Acta orthop. scand. 45, 490–498, 1974

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ALTERATION OF EPIPHYSEAL GROWTH BY AN EXPERIMENTALLY PRODUCED ANGULAR DEFORMITY

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Accepted 3.xii.73

Spontaneous correction of angular deformity of the growing long bone is a well-known phenomenon in clinical practice (Pauwels 1950, Blount 1955, Sharrard 1971, Ryöppy 1972). Correction of the deformity caused by a bone bridge between the epiphysis and the metaphysis has been observed after operative removal of the bridge (Langenskiöld 1967).

The mechanism of this process and the factors influencing it are less well known. It is generally accepted that the straightening of the deformity caused by a malunited fracture is due mainly to apposition and resorption at the fracture site (Frost 1964). The bone is normally exposed to the action of gravity, acceleration and deceleration forces, and forces due to the action of muscles (Zarek 1966). In the growing organism these forces are capable of modifying the growth pattern (Hall-Craggs 1969).

Extremely mild forces can inhibit or modify epiphyseal growth (Strobino et al. 1952, Arkin & Katz 1956, Tschantz & Rutishauser 1967, Hindrichsen & Storey 1968). Appleton (1934) has shown experimentally that increased pressure on the end of the bone modifies the direction of growth of an epiphysis. The experiments of Arkin & Katz suggest that pressure acting obliquely on the epiphysis deflects the direction of its growth.

In the present study the influence of mechanical forces acting on epiphyseal growth has been studied by producing an angular deformity in a weightbearing bone experimentally.

MATERIAL AND METHODS

A closed fracture was made in the right hind leg of each member of a group of Sprague-Dawley rats aged 3 weeks. After the fractures had stabilized, the animals were examined radiologically and 30 were chosen for the study. They were divided into four groups, two with pure lateral angulation (valgus and varus) and two with pure sagittal angulation (antecurvation and recurvation). The animals were killed 5–9 weeks after the fractures.

X-ray pictures in two planes were taken under general anaesthesia immediately after fracture and then at intervals of one to two weeks. The degree of angulation, the longitudinal growth of the tibia and the remodelling changes were registered on the radiographs.

Tetracycline (Ocytetracycline, Terramycin®, Pfizer*), 50 mg per kg body weight, was administered intramuscularly 14 days before the animals were killed. After the killing of the animals the tibiae were dissected out and examined macroscopically. Those in the groups with lateral angulation were cut in the frontal plane with a rotating blade. The cut surfaces were ground smooth and examined and photographed in reflected ultraviolet light by a technique published previously (Karaharju 1967).

For examination of the growth of the proximal tibia after administration of tetracycline the two legs were photographed on the same film. The distance between the metaphyseal border of the growth plate and the tetracycline-labelled zone in the metaphysis was measured at three points in the photographs. It was thus possible to calculate the growth on both sides in mm per day.

RESULTS

The growth in length from the proximal epiphyseal plate is seen in Figure 1. The average increase in length during the observation period was 0.13 mm per day. The growth per day diminished from 0.18 mm at the age of five weeks to 0.10 mm at the age of nine weeks. No significant difference was seen in the longitudinal growth of the fractured and control legs. The growth corresponded to that recorded with tetracycline labelling in a normal series by Tapp (1966).

The correction of angulation in valgus is seen in Figure 2. Correction was quite rapid during the first two weeks, then slowed down and became more even. The rate of correction in cases with more angulation was more rapid during the initial phase than in cases with less angulation. This finding was not so obvious in the group with antecurvation (Figure 4) as in others (Figures 2, 3 and 5). During the latter part of the observation period the rate of correction was about the same in cases with more and with less initial angulation. However, in the group of valgus angulation the rate of correction during the latter part of the observation period seemed to be slightly more rapid

* The authors are greatly indebted to Pfizer for the donation of the Terramycin® used in this study.

