

# Bone healing after metal plate fixation and external fixation of the osteotomized rabbit tibia

Controversy still exists as to the best method of treatment of long bone fractures. The purpose of the present study was to compare the effects on the healing bone of external fixation and metal plate fixation. In an experimental model on the rabbit tibia the stiffness of the fixation corresponded intentionally to that of the same methods in human fracture treatment.

A transverse, midshaft osteotomy was made on one tibia, and fixed with a steel plate (45 × 5 × 1 mm) or external mini-fixation. The animals were killed after 4, 6 or 12 weeks. The bone healing was evaluated by radiography, histology and biomechanical testing in three-point bending. There were no significant differences between plate fixation and external fixation in the pattern of bone healing, as it occurred by periosteal, intramedullary and intercortical callus after both methods. The stiffness increased more rapidly than the strength, and reached normal values after about 6 weeks. No significant differences in stiffness between the two methods were found. The strength was significantly greater after plate fixation than after external fixation at 6 weeks, while no significant differences were found at either 4 or 12 weeks.

It is concluded that the speed of bone healing was more rapid after plate fixation. However, in the later stages of healing the plated bones were secondarily weakened because of the stress-protecting effect of the plate.

**Key words:** bone strength; external fixation; fracture fixation; internal fixation plates.

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The optimum mechanical conditions for fracture healing have not yet been delineated, despite a considerable number of clinical and experimental studies. This is well demonstrated by the present-day clinical use of such widely divergent methods as cast-bracing and internal fixation. Obviously, additional experimental research is necessary.

From the functional point of view, the healing of a long-bone fracture may be measured by the return of normal strength and stiffness in the healing bone (Henry et al. 1968). Considerable differences in biomechanical qualities of healing bone compared with normal bone have been reported after metal plate fixation (Braden et al. 1973, Jäger et al. 1976, Paavolainen et al. 1979, Rand et al. 1981). The reasons for the discrepancy might be the varying stiffness of the fixation and the various periods of time that have been used.

Mechanical factors qualitatively and quantitatively influence bone production. The problem is that the stiffness of the fixation in the various investigations is unknown, thereby making comparison of the results difficult. So, as a basis for the present study, *in vitro* biomechanical tests were performed on rabbit and human tibiae of metal-plate fixation and external fixation. Good agreement was found between the relative stiffness of the applied plate on osteotomized rabbit tibiae and that of tibial plates on human tibiae (Terjesen & Benum 1983a). The same was true for the stiffness of the applied external mini-fixation on rabbit tibiae and external fixation with the Vidal-Adrey double frame on human tibiae (Terjesen & Benum 1983b).

Thus, the present study was designed to compare the biomechanical properties of healing rabbit tibial osteotomies after treat-

ment by metal plate fixation or by external fixation after different periods of time. The stiffness of fixation corresponded intentionally to that of human fracture treatment.

## Materials and methods

### Operative procedure

Fifty-eight Chinchilla rabbits of both sexes, weighing from 2200 to 3390 g, were operated. The rabbits were anaesthetized with intramuscular injections of Hypnorm® Vet. (Leo. Five animals died during the operation, probably due to decreased tolerance to the anaesthetic drugs. The others tolerated the procedure well.

All operations were performed under strictly sterile conditions. The right or left leg was operated, while the other served as control. A longitudinal anterior incision was used, and the anterolateral aspect of the tibia was exposed by retracting the tibialis anterior muscle. A transverse, midshaft osteotomy was made with an oscillating saw about 5 mm distal to the tibio-fibular junction. In half of the animals the osteotomy was treated by external mini-fixation (Jaquet Orthopedie S.A., Geneva). Two proximal and two distal smooth, transfixing pins of 1.5 mm diameter were used, with a pin group separation of 3 cm. The pins were inserted in the frontal plane, or slightly oblique to this, and the external frame was mounted. In the other half of the rabbits, osteosynthesis was accomplished with a straight, six-hole, stainless steel plate (Zimmer, USA). The plate measured  $45 \times 5 \times 1$  mm, and was applied to the anterolateral aspect of the tibia with screws of 2.0 mm diameter. The osteotomies were exactly reduced, but compression was not applied either in animals with plate fixation or in those with external fixation. The fascia and skin were sutured with Dexon®. In the rabbits with external fixation, the frame had to be bandaged with a padded dressing. Both tibiae were radiographed immediately after the operation.

