Acta Orthop Scand *55*, 192–196, 1984

Healing of rabbit tibial fractures using external fixation

Effects of removal of the fixation device

Terje Terjesen

Department of Orthopaedic Surgery, Trondheim University Hospital, N-7000 Trondheim, Norway

Bone healing after external fixation of rabbit tibial osteotomies was studied in order to throw light on the problem of the optimal time for removal of external fixation. The animals were divided into various groups according to different periods of time for removal of external fixation and sacrifice. The strength and stiffness of the healing bones at 12 weeks were greater in tibiae where the external fixator was removed at 4, 6 or 9 weeks than in those with the continuous presence of the fixator for 12 weeks. Although fixation is essential in the early healing period, it seems that bone healing is stimulated by the removal of the fixation after a certain period of time. The optimum time for removal of external fixation in the rabbit tibia was at 6 weeks of healing, when the bone had regained normal stiffness and about 50 per cent of normal strength.
The clinical relevance of this investigation is that it might be rational to remove the external fixator before bone healing has been completed. If it is felt that healing is not secure when the fixator is removed, a tibial brace might subsequently be used for a short period.

Key words: bone and bones; fracture fixation; fractures; stress, mechanical; tibia, rabbit.

The timing of external fixation removal is rather variable in clinical practice (Ordway 1982, Seligson & Stanwyck 1982), and no experimental work seems to have been performed on this problem. In a previous investigation on intact rabbit tibiae, a slight stress-protecting effect caused by external fixation was found after 12 weeks (Terjesen & Benum 1983b). In order to avoid this adverse effect on the bone, it might be advantageous to remove the external fixator before bone healing has been completed.

In the present radiological and biomechanical study of fracture healing in rabbit tibiae, the effects of removal of external fixation after different periods of time were examined. The purpose was to gain information as to the optimum time for removal of external fixation.

Material and methods

Operative procedure

Thirty-nine Chinchilla rabbits of both sexes, weighing from 2410 to 3600 g, were used. The rabbits were anaesthetized with intramuscular injections of Hypnorm® Vet (Leo). The right or left leg was operated, while the other served as a control. A transverse, midshaft tibial osteotomy was made with an oscillating saw. The osteotomy was fixed with external minifixation (Jaquet Orthopedie S.A., Geneva), as previously described (Terjesen & Benum 1983b). Two smooth transfixing pins of 1.5 mm diameter were used in each fragment, with a pin group separation of 3 cm. The osteotomies were exactly reduced, but compression was not applied.

Postoperative treatment and complications

The animals began partial weight-bearing on the operated leg after a few days. Full weight-bearing was apparently resumed after 2–3 weeks. Complications occurred in three animals. One rabbit died from an unknown cause 3 weeks postoperatively. In two animals in which the fixation was removed after 4 weeks, gross angulation and pseudarthrosis subsequently occurred. These animals were not included in the biomechanical testing.

The remaining 36 rabbits were divided into six groups, according to the following procedures:

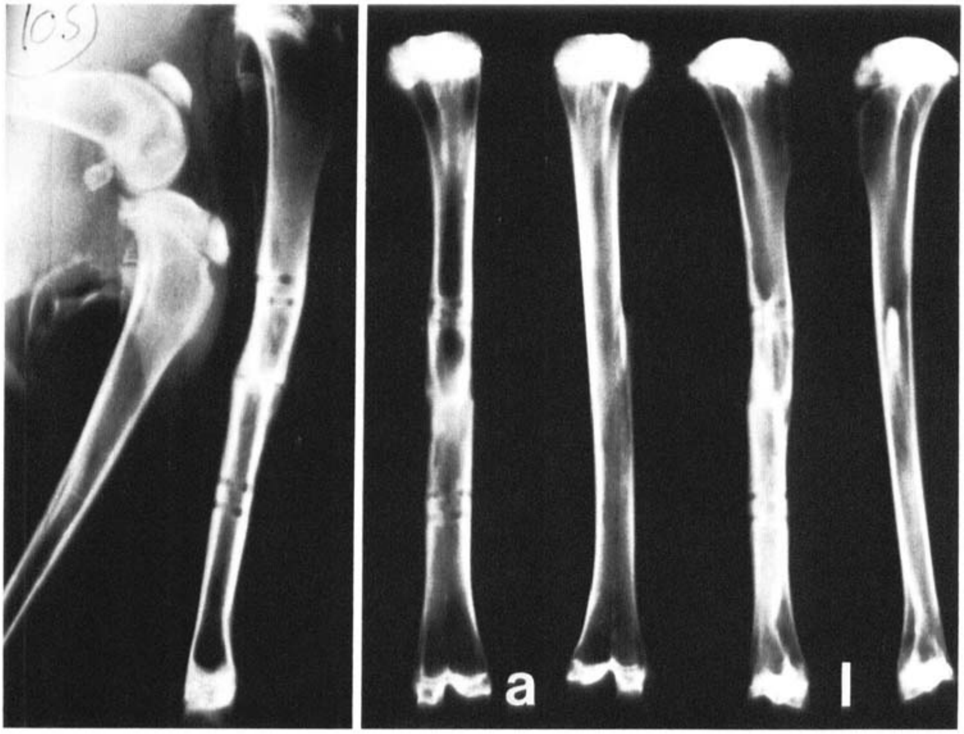

Figure 1. Lateral radiograph (left) after removal of external fixation at 4 weeks, and antero-posterior (a) and lateral (l) radiographs (right) after sacrifice at 6 weeks. The osteotomy line is still visible at 4 weeks.

Group 1 Removal of external fixation after 4 weeks; sacrifice after 6 weeks.
Group 2 Removal of external fixation after 4 weeks; sacrifice after 12 weeks.
Group 3 Removal of external fixation after 6 weeks; sacrifice after 12 weeks.
Group 4 Removal of external fixation after 9 weeks; sacrifice after 12 weeks.
Group 5 Removal of external fixation and sacrifice after 6 weeks.
Group 6 Removal of external fixation and sacrifice after 12 weeks.

Each group consisted of six animals. After removal of the external fixator in Groups 1 to 4, both tibiae were radiographed (Figure 1). No internal or external fixation was subsequently applied. The rabbits were sacrificed with lethal doses of mebumal. In Groups 5 and 6, the external fixation was removed after sacrifice. Both tibiae were dissected free of all soft tissue, and then radiographed. The bones were wrapped in towels soaked with Ringer's solution and stored at −18°C until testing.

Evaluation of bone healing

In order to determine the amount of periosteal callus, the outer antero-posterior and transverse diameters were measured at the osteotomy site and at the corresponding level of the control bones. The radiographs were studied to evaluate the angulation of the bone fragments.

The bone mineral content was measured by photon absorptiometry with a scanning device using gamma radiation from ^{241}Am (AB Gambro, Lund). Scanning of the bones was made at two levels: 5 mm proximal to the distal pin group, and 10 mm distal to the distal pin hole. The control bones were scanned at the corresponding levels.

Biomechanical tests. The tibiae were tested in three-point bending in the antero-posterior direction in an Instron® testing machine, as previously described (Terjesen & Benum 1983a). The load was applied at the osteotomy site. The deformation was measured in a 3-cm-long, mid-diaphyseal segment with a linear variable differential transformer (LVDT). The osteotomy represented the middle of this bone segment. From the load-deformation diagrams, the bending strength, elastic stiffness and deformation at fracture were obtained. The values were given as the percentages of the values for the corresponding control bones. This could be done because of the high degree of symmetry as regards biomechanical properties between paired bones in rabbits (White et al. 1974, Terjesen & Benum 1983b).

Statistical analysis

The Wilcoxon two-sample test (two-tailed test) was used to calculate the statistical differences between the groups. Differences were considered significant at P-values below 0.05.

Results

There were no significant differences between those tibiae where the external fixation was removed before sacrifice and those where it remained until sacrifice, either after 6 weeks (Groups 1 and 5) or after 12 weeks (Groups 2, 3, 4 and 6).

In most of the osteotomies, radiological healing was not demonstrated at 4 weeks. From 6 weeks onwards, bone healing had taken place in all the osteotomies. Most tibiae healed without or with minimal angulation of the bone fragments, and there were no significant differences between the groups. As previously pointed out, increased angulation occurred in two cases where the external fixation was removed at 4 weeks. In the others no increase in angulation and no refractures were seen after removal of the fixation in Groups 1 to 4.

