The effects of function and fixation stiffness on experimental bone healing

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In tibial shaft fractures in the rabbit, the early stage of bone healing after metal-plate fixation was compared with that after treatment with a long or short plaster cast. The animals were killed after 6 weeks. The plate-fixed bones healed more rapidly, with less periosteal callus and less angulation of the fragments, than those treated with a cast. The results indicated that function of the muscles and joints of the injured limb, including weight bearing, promotes bony union, whereas the degree of fixation stiffness is relatively unimportant.

Our experiment addresses the following questions:

1. Is there any difference in the speed of bone healing between osteotomies treated with metal plate fixation and those with a plaster cast?

2. If such a difference exists, is it caused by the difference in applied fixation stiffness of the two methods or by the difference in function of the limb during the healing period?

Material and methods

Forty-four Chinchilla rabbits of both sexes, weighing 2.5–3.5 kg, were used. One tibia was operated on, whereas the other served as a control. A transverse, midshaft osteotomy was made with an oscillating saw. In 18 animals (Group A) the osteotomy was fixed with a six-hole, stainless steel plate, measuring 45 x 5 x 1 mm (10 animals) or 45 x 4 x 0.9 mm (8 animals). The plate was applied on the anterolateral aspect of the tibia with steel screws of 2 mm diameter. In 9 animals (Group B) the osteotomy was fixed by a steel plate of 45 x 5 x 1 mm, and, in addition, a long plaster cast was applied. Data for the animals in this group and from those of Group 1 with the same type of plate without a plaster cast have been previously published (Terjesen and Svenningsen 1986), and these data were included in the present study for a more adequate evaluation of the effects of functional use and fixation stiffness on bone healing.

In the remaining rabbits the osteotomies were fixed by an intramedullary Kirschner pin (K-pin) and a plaster cast. The K-pin was inserted from the anterior aspect of the proximal tibia and prevented gross angulation and redislocation during the first postoperative days. A plaster cast from the toes to midthigh was applied, immobilizing the ankle joint in the zero position and the knee joint in 90° of flexion. The K-pin was removed after 1 week. In 8 rabbits (Group C) the long plaster cast remained until death. In the others (Group D) the size of the cast was reduced 3 weeks postoperatively, as it was cut just distal to the knee and proximal to the ankle, permitting full mobility of these joints.

The following groups were compared according to the outlined methods of treatment:

Group A. Metal plate fixation only.
Group B. Metal plate fixation plus a long plaster cast.
Group C. Long plaster cast.
Group D. Short plaster cast.

Complications occurred in 4 animals, which were excluded from further study. In 2 animals of Group A a peroperative fracture through one of the screw holes occurred, and 1 rabbit of Group B had redislocation due to loosening of the screws in the distal fragment. One rabbit in Group D was constantly biting the forefoot of its operated leg, and the wound would not heal.

The animals were killed after 6 weeks. Both tibiae were dissected free of all soft tissue; the plates and screws were removed. Both tibiae were radiographed and stored at –18 °C until testing.

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Evaluation of bone healing

The outer anteroposterior (AP) and lateral diameters at the osteotomy site of the test bone and at the corresponding level of the control bone were measured with a caliper. The cross-sectional areas were calculated, assuming them to be triangular. The area of periosteal callus was determined by subtracting the cross-sectional area of the control bone from that of the test bone.

Healing was assessed from the radiographs taken at 6 weeks. The criterion for solid union was bone bridging the osteotomy, regardless of whether it was still visible. The angulation of the fragments was measured on the radiographs.

Both tibiae were tested in 4-point bending in an Instron testing machine. The load was applied at the osteotomy site, and the deformation was measured with a linear variable differential transformer. The bending strength and elastic stiffness were determined from the load-deformation diagram; the values for the healing tibiae were expressed as the percentages of the corresponding values for the control bones.

The statistical evaluation was made by a paired Student's *t*-test and by one-way analysis of variance. Differences were considered significant at *P*-values below 0.05.

Results

The animals with plate osteosynthesis resumed partial weight bearing a few days postoperatively; and normal function of the limb, including full weight bearing, was regained after approximately 2 weeks. In the rabbits with a long plaster cast, weight bearing was resumed later; and they had impaired function of the limb throughout the experiment. The animals with a short plaster cast resumed full weight bearing and normal mobility of the knee and ankle joints during the last 3 weeks; thus, the function of the limb was better than in those with a long plaster cast.

All the plated osteotomies had healed at 6 weeks, and the angulation of the fragments did not exceed 5° (Figure 1). The animals with plaster fixation showed less favorable healing. In three osteotomies treated with a long cast and in one treated with a short cast, radiographic healing had not taken place, and a moderate angulation of the fragments occurred in all the osteotomies (Figure 2). The median angulation in Group C was 5° (0–13°) in the frontal plane and 10° (6–20°) in the lateral plane. In Group D the corresponding values were 7° (0–18°) and 9° (0–14°). Thus, the position of the fragments was best in the plate-fixed osteotomies, whereas there was no difference between those with a long and a short plaster cast.