### Postoperative treatment and complications

The rabbits were kept in separate cages where they could move freely. They received standard food and water supply, and were observed daily. The post-operative course was uneventful in most cases. In both the plate and the external fixation groups the animals began partial weight-bearing on the operated leg after a few days, and full weight-bearing

was apparently resumed after about 2 weeks. Weight-bearing seemed to occur somewhat earlier in the plate-fixed animals.

Three animals were excluded from the study because of post-operative complications (two cases) and technical failure during the preparation for the biomechanical testing (one case). The complications included one rabbit which died from an unknown cause 1 day after the operation, and one which fractured the operated tibia through the distal screw-hole a few hours post-operatively. There were no problems with the pins used for external fixation, nor were there any wound infections.

Fifty animals remained for the further investigations. The rabbits with plate fixation as well as those with external fixation were divided into three groups, and killed with injections of lethal doses of mebumal after 4, 6 and 12 weeks, respectively. Each group consisted of eight or nine animals.

After sacrifice, the fixation equipment was re-

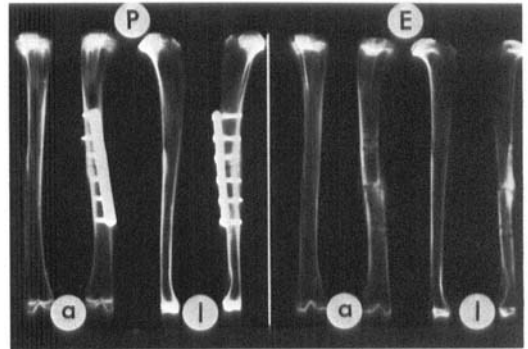


Figure 1. Antero-posterior (a) and lateral (l) radiographs after plate fixation (P) and external fixation (E) at 4 weeks. The osteotomies are still visible.

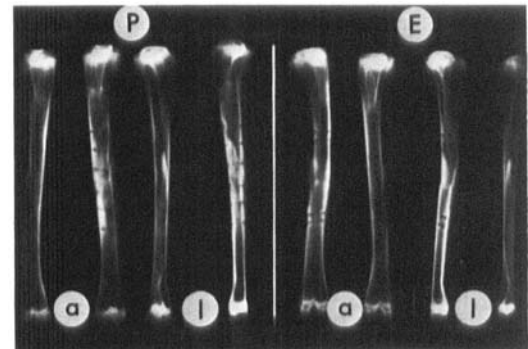


Figure 2. Antero-posterior (a) and lateral (l) radiographs after plate fixation (P) and external fixation (E) at 6 weeks. In both cases bone healing has taken place with little periosteal callus.

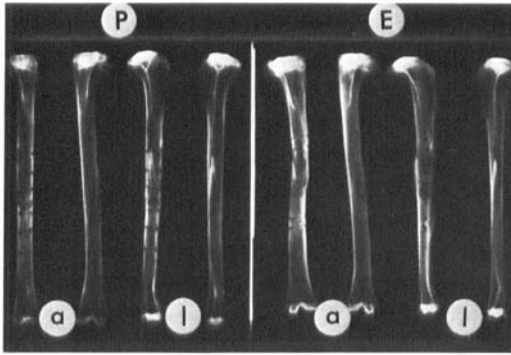


Figure 3. Antero-posterior (a) and lateral (l) radiographs after plate fixation (P) and external fixation (E) at 12 weeks, showing bony union with little periosteal callus.

moved and both tibiae were dissected free of all soft tissue. The fibulae were also removed. The bones were radiographed (Figures 1, 2 and 3), and then wrapped in towels soaked with Ringer's solution, and stored at  $-18^{\circ}\text{C}$  until testing.