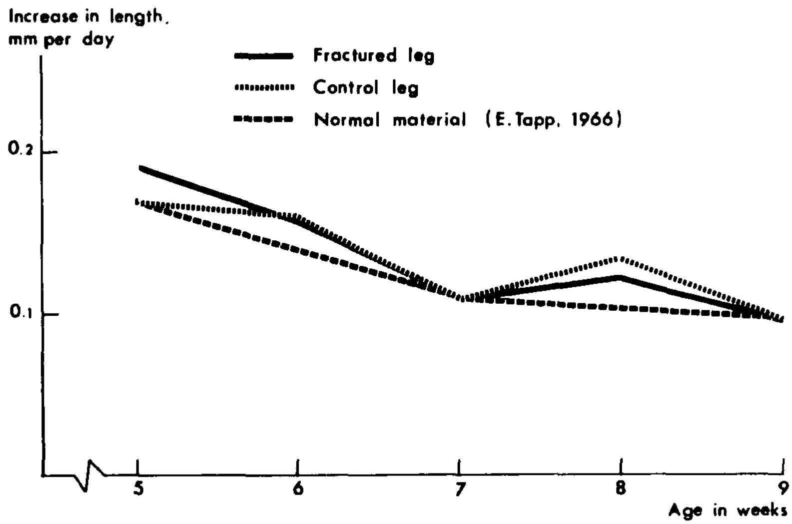

Figure 1. The growth of the proximal epiphyseal plate of the fractured and control tibiae. The same figure shows the rate of growth in a group of normal rats.

than in the other groups, taking place at a rate of about 5–15 degrees in four weeks against 5–10 degrees in four weeks in the other groups.

Correction of the lateral angulation is illustrated in Figures 6 and 7, which show a series of X-ray pictures of two cases.

Examination of the tetracycline-labelled specimens revealed that the longitudinal growth of the proximal tibial epiphysis had been asymmetric. The growth on the concave side exceeded that on the convex side. This finding was constant in both the valgus and varus deformity groups. No significant correlation was found between the asymmetric epiphyseal growth and the amount of total correction or degree of angulation. Increased apposition on the convex side of the metaphysis provided some evidence that the processes of resorption and apposition in the metaphyseal area were modified by the deformity. These findings are illustrated in Figure 8.

DISCUSSION

Angulation is always in one plane. A slight change in projection in the X-ray examination causes an error in the measurement. The influence of this factor on the results was determined in a series of pilot experiments by taking X-ray pictures of the malunited fractures, and

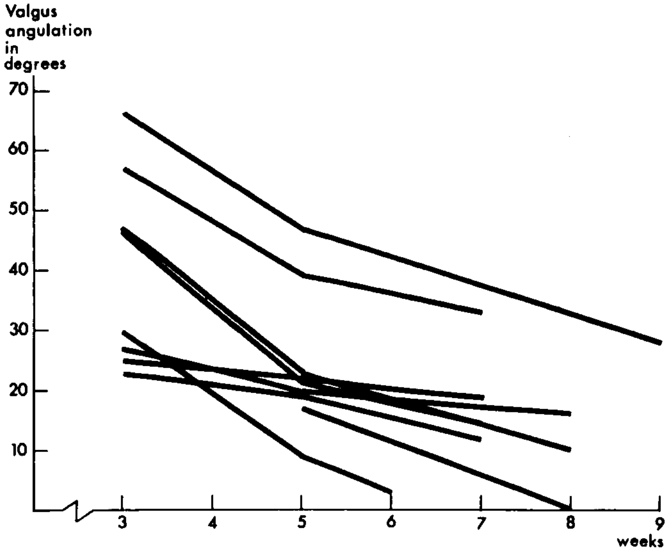

Figure 2.

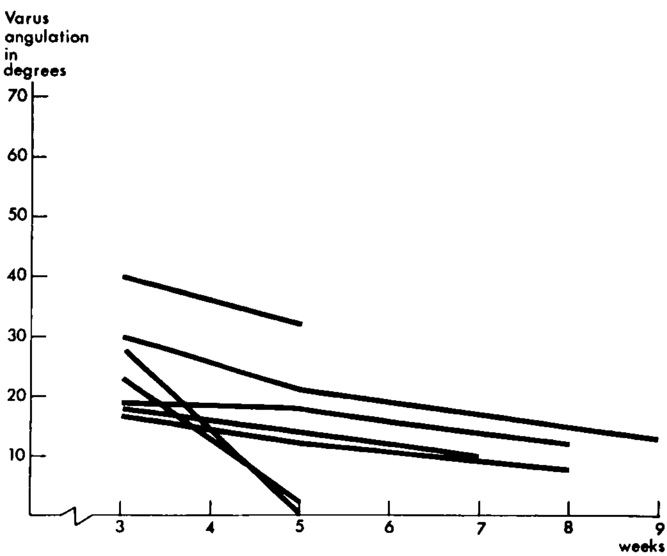

Figure 3.