Figure 1

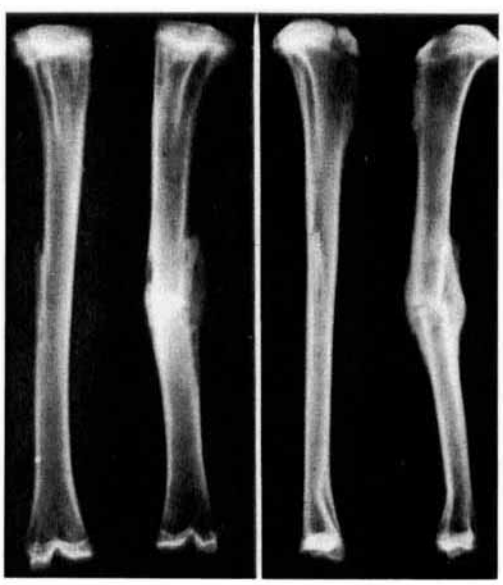

Figure 2

Figure 1. Anteroposterior (left) and lateral (right) radiographs of plate-fixed osteotomy and control bone after 6 weeks. Bone healing with little periosteal callus has taken place.

Figure 2. Anteroposterior (left) and lateral (right) radiographs 6 weeks after osteotomy treated by a long plaster cast. A moderate angulation has occurred, and bony healing with relatively abundant periosteal callus has taken place.

Table 1. Periosteal callus (mm^2), bending strength and stiffness. The mechanical properties of the healing bones are expressed as a percentage of the corresponding values for the control bone. Values are mean *SD*, (range)

Group	A Plate n 16	B Plate + long cast n 8	C Long cast n 8	D Short cast n 8
Callus	25 *8,5*	19 *13*	60 *8,5*	47 *17*
Strength	98 *27*	57 *14*	57 *27*	76 *16*
	(54–135)	(37–76)	(29–94)	(48–98)
Stiffness	131 *30*	88 *23*	69 *53*	110 *27*
	(54–188)	(67–135)	(17–133)	(55–138)

Most plaster-treated osteotomies healed with abundant periosteal callus (Table 1). The plated osteotomies healed with less periosteal callus. In three of the plated osteotomies in each of Groups A and B, healing occurred without radiographic periosteal callus.

The stiffness of the healing bones had regained normal values or values above normal in most animals with short casts, and in those with plate fixation, while those treated with a long plaster cast showed inferior values.

Normal bending strength was regained in most osteotomies in Group A, whereas this was not the case in any of the other groups (Table 1). The differences in strength between Group A and all the other groups were significant. The strength was significantly greater in Group D than in Group B ($P < 0.05$).

The mechanical properties of bones treated with a long plaster cast were remarkably similar whether or not plate fixation was used; the difference in periosteal callus was unimportant. There was a marked trend towards better mechanical properties of the bones treated with a short plaster cast during the last 3 weeks than in those with a long cast.

Discussion

The intention to assess the first stage of the bone healing process was the reason why such a short observation time as 6 weeks was chosen. Given a longer period of observation, the plate-fixed bones would be secondarily weakened because of the stress-protecting effect caused by rigid metal plates (Paavolainen et al. 1979, Terjesen 1984). Compared with plaster fixation only, plate fixation resulted in more rapid bone healing with less deformity and less periosteal callus. This is in agreement with the experience of Lettin (1969) in the rabbit, and is also in keeping with the results of the only prospective clinical study of this problem (van der Linden and Larsson 1979). However, Hutzschenreuter et al. (1980) did not find any differences between the methods in mechanical properties of sheep metatarsal osteotomies after 16 weeks, and Jäger et al. (1976) reported more rapid healing of rabbit tibial osteotomies after plaster cast treatment than after plating. In the latter study overdimensioned plates were used, and tenotomies of the Achilles and patellar tendons were performed; increased stress protection, as well as impaired function, probably contributed to the slow healing.

There are at least two different explanations why plating results in more rapid bone healing: viz, better fixation and better function during the healing period. The former is less likely, since no differences in mechanical properties of the bones occurred with a long plaster cast whether the fixation was rigid or not. The advantage of early function is supported by the fact that the plated bones of Group A rapidly regained normal mechanical properties, whereas the healing of the Group B plated bones with an additional long cast was seriously delayed. Thus, it seems that normal function of the muscles and joints of the injured limb, including full weight bearing, is the most important stimulus for the acceleration of the bone healing process, whereas the degree of stiffness of the fixation is relatively unimportant in this respect. Which of the factors weight bearing and muscle-joint function is the most effective stimulus is difficult to evaluate, as both suffer from a long cast.

The amount of periosteal callus was considerably less in the plated bones than in those with a plaster cast. This does not accord with the widely held view of periosteal callus representing the most rapid way of bone healing (Sarmiento 1974, McKibbin 1978). The results show that the quality of the callus is more important than its quantity.

There was a marked trend towards better mechanical properties of the osteotomies with a short cast during the last 3 weeks, related both to bones with plating and a long cast and to bones with a long cast only. With a short cast, the function of the limb was definitely better than with a long cast. This difference in function is probably the reason for the rapid bone healing (Sarmiento et al. 1977, Terjesen and Svenningsen 1986).

The present study showed that bone healing was 1) most rapid after plating involving the most rapid and most complete functional use of the extremity, 2) intermediate after a short plaster cast involving an intermediate degree of function, and 3) slowest after a long plaster cast involving impaired function during the whole healing period. Provided that similar principles determine bone healing in man as in animals, these results support the clinical experience that the method involving the most rapid return to normal function is the optimal one.

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