## Evaluation of bone healing

*Inspection and measurements of specimens.* The bones were examined by gross inspection. In order to determine the amount of periosteal callus, the outer anteroposterior and transverse diameters were measured at the osteotomy site. After the biomechanical testing, the cross-sections of the broken bone ends were examined regarding the amount of intramedullary callus.

*Radiological and histological examination.* The initial radiographs as well as those taken after sacrifice were studied regarding the position of the bone fragments, the amount of periosteal bony callus, and whether or not bony healing had taken place. Healing was defined as the osseous bridging across the osteotomy gap, regardless of whether the osteotomy line was still visible.

Histological sections were made from representative samples of healing bones to examine the type of fracture healing. After decalcification with nitric acid and paraffin embedding, sections were made and stained with hematoxylin and eosin.

*Biomechanical tests.* The tibiae were thawed to room temperature before testing. They 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 previous osteotomy site. The deformation was measured in a 3 cm long mid-diaphyseal

segment with a linear variable differential transformer (LVDT). The previous 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. The values were given as the percentages of the corresponding values for the control bone. This was done because of the high degree of symmetry regarding biomechanical properties between paired bones in rabbits (White et al. 1974, Låftman et al. 1980, Terjesen & Benum 1983c).

*Bone mineral content.* The mineral content of the tibiae was measured by photon absorptiometry with a scanning device using gamma radiation from  $^{241}\text{Am}$  (AB Gambro, Lund). Scanning was performed across the bones at two levels. In the plated tibiae the scanning levels were between the two distal screw holes, and 10 mm distal to the distal screw hole. In those with external fixation the mineral content was measured 5 mm proximal to the distal pin group, and 10 mm distal to the distal pin. Thus, the mineral content was measured at a diaphyseal level stabilized by the plate or external fixation but outside the osteotomy site, as well as distal to the fixation device. The control bones were scanned at the corresponding levels.

## Statistical analysis

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

## Results

By inspection, all osteotomies appeared to be united even after 4 weeks. The amount of external callus, expressed as the sum of the transverse and anteroposterior diameters at the osteotomy site in relation to that of the control tibia, is shown in Table 1. In plate-fixed as well as externally fixed bones, the amount of periosteal callus was significantly greater after 4 weeks than after 12 weeks ( $P = 0.043$  and  $0.005$ , respectively). There were no significant differences between the methods either after 4, 6 or 12 weeks.

As the intramedullary callus was not examined till after fracture, it could not be

Table 1. The amount of periosteal callus, given as the sum of outer antero-posterior and transverse diameters at the osteotomy site, and expressed as the percentage of the values for the control bones

	4 weeks	6 weeks	12 weeks
Plate fixation			
Median	148.5	142.7	132.1
Range	113.9–164.3	112.8–164.4	113.6–139.7
External fixation			
Median	153.1	134.0	115.9
Range	129.5–166.0	101.9–188.1	104.6–145.3

exactly quantitated. However, it was obvious by inspection that the amount was greatest after 4 weeks, and less after 6 weeks. At 12 weeks the intramedullary callus was lost in most of the osteotomized bones.

All osteotomies were healed by radiological evaluation after 6 and 12 weeks. At 4 weeks about half the osteotomies were healed in both groups. However, at this early stage it was often difficult to decide whether a bone was radiologically soundly healed or not. In almost all cases external callus was radiologically observed. It was most abundant after 4 and 6 weeks, in accordance with the findings of the gross inspection and the periosteal measurements.

Most osteotomies healed without angulation or with minimal angulation. There were no differences in this respect between plated

bones and those with external fixation. Thus, satisfactory positioning of the fragments was obtained by both methods.