Figures 2–5. Correction of an angular deformity produced experimentally in the rat tibia. Angulation was measured 3–9 weeks after the fracture in X-ray pictures in two planes for the four different types of deformity.

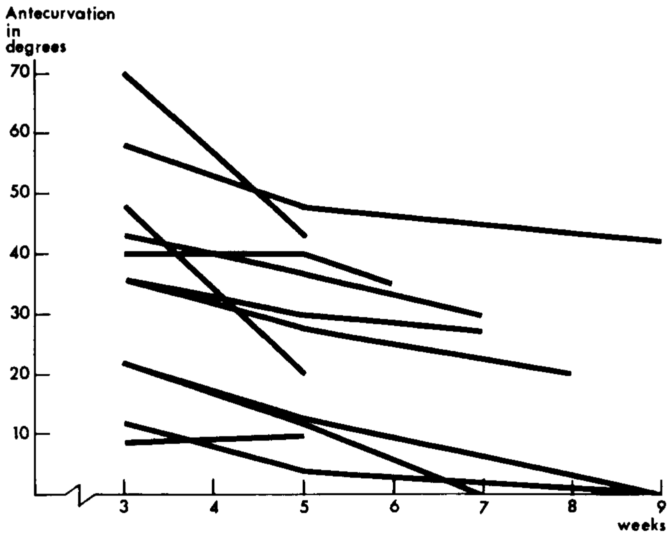

Figure 4.

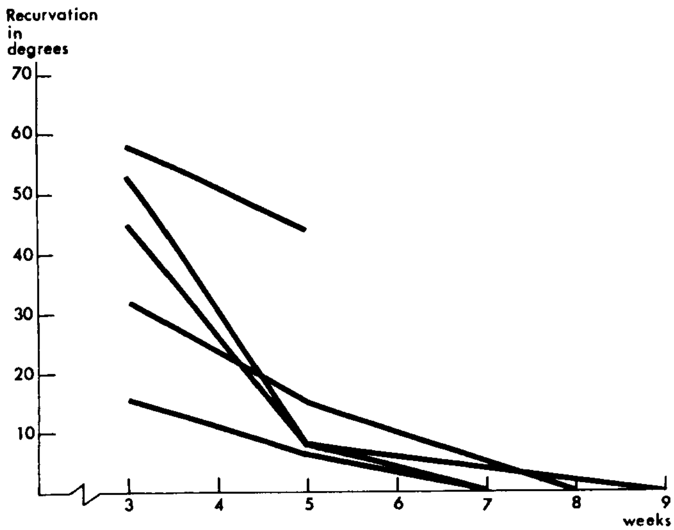

Figure 5.

comparing the angulation found with the real angulation measured from the specimens. It was noticed that the experimental error did not significantly influence the results when X-ray pictures were taken with care under general anaesthesia.

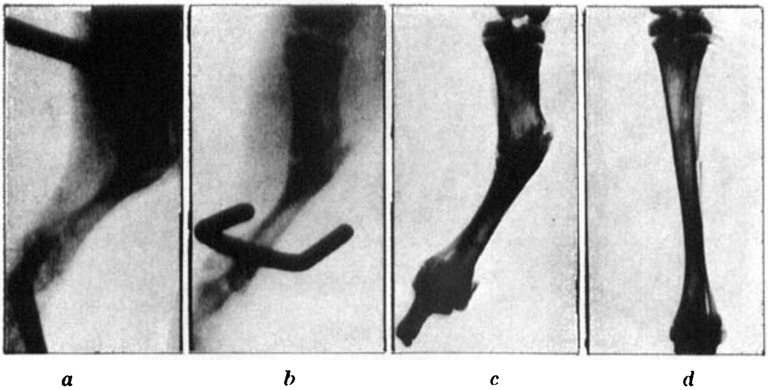

Figure 6. X-ray picture of a rat tibia with a fracture consolidated in valgus a) three weeks, b) five weeks and c) eight weeks after the fracture. Control tibia on the right (d).