No significant differences in bone mineral content were found between bones where the external fixation was removed at the various time intervals before sacrifice and those where it remained until sacrifice.

Biomechanical testing. The median strength of the healing tibiae was greater in all the groups in which the fixation was removed before sacrifice compared to those in which the fixation remained until sacrifice. However, the difference was significant only in Group 2, where the fixator was removed after 4 weeks and the animals were sacrificed after 12 weeks ($P = 0.026$). When the bones with removal of the fixation at 6 and 9 weeks were regarded as one group and compared to those with the continuous presence of the fixation until sacrifice at 12 weeks, the strength was significantly greater in the tibiae with removal of the fixator at the specific intervals before sacrifice ($P = 0.028$).

Although the median stiffness of healing tibiae in all the groups where the fixator was removed at varying periods before sacrifice was greater than that of those where the fixation remained until sacrifice, the differences were not significant. However, when the bones of the animals with removal of the fixation after 4, 6 and 9 weeks were regarded as one group and compared to those with fixation for 12 weeks, the stiffness was significantly greater in those with the fixation removed before sacrifice ($P = 0.030$). There were no significant differences in deformation at fracture between the various groups.

Table 1. Observations in the osteoromized tibiae expressed as percentage (range) of control values. See text for explanation of group characteristics. The amount of periosteal callus is given as the sum of outer antero-posterior and transverse diameters at the osteotomy site. Median bone mineral content was determined 5 mm proximal to the distal pin group (central) and 10 mm proximal to the distal pin hole (distal)

Group	Periosteal callus	Mineral content Central	Mineral content Distal	Bending strength	Elastic stiffness	Deformation at fracture
1	129 (116–149)	170	141	73 (61–119)	117 (97–214)	70 (57– 74)
2	120 (117–131)	152	108	89 (77–118)	125 (106–150)	77 (67–115)
3	121 (105–127)	176	108	100 (60–118)	127 (94–158)	83 (79–110)
4	122 (112–155)	140	98	82 (74–118)	127 (103–198)	88 (55– 92)
5	130 (102–188)	145	119	51 (39– 83)	103 (75–130)	66 (46– 86)
6	116 (105–145)	139	99	72 (50– 87)	109 (92–127)	77 (48–101)

Discussion

In a previous study, good agreement was found between the *in vitro* biomechanical effects of external mini-fixation of osteotomized rabbit tibiae (with the same frame mounting as in the present study) and those of the Vidal-Adrey double frame on osteotomized human tibiae (Terjesen & Benum 1983a). In both cases the bending stiffness in the antero-posterior direction was about 9 per cent in relation to the stiffness of intact tibiae, when compression was not applied. Thus, from a biomechanical point of view, external mini-fixation with the applied frame mounting seems to be a suitable model for the study of bone healing in rabbit tibiae.

There were no significant differences in the amount of periosteal callus, the position of the bone fragments, and the bone mineral content between animals with the external fixation removed at various periods before sacrifice and those where it remained until sacrifice. Thus, the differences in biomechanical qualities between the groups could hardly be due to different patterns of healing.

The strength was significantly greater in tibiae where external fixation was removed at 4 weeks compared to those with the fixation remaining for 12 weeks. The same trend was found in the other groups with removal of the fixator at the various time intervals before sacrifice compared to those where it remained until sacrifice. This indicates that the optimum method of treatment is a more rigid fixation in the initial stage of healing, combined with a less rigid fixation, or no fixation, in the later stage, as has also been maintained by Akeson et al. (1980) and Wolf et al. (1981). Although fixation is essential in the early healing period, it seems that bone healing is stimulated by the removal of fixation after a certain period of time.

No previous experimental work seems to clarify the optimum time for removal of external fixation. Too early removal entails the risk of displacement of the bone fragments or refracture. In the present study, increased angulation occurred in two cases after removal of fixation at 4 weeks. In a previous study of external fixation of rabbit tibial osteotomies, the strength and stiffness at 4 weeks were only 32 and 65 per cent, respectively, of the values for the control bones (Terjesen 1983). Hence, the fixator should remain longer than 4 weeks.

