congenital abnormality (Siffert 1966; Ferguson 1981). Although there is a tendency towards spontaneous recovery in growing bone (Ryöppy 1972), some deformities need operative correction.

There are a number of clinical methods for correcting limb deformities. Phemister (1933) and Blount and Clarke (1949) described methods of epiphysodesis for the treatment of leg-length inequality and angular deformity. Corrective osteotomies are commonly used to correct angulation (Tachdjian 1972). In animals, angular deformity may be due to vitamin or mineral deficiency or surplus, and operation is often needed to achieve functional normality (Newton 1974; Auer, Martens and Williams 1982).

Epiphysial distraction by external fixation devices has been used for leg lengthening, both experimentally (Letts and Meadows 1978; Monticelli and Spinelli 1981a; Peltonen et al. 1984), and clinically (Ilizarov and Soibelman 1969; Monticelli and Spinelli 1981b). Monticelli and Spinelli showed experimentally that epiphysial distraction is a practical and relatively non-invasive method of lengthening a limb. Few studies of the correction of angular deformity by epiphysial distraction have been reported (Ray, Connolly and Huurman 1978; Olerud 1982). We have ourselves reported the use of epiphysial distraction for leg lengthening in sheep and pigs (Peltonen et al. 1984), and in these experiments, the separation between the epiphysis and metaphysis usually healed without damage to the epiphysial plate.

In the present study an angular deformity was produced by asymmetrical epiphysial distraction, and spontaneous correction of the deformity then followed. The possible use of the method in the correction of angulation in the epiphysial area also was studied.

MATERIALS AND METHODS

Asymmetrical epiphysial distraction at the distal radius was applied to 15 sheep. Group A included 11 young sheep, aged from 10 to 20 weeks at the start of distraction. Group B contained four sheep all over the age of 24 weeks. The distal epiphysis of the radius of one limb was distracted and measurements were compared with those of the contralateral control limb. The animals were sedated for operation with 0.3 ml of 2% xylaslin solution given intravenously.

Operation. Two 1.7 mm pins were drilled percutaneously on parallel tracks through the epiphysis of the distal radius, and one 2 mm pin was placed through the diaphysis of the bone. A compression-distraction device, designed by the authors, was applied on each side of the bone (Figs 1 and 2). The correct position of the pins was confirmed radiographically. Asymmetrical force on the epiphysial line was achieved by distraction on the medial side of the limb. The rate of distraction was 1.0 to 1.5 mm every two days. Distraction was continued for two to five weeks. The device was then kept in place for a further one to two weeks without distraction and finally removed.

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The limb was examined clinically every day and, if any signs of infection were seen, dihydrotetracycline and procaine penicillin were given by intramuscular injection. The developing valgus angulation was measured clinically, and radiographs were taken weekly. The film to focus distance was 1 m. Angulation was measured from anteroposterior radiographs: lines were drawn parallel to the metacarpal bones and to the radius (Fig. 3); these lines intersect at the level of angulation and form an angle which is the degree of deformity (Pharr and Fretz 1981).

Longitudinal growth of the radius was measured on the radiographs from the distances between the midpoints of the distal and proximal epiphyses. The thickness and width of the growing epiphysial area also were measured.

The period of follow-up from operation to the time the sheep were killed varied from 6 to 13 weeks in Group A, and from 5 to 12 weeks in Group B.

Oxytetracycline bone labelling was used to study bone formation (Milch, Rall and Tobie 1958). Doses of oxytetracycline, 50 mg/kg intramuscularly, were given just after removal of the distraction device and again one week before the animal was killed. The operated and the control radii were both cut longitudinally (with a saw) in a coronal plane and the cut surfaces were photographed in reflected fluorescent light.

Corrective epiphysial distraction was subsequently applied to two sheep in which an angular deformity of over 20° had been induced (Fig. 4). This renewed distraction, on the concave side of the limb, was started four weeks after the end of the first distraction period. Both sheep were aged 18 weeks at the beginning of the second, corrective, distraction.

**RESULTS**

In Group A (the younger sheep) separation of the epiphysis and development of valgus angulation was seen radiographically after six to seven days of asymmetrical distraction (Fig. 5). The valgus deformity increased as distraction was continued for two weeks in two sheep, and for four to five weeks in nine. In all this group, epiphysial separation occurred rapidly, though the distracting force was only mild. Healing of the line of separation between epiphysis and metaphysis was first seen radiographically within four weeks. The distraction device was removed one to two weeks after distraction ceased.

Lines drawn along the axis of the metacarpals and that of the radius intersect at the site of angulation; this was found to be at the epiphysial separation line during the first weeks of distraction, but after six to seven weeks the intersection had moved towards the metaphysis.
In this group the induced angulation, if it was less than 20°, corrected spontaneously and gradually over a period of one to two weeks after removal of the distraction device (Fig. 6). If the induced angulation exceeded 20°, correction was poor. In one case (R in Figure 6) angulation increased after removal of the device. In this sheep, lateral rotation of the limb had also developed during distraction and did not correct.