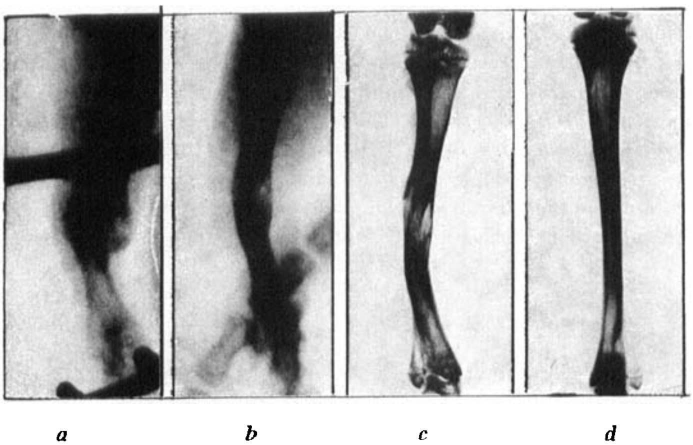

Figure 7. X-ray picture of a rat tibia with a fracture consolidated in varus (a) three weeks, b) five weeks and c) eight weeks after the fracture. Control tibia on the right (d).

The failure to demonstrate stimulation of longitudinal growth does not accord with the generally accepted view that a diaphyseal fracture stimulates growth of the affected bone (Blount 1955, Sunden 1967). The relatively short time of observation and the retardation of growth in some cases with delayed union may explain this result. This phenomenon is clearly illustrated in Figure 8. An additional study is in progress to elucidate the influence of non-union on longitudinal

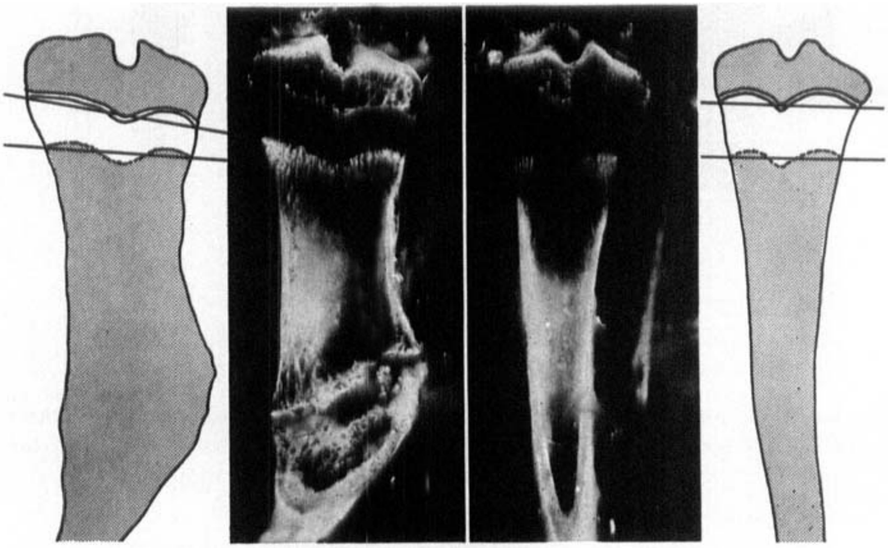

Figure 8. A specimen labelled with tetracycline. Frontal plane section of a rat tibia with fracture malunited in valgus and labelled with tetracycline 14 days before killing, photographed in ultraviolet light. New bone apposition in the metaphysis on the convexity. The line drawing depicts the asymmetric longitudinal growth. (The borderline between the growth plate and the metaphysis, as well as some other details, are poorly seen in the black and white picture. The measurements were made from colour films). Control tibia on the right. Note the significant retardation of growth in the operated tibia, probably caused by delayed union of the fracture.

growth. The case in Figure 8 also shows that asymmetric growth is independent of the stimulation of longitudinal growth. The generally accepted view has been that increased pressure on the concave side results in retardation of growth (Evans 1957). However, in experimental scoliosis it has been found that the number of cells on the concave side in the epiphyseal plate is increased and that growth takes place in the direction of the concavity (Karaharju 1967). This finding and the asymmetric epiphyseal growth do not accord with the law of Hueter-Volkman.

