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Plate fixation of tibial fractures in the rabbit

Correlation of bone strength with duration of fixation

Bone healing after metal plate fixation of rabbit tibial osteotomies was studied in order to gain information as to the optimum time for plate removal. The fracture had regained almost normal biomechanical properties after 6 weeks. Significantly greater strength and stiffness of the healing tibiae were obtained at 12 weeks when the plate was removed after 4, 6 or 9 weeks and no further fixation was subsequently applied, compared to those plated for 12 weeks. The results indicate that a metal plate should be removed as soon as the fracture has regained normal biomechanical properties; i.e. before the stress-protecting effect has secondarily weakened the bone.

The findings suggest that metal plates should be removed at an earlier stage of the healing period than is usual in clinical practice.

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Internal fixation by metal plates provides satisfactory conditions for fracture healing in diaphyseal bone (Schenk & Willenegger 1963, Anderson 1965, Rhinelander 1974, Paavolainen et al. 1979, Terjesen 1984a). However, in the stage of remodelling the stress-protecting effect of the rigid plate causes osteopenia and reduced strength of the plated bone (Uhthoff & Dubuc 1971, Noser et al. 1977, Paavolainen et al. 1979). In order to avoid this secondary weakening of the bone, removal of the plate shortly after the fracture has healed seems rational. This was supported by the findings of a recent report of Uhthoff & Finnegan (1983), as early plate removal contributed to the restoration of normal bone physiology. However, the optimum time for plate removal has not been determined.

In the present investigation the biomechanical effects of plate removal after various periods of time on healing rabbit tibiae were examined. The purpose was to gain information as to the optimum time for removal of a rigid metal plate in diaphyseal bone. The experiments were modelled on a similar study of external fixation (Terjesen 1984b).

Materials and methods

Operative procedure

Forty-four Chinchilla rabbits of both sexes weighing 2390–3510 g were used. They were anaesthetized with intramuscular injections of Hypnorm® Vet (Leo). One rabbit died during the operation, probably due to decreased tolerance to the anaesthetic drugs. The others tolerated the procedure well. The right or left leg was operated while the other served as control. A transverse midshaft tibial osteotomy was made with an oscillating saw. The osteotomy was fixed with a straight, six-hole stainless steel plate measuring 45 × 5 × 1 mm (Zimmer, USA). The plate was applied on the antero-lateral aspect of the tibia with screws of 2.0 mm diameter. The osteotomies were exactly reduced, but compression was not applied. Both tibiae were radiographed immediately after the operation (Figure 1).

Postoperative treatment and complications

The postoperative course was uneventful in most cases. The animals began partial weight-bearing on the operated leg after a few days, and full weight-bearing was apparently resumed after approximately 2 weeks.

Seven rabbits were excluded from the study because of postoperative complications. These included redislocation of the fracture due to loosening of the screws in the distal fragment (three animals) and

Table 1. Observations in the osteotomized tibiae expressed as percentage (range) of the values for the corresponding control bones. Median bone mineral content was determined between the two distal screw holes (central) and 1 cm distal to the plate (distal).

Group	Weeks postoperatively Plate removal	Sacrifice	Mineral content Central	Distal	Bending strength	Elastic stiffness
1	4	6	17[illegible]	109	70 (53–114)	124 (80–138)
2	4	12	166	109	117 (109–148)	173 (124–355)
3	6	12	168	111	121 (97–183)	216 (136–261)
4	9	12	201	103	124 (90–133)	154 (126–188)
5	6	6	172	100	87 (58–145)	111 (89–227)
6	12	12	136	111	66 (51– 91)	135 (74–169)

fracture through one of the distal screw holes (three animals). One rabbit died about 2 weeks postoperatively after a period of diarrhoea.

The remaining animals were divided into six groups according to duration of plate fixation and time of sacrifice (Table 1).

Each group consisted of six animals. After plate removal in Groups 1–4, both tibiae were radiographed (Figure 2). Subsequently, no internal or external fixation was applied.

After sacrifice, the plates in Groups 5 and 6 were removed. 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.

Figure 1. Postoperative radiograph showing tibial osteotomy fixed with a six-hole steel plate.

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 position of the bone fragments.