During the biomechanical testing, fracture occurred at the osteotomy site in most of the bones. In a few plate-fixed tibiae the fracture was oblique, going through the osteotomy site

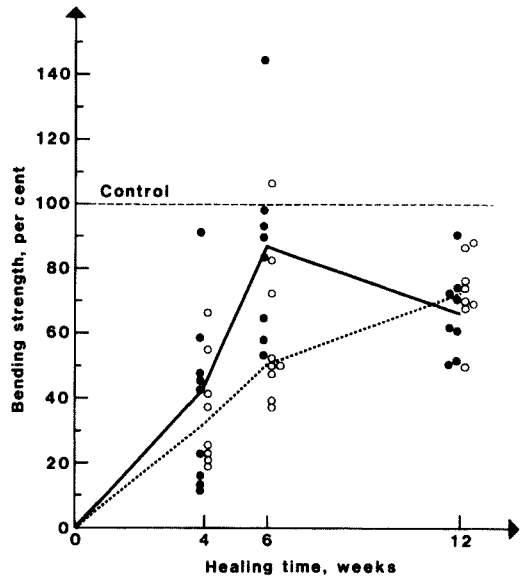


Figure 4. Median bending strength of osteotomized bones after plate fixation (—) and external fixation (-----). The percentage of strength of the osteotomized tibia in relation to the control tibia is indicated for all the animals (● plate fixation, ○ external fixation). Note the considerable variation of the values, especially at 4 and 6 weeks.

Table 2. Bending strength, elastic stiffness and deformation at fracture of osteotomized tibiae, expressed as the percentage of the corresponding values for the control bones

	4 weeks		6 weeks		12 weeks	
	Plate fixation n=9	External fixation n=8	Plate fixation n=8	External fixation n=9	Plate fixation n=8	External fixation n=8
Strength						
Median	43.0	31.8	87.2	50.2	66.4	72.4
Range	13–92	19–67	54–145	38–107	51–91	50–87
Stiffness						
Median	87.9	64.8	110.5	119.2	127.1	110.7
Range	10–172	15–121	89–227	74–178	74–169	92–141
Deformation						
Median	64.8	80.6	90.1	71.9	68.2	71.0
Range	52–248	30–262	41–123	13–86	47–97	48–101

and the nearest screw hole. The bending strength, elastic stiffness and deformation at fracture are shown in Table 2. The strength and stiffness percentages varied considerably, especially after 4 and 6 weeks (Figure 4). At 12 weeks the values were more even. The tibiae treated with a plate tended to be somewhat stronger than those with external fixation after 4 weeks, but the difference was not significant. At 6 weeks the strength of the plated bones was significantly greater than those externally fixed ( $P = 0.03$ ). At 12 weeks the strength was slightly higher in the external fixation group, but the difference was not significant. The strength of the plate-fixed tibiae increased up to 6 weeks, when it had almost reached the values of the control bones. From 6 to 12 weeks the strength decreased, but the difference was not significant. In animals with external fixation the strength increased significantly from 4 to 6 weeks, and from 6 to 12 weeks.

The stiffness increased more rapidly than the strength (Table 2). The stiffness was above normal value at 6 weeks, but thereafter did not increase further (Figure 5). No significant differences regarding stiffness were found between the methods of treatment at either time interval. The same was true regarding the deformation at fracture. Neither was there any significant relation between the mechanical properties and the amount of periosteal callus in any of the groups.

Table 3 shows the bone mineral content. It was greatly increased at the diaphyseal level between the distal screw-holes in the plate and

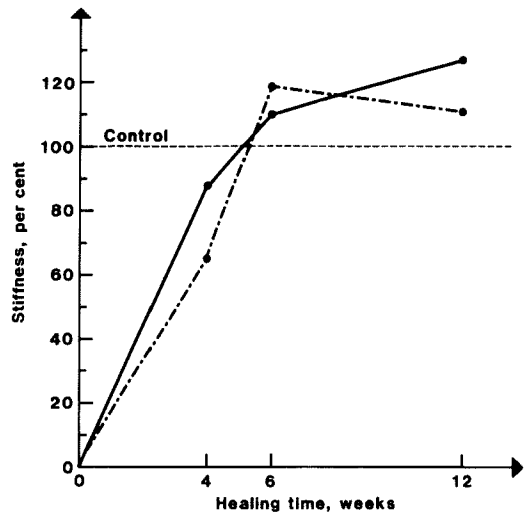


Figure 5. Median elastic stiffness of osteotomized bones after plate fixation (—) and external fixation (---). The stiffness exceeds normal values at an early stage of healing.