Theoretically, several factors may be involved in the remodelling process. The diagram in Figure 9 shows the factors which in our opinion probably contribute to the remodelling process of the growing long bone. This also serves as a working hypothesis for an experimental project designed to elucidate the various factors involved. In this first

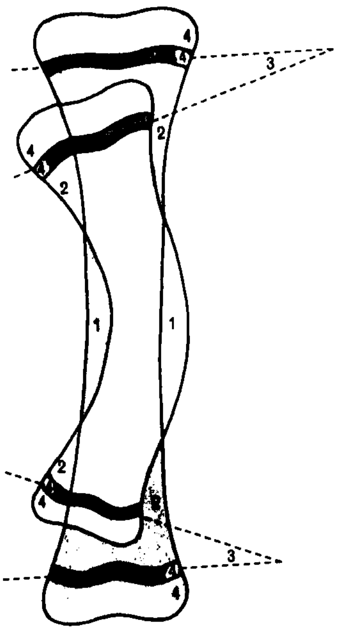

Figure 9. The corrective mechanisms possibly acting in the remodelling of the growing long bone.
1) Local remodelling of diaphyseal deformity: apposition and resorption.
2) Metaphyseal remodelling: resorption more intense on the concave side and less intense, absent or substituted by apposition of new bone on the convex side.
3) Asymmetric growth of the epiphyseal plate.
4) A process comparable to that occurring in the metaphysis (2) may also take place in the epiphyseal plate and the epiphysis itself.

series of experiments, the importance of local remodelling by asymmetric epiphyseal growth and the change in the process of resorption and apposition in the metaphysis were confirmed.

REFERENCES

Appleton, A. B. (1934) Postural deformities and bone growth. *Lancet* iii, 451–454.

Arkin, A. M. & Katz, J. F. (1956) The effects of pressure on epiphyseal growth. *J. Bone Jt Surg.* **38**-A, 1056–1076.

Blount, W. P. (1955) *Fractures in children.* p. 2. Williams and Wilkins Company, Baltimore.

Evans, F. G. (1957) *Stress and strain in bones.* p. 106. Charles C Thomas, Springfield.

Frost, H. M. (1964) *The laws of bone structure.* Charles C Thomas, Springfield.

Hall-Craggs, E. C. B. (1969) Influence of epiphyses on the regulation of bone growth. *Nature (Lond.)* **221**, 1245.

Hindrichsen, G. J. & Storey, E. (1968) The effect of force on bone and bones. *Angle Orthodont.* **38**, 155–165.

Karaharju, E. O. (1967) Deformation of vertebrae in experimental scoliosis. *Acta orthop. scand.*, Suppl. 105.

Langenskiöld, A. (1967) The possibilities of eliminating premature partial closure of an epiphyseal plate caused by trauma or disease. *Acta orthop. scand.* **38**, 267–279.

Pauwels, F. (1950) Über die mechanische Bedeutung der gröberen Kortikalisstruktur beim normal und patologisch verbogenen Röhrenknochen. *Anat. Nachr.* **1**, 53–67.

Ryöppy, S. (1972) Injuries of the growing skeleton. *Ann. Chir. Gynaec. Fenn.* **61**, 3–10.

Sharrard, W. J. W. (1971) *Paediatric orthopaedics and fractures.* 1st ed., p. 929. Blackwell, Oxford and Edinburgh.

Strobino, L. J., French, G. O. & Colonna, P. C. (1952) The effect of increasing tension on the growth of epiphyseal bone. *Surg. Gynec. Obstet.* **95**, 694–700.

Sunden, G. (1967) Some aspects of longitudinal growth. *Acta orthop. scand.*, Suppl. 103.

Tapp, E. (1966) Tetracycline labelling methods of measuring the growth of bones in rat. *J. Bone Jt Surg.* **48**-B, 517–525.

Tschantz, P. & Rutishauser, E. (1967) La surcharge mécanique de l'os vivant. *Ann. Anat. path.* **12**, 223–248.

Zarek, J. M. (1966) *Dynamic considerations in load bearing bones with special reference to osteosynthesis and articular cartilage in studies on the anatomy and function of bones and joints.* Springer-Verlag, Berlin, Heidelberg, New York.

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