In Group B (sheep over 24 weeks of age) separation of the epiphysis was achieved in only one of the four, and required more distractive force than was used in Group A. Correction of this deformity after removal of distraction was poor. Asymmetrical distraction caused diaphysial fractures in two sheep of Group B and in one there was no separation even after three weeks of distraction (Fig. 7).

There were no statistically significant differences in longitudinal growth between the operated and the control bones (Fig. 8). Growth in width of the epiphysis seemed to be slightly stimulated. Seven to 10 weeks after operation, widening of the distal radial epiphysis was seen in five of the sheep in Group A. These bones had been distracted for five weeks and the average excess width of the epiphyses was 2.4 mm (range 1 to 5 mm). In two sheep after a period of distraction of 5 weeks, a slight narrowing in the thickness of the epiphysis was noted 3 to 5 weeks after cessation of distraction. In all cases, the epiphysial plate remained radiographically open during the period of follow-up.

In the absence of any spontaneous correction of the induced angulation, bending of the metaphysis and of the diaphysis was seen 10 to 12 weeks after operation (Figs 9 and 10).

In two cases where angulation exceeded 20°, corrective distraction was performed. In both cases this fully corrected the angulation (Fig. 11). The subsequent growth in these limbs was equal to that on the control sides, and the epiphysial plates were still radiographically open 20
weeks after the operation.

Examination of the oxytetracycline labelled bones from Group A sheep showed more intensive fluorescence on the concave side of the metaphysial area of the operated radius. This confirmed that there was a tendency towards asymmetrical epiphysial growth in the concavity during the correction of angulation (Figs 12 and 13).

DISCUSSION
In this study, asymmetrical epiphysial distraction was used to produce and to correct valgus angulation of the distal radius of sheep. After discontinuing the distraction spontaneous correction of the angulation took place rapidly in the younger animals, but there was less correction if the valgus deformity exceeded 20°. It seems possible that unequal axial loading of the epiphysial area delays correction in these cases. It has been shown that an angular deformity of growing bone tends to correct spontaneously (Nonnemann 1969), but the limit of angulation beyond which no spontaneous correction occurs is not known. Among factors which influence this correction are the stage of the growth period, the direction of the angulation and its relation to the epiphysial area (Ryöppy 1972).
Oxytetracycline fluorescence studies revealed that angulation is corrected partly by asymmetrical epiphysial growth and partly by remodelling in the metaphysial area. Karaharju, Ryöppy and Mäkinen (1976) have shown that asymmetrical epiphysial growth is an important factor in the correction of diaphysial angulation, and that longitudinal bone growth in the presence of angular deformity is more intense in the concavity of the bone (Karaharju 1967).

Lines drawn along the axis of the metacarpals and of the radius intersect at the site of angulation (Pharr and Fretz 1981). Six weeks after the operation, during continued growth, this point shifted towards the metaphysial area, suggesting that the angulation is then situated in this region. When angulation was not corrected, the point of intersection remained in the metaphysial region. Bending of the diaphysis in the direction of the angulation was also seen when deformity persisted. In one sheep (R in Figure 6), there was lateral rotation of the limb, and angulation increased after removal of the device. This rotation may have been due to instability of the distraction device.

It has been reported that the force needed to produce epiphysial separation depends on the age of the individual (Chung, Batteman and Brighton 1976). The distractive force used in this study was not measured, but it was clear that more force was needed to cause separation in the older Group B animals. In this group distraction had poor results and caused a diaphysial fracture in two animals. Letts and Meadows (1978) have suggested that epiphysial distraction is best performed in the final part of the growth period but, with regard to asymmetrical distraction, our studies do not support this view. Separation occurs more easily in the younger animals and, in them, healing after distraction is rapid.

It has been suggested that epiphysial distraction impairs further growth of the bone (Jani 1975; Letts and Meadows 1978), but we found no statistically significant differences in longitudinal growth between operated and control limbs. In five animals in which the distraction device was retained for five weeks, some stimulation of the growth in width of the operated epiphysis was noticed. This may be due to stimulation of osteogenesis near the epiphysial plate by the operation. In all cases the epiphysial plate remained radiographically open at the end of follow-up.

Corrective asymmetrical distraction was applied in two cases and it proved possible to correct the valgus angulation by this method. There are only sporadic reports on the use of epiphysial distraction in correcting angular deformities. Olerud (1982) has shown clinically that congenital angular deformity can be corrected by epiphysial distraction and that the leg can be lengthened during the same procedure. In veterinary practice, a good result has been obtained from ulnar epiphysial distraction in a growing dog suffering from radial anterior bowing of a fore limb (Paatsama et al. 1983). The present study seems to indicate a method for the correction of angular deformity, but the long-term effect of distraction on the quality of growing bone is not yet well enough known. Further investigation is also needed to discover the optimal timing of the procedure.

REFERENCES