5 mm proximal to the distal pin group in tibiae with external fixation. Although the mineral content tended to be greater in plate-fixed bones after 4 and 6 weeks, there were no significant differences between the methods. In the diaphysis distal to the fixation device, only a slight increase in bone mineral content was found.

Histological examination showed that the healing pattern was predominantly by periosteal and endosteal callus in the early stages of healing, that is after 4 and 6 weeks. After 12 weeks most of the endosteal callus had been resorbed. Between the cortical ends

Table 3. Bone mineral content at the diaphyseal level previously stabilized by the plate or external fixation but outside the osteotomy site (central level), and 1 cm distal to the fixation device (distal level). The values for osteotomized bones are given as the percentage of the values for the control bones

	4 weeks		6 weeks		12 weeks	
	Plate fixation	External fixation	Plate fixation	External fixation	Plate fixation	External fixation
<b>Central level</b>						
Median	198	161	172	147	136	139
Range	132-222	121-206	129-268	141-208	84-164	76-179
<b>Distal level</b>						
Median	114	116	100	118	112	105
Range	96-144	84-148	79-116	84-132	93-115	84-116

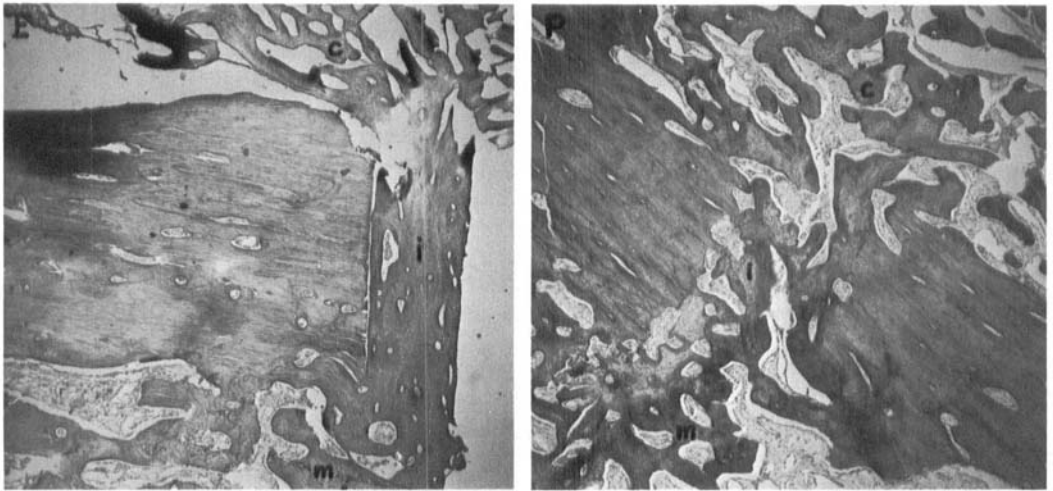


Figure 6. Photomicrographs ( $\times 39$ ) demonstrating the healing pattern after external fixation (E) and plate fixation (P) at 6 weeks. Healing occurred by periosteal (c), intramedullary (m) and intercortical (i) callus after both methods. Note the orientation of the intercortical bone lamellae perpendicular to the long axis of the cortical bone.

of the two fragments bone healing occurred as "gap healing". No obvious differences in the healing pattern between the two methods were observed (Figure 6).