The stress-protecting effect due to external fixation on intact rabbit tibiae after 12 weeks is less pronounced than that due to a metal plate (Terjesen & Benum 1983b). Although the stress protection due to external fixation is moderate, it seems rational to remove the fixator before this adverse effect on the bone sets in. No significant stress-protection occurred after external fixation for 6 weeks (Terjesen & Benum 1983b). In the present investigation the healing bones had regained about 50 per cent of normal strength and about 100 per cent of normal stiffness after 6 weeks. All osteotomies were radiologically healed at 6 weeks. Thus, the optimum time for removal of external fixation in healing rabbit tibial osteotomies seems to be about 6 weeks. This implies that the fixation should be removed when the bone has regained normal stiffness of the fracture area, although the strength is below normal values.

What are the clinical consequences of the findings in the present study? First it should be emphasized that the problems may be different in clinical practice where the main indication for external fixation is comminuted fractures, in contrast to the transverse osteotomies used in the present study. Secondly, one must remember that the results of experimental studies in animals cannot be directly transferred to clinical cases. The timing of removal of the external fixator is somewhat variable in clinical practice (Ordway 1982, Seligson & Stanwyck 1982). In one view, the fixator is applied until the soft tissue problems are solved and is then replaced by some other form of fracture treatment to secure union (Stone & Mears 1981). According to the other view, the fixator is used for the entire period of treatment (Vidal 1968, Vidal et al. 1976). The results of the present study indicate that it might be rational to remove the external fixator before bone healing has been completed, provided that the stiffness has reached normal values. This is in accordance with the results of measurements of stiffness in patients with crural fractures (Jørgensen 1972). If it is felt that healing is not secure when the fixator is removed, a tibial brace might subsequently be used for a short period.

Acknowledgements

The author wishes to express his thanks to the Materials Technology Division, The Foundation of Scientific and Industrial Research at The Norwegian Institute of Technology, for expert assistance in the mechanical testing.

This work was supported by grants from the Norwegian Research Council for Science and the Humanities.

References

Akeson, W. H., Coutts, R. D. & Woo, S. L.-Y. (1980) Principles of less rigid internal fixation with plates. *Can. J. Surg.* **23**, 235–239.

Jørgensen, T. E. (1972) Measurements of stability of crural fractures treated with Hoffmann osteotaxis. *Acta Orthop. Scand.* **43**, 207–218.

Ordway, C. B. (1982) Application of external fixation to the tibia. In: *Concepts in external fixation.* (Eds. Seligson, D. & Pope, M.), pp. 219–245. Grune & Stratton, New York.

Seligson, D. & Stanwyck, T. S. (1982) The general technique of external fixation. In: *Concepts in external fixation.* (Eds. Seligson, D. & Pope, M.), pp. 79–107. Grune & Stratton, New York.

Stone, J. P. & Mears, D. C. (1981) External fixation of open tibial fractures. *Contemp. Orthop.* **3**, 310–319.

Terjesen, T. (1984) Bone healing after metal plate fixation and external fixation of the osteotomized rabbit tibia. *Acta Orthop. Scand.* **55**, 69–77.

Terjesen, T. & Benum, P. (1983a) *In vitro* effects of external fixation on intact and osteotomized tibiae. *Acta Orthop. Scand.* **54**, 212–219.

Terjesen, T. & Benum, P. (1983b) Stress-protection after external fixation on the intact rabbit tibia. *Acta Orthop. Scand.* **54**, 648–654.

Vidal, M. J. (1968: Notre expérience du fixateur externe d'Hoffmann, *Montpellier Chir.* **14**, 451–460.

Vidal, J., Buscayret, C., Connes, H., Paran, M. & Allieu, Y. (1976) Traitement des fractures ouvertes de jambe par le fixateur externe en double cadre. *Rev. Chir. Orthop.* **62**, 433–448.

White, A. A., Panjabi, M. M. & Hardy, R. J. (1974) Analysis of mechanical symmetry in rabbit long bones. *Acta Orthop. Scand.* **45**, 328–336.

Wolf, J. W., White, A. A., Panjabi, M. M. & Southwick, W. O. (1981) Comparison of cyclic loading versus constant compression in the treatment of long-bone fractures in rabbits. *J. Bone Joint Surg.* **63**-A, 805–810.