The mineral content of the bones was measured by photon absorptiometry with a scanning device using gamma radiation from ^{241}Am (AB Gambro, Lund). Scanning was performed across the bones at two levels: between the two distal screw holes, and 10 mm distal to the distal end of the plate. 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 site represented the middle of this bone segment. From the load-deformation diagrams the bending strength, elastic stiffness and deformation at fracture were obtained.

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.

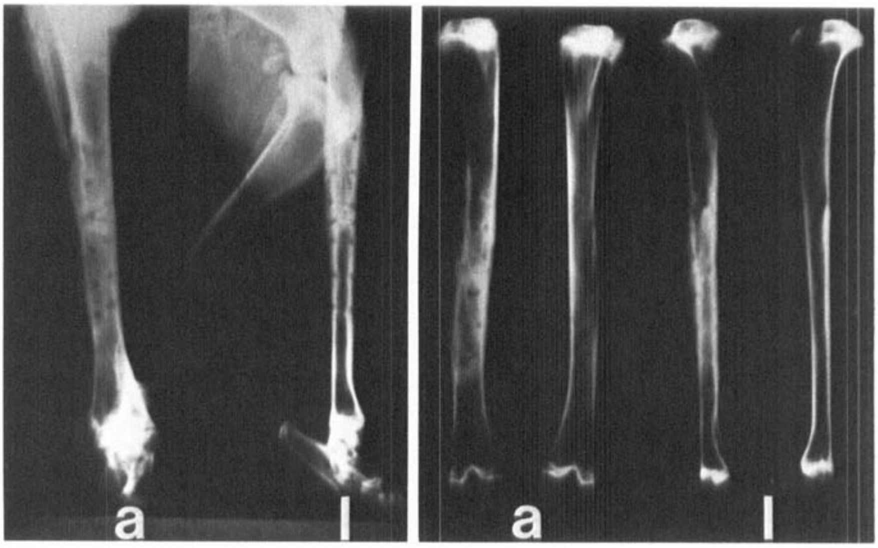

Figure 2. Antero-posterior (a) and lateral (l) radiographs after plate removal at 4 weeks (left) and after sacrifice at 6 weeks (right). After 6 weeks, radiographic healing has taken place, while the osteotomy line is still visible at 4 weeks.

Results

There were no differences in amount of periosteal callus between those tibiae where the plate was removed before sacrifice and those plated until sacrifice, either at 6 weeks or at 12 weeks. Most osteotomies healed without or with minimal angulation of the fragments, and no differences between the groups were found. There was no increase in angulation and there were no refractures after plate removal in Groups 1–4.

The mineral content at the level between the distal screw holes was greater in tibiae with plate removal at 4, 6 or 9 weeks compared to those with the plate remaining for 12 weeks ($P < 0.05$, Table 1). Distal to the site of the plate, there were no differences in mineral content between the various groups.

There was no significant difference in *bending strength* between tibiae with plate removal at 4 weeks and those where the plate remained until 6 weeks (Table 1). However, the strength of the bones with plate removal at 4, 6 or 9 weeks was greater than that of the bones with the plate remaining for 12 weeks ($P < 0.01$). The median strength values of osteotomized bones in Groups 2, 3 and 4 were greater than those of their corresponding control bones.

The elastic stiffness (Table 1) was greater in the tibiae with plate removal after 6 weeks compared to those plated until 12 weeks ($P < 0.05$). When the bones with plate removal after 4, 6 and 9 weeks were regarded as one large group, and compared to those with the continuous presence of the plate for 12 weeks, the stiffness was greater in bones with plate removal before sacrifice ($P < 0.05$). The stiffness of all the osteotomized tibiae in Groups 2–4 was greater than that of their corresponding control bone.

The deformation at fracture of the healing tibiae was greater in Group 4 compared to that of the tibiae in Group 6 ($P < 0.05$). For the rest, no differences in deformation between the various groups were found.

Discussion

If the findings of experimental fracture healing by metal plate fixation are intended to elucidate fracture healing in man, the stiffness of fixation should preferably be comparable to that achieved by plate fixation of the corresponding human bone. In a previous *in vitro* study, a median bending stiffness of approximately 40 per cent related to the stiffness of intact tibiae was obtained after fixation of rabbit tibial osteotomies with a steel plate of the same size as that used in the present investigation (Terjesen & Benum 1983a). This corresponded well to the median stiffness of approximately 50 per cent obtained after tibial plate fixation using a self-compression plate (DCP) on osteotomized human tibiae. Thus, fixation with the applied plate seemed to be a suitable model for the study of bone healing in rabbit tibiae.

No significant differences in the amount of periosteal callus between animals where plates remained until sacrifice and those where the plates were removed before sacrifice were found. Neither did the radiographic examination show any differences between the groups regarding the angulation of the bone fragments. Thus, the differences in biomechanical qualities between some of the groups could hardly be due to different patterns of healing.

The mineral content beneath the plate was greater when the plate was removed early, compared to those with the plate remaining for 12 weeks. This is probably due to the stress-protecting effect of the plate (Terjesen & Benum 1983b). Distal to the plate, no significant differences in mineral content were observed. Thus, no disuse osteoporosis had occurred in the healing bones; weight-bearing was resumed a few days postoperatively.

The strength of the healing bones was somewhat greater where the plates remained for 6 weeks compared to that where the plates were removed at 4 weeks and the animals were sacrificed at 6 weeks, although the difference was not significant. This is in accordance with previous observations that initial phases of bone healing advance faster with rigid fixation (Rhinelander 1974, Wolf et al. 1981, Terjesen 1984a). However, in the phase of remodelling, the bone is secondarily weakened because of the stress-protecting effect (Paavolainen et al. 1979, Terjesen 1984a). Hence it seems rational to remove the plate before this detrimental effect on the bone sets in. This has been confirmed by experimental studies (Jäger et al. 1976, Uhthoff & Finnegan 1983). By histomorphometry of healing bones after femoral osteotomy in dogs, Uhthoff & Finnegan (1983) found an increase in bone mass when the plate was removed several weeks before sacrifice, and a decrease when the plate remained until sacrifice. The time of observation was extended to 60 weeks, and early plate removal at 8 weeks was followed by a more marked remodelling and restoration of normal bone physiology than late removal at 40 weeks. The results of the biomechanical testing in the present study are in accordance with these findings.

Uhthoff & Finnegan (1983) maintained that the duration of return to normal Haversian architecture, and thus strength, is still unknown, and that it would appear to be longer than previously thought. This is probably true as to the bony architecture, but the results of the present study show that the return of normal strength and stiffness to the bone is a much more rapid process. Even after 6 weeks the biomechanical properties had reached almost normal values. Most of the healing bones were stronger and stiffer than their control bones when the plate was removed at 4, 6 or 9 weeks followed by sacrifice at 12 weeks. These results indicate that fracture healing is stimulated by early plate removal, which allows the bone to be exposed to normal functional loads.

Too early plate removal entails the risk of refracture. In a previous study the median strength of osteotomized rabbit tibiae was approximately 40 per cent of normal values after plating for 4 weeks (Terjesen 1984a). Consequently, the risk of refracture seems to be considerable after plate removal at this early stage. Thus, the optimum time for plate removal in the rabbit tibia seems to be at about 6 weeks. In larger animals like the dog, plate removal at 8 weeks seems rational; no refractures occurred after plate removal (Uhthoff & Finnegan 1983). This only holds true for osteotomies and fractures where the blood supply is not too seriously damaged, where there is good bony contact between the fragments, and where there is no comminution of the fracture. In severe fractures with comminution and inadequate blood supply, bone healing progresses more slowly, and the plate should probably remain somewhat longer.

Healing of most non-comminuted tibial fractures in patients takes place in approximately 3–4 months. Removal of tibial plates at 18–24 months postoperatively has been recommended by the AO-group (Müller et al. 1979). The findings of the present study indicate that it might be rational to remove the plates at an earlier stage.

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Note

In my previous article (Terjesen 1984b) there were two misprints.

(1) The first sentence under Results should read "There were no significant differences in the amount of periosteal callus between . . .".

(2) The last line in the legend of Table 1 should read "and 10 mm distal to the distal pin hole (distal)." Reprints of the article have the correct versions.

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