## Discussion

Tibial osteotomies treated by external fixation in the present study healed by periosteal as well as intramedullary and intercortical callus, which is in agreement with previous reports (Yamagishi & Yoshimura 1955, Laros 1974, Aalto et al. 1981). Healing occurred in the same manner in plate-fixed bones. It was somewhat unexpected that no significant differences regarding the amount of periosteal callus were found, as plate fixation represented a more rigid fixation than did external fixation (Terjesen & Benum 1983b). However, relatively great bending loads are apt to occur at the osteotomy site in rabbit tibiae, as weight-bearing is resumed shortly after the operation, and the bone is under considerable bending stress during sitting and jumping. In addition, a relatively thin steel plate was used, which obviously permitted sufficient mobility at the osteotomy site to stimulate periosteal callus formation. With more rigid plates on the rabbit tibia, healing

takes place with very little or no periosteal callus (Rahn et al. 1971, Paavolainen et al. 1979).

The amount of intramedullary callus was greatest after 4 weeks, less after 6 weeks and almost disappeared after 12 weeks. These findings are in agreement with those of other experimental fracture studies (Falkenberg 1961, Anderson 1965, Olerud & Danckwardt-Lillieström 1968, Rhineland 1974). Hence, it seems that this type of callus has a temporary character. It represents the earliest bony union, provided that the fixation and the intramedullary blood supply are sufficient (Anderson 1965, Rhineland 1974).

The bone mineral content in the diaphysis stabilized by the plate or external fixation was increased compared to the control tibiae after all time intervals. The main reason was probably that it was measured so near the osteotomy site that some periosteal callus was included in the measurements. The mineral content decreased with time, partly because of the remodelling process with the decreasing amount of periosteal callus, and partly because of the stress-protecting effect of the fixation. The mineral content in the distal part of the diaphysis was mainly unaltered, indicating that no disuse osteoporosis had taken place in the osteotomized bones.

The stiffness increased more rapidly than the strength in both plated and externally fixed tibiae. This is in accordance with the results of Henry et al. (1968) and Rand et al. (1981), but not with those of others (Braden et al. 1973, Paavolainen et al. 1979). It has been suggested that the rate of healing is regulated by the stiffness of the healing bone (Henry et al. 1968). The present results indicate that there is a rapid return of normal stiffness to the bone after plate fixation as well as after external fixation. However, the factors that regulate the process are not known at present.

The strength was greater after plate fixation than after external fixation in the early stages of healing. It has been shown that increased stability favours the early restoration of the torn medullary vessels (Rhineland et al. 1968, Ganz et al. 1970), and stimulates the early production of intramedullary callus (Anderson 1965, Rhineland 1974). These observations might explain why bone healing was more rapid after plate fixation than after external fixation.

Previously only one report comparing the biomechanical properties of the healing bones after metal plate fixation and external fixation has been published (Aalto et al. 1981), but quantitative data were not given. The torsional strength increased from 3 to 12 weeks in both groups, and external fixation provided more favourable conditions for fracture repair than did plate fixation. These findings were not confirmed in the present study. However, plates of different stiffness and different external fixation devices were used, making direct comparison of the results difficult.

The biomechanical properties of the healing bones after external fixation are in accordance with those of White et al. (1977). They found an average strength (torque) of about 34 and 59 per cent in relation to control bones after 4 and 6 weeks, respectively. The results of biomechanical studies after plate fixation of rabbit tibiae are more divergent. In the present study the strength and stiffness had reached about normal values after 6 weeks, as has also been reported after the use of a much more rigid plate (Paavolainen et al. 1979). However, a strength percentage of only 20 and 30 after 8 and 16 weeks, respectively, was re-

ported by Jäger et al. (1976). Their method was somewhat different, as a more distal tibial osteotomy was made, and the patellar and Achilles tendons were cut. The various stiffnesses of the applied fixation may also be partly responsible for the divergent results, but this is difficult to assess because the stiffness has not been determined in any of the series, apart from the present study.

The period of time plays an important role in the evaluation of bone healing. The findings in the present study confirm those of numerous previous investigations, that bone healing of experimental osteotomies after plate fixation is a rapid process (Bagby & Janes 1958, Schenk & Willenegger 1963, Anderson 1965, Olerud & Danckwardt-Lillieström 1968, Rahn et al. 1971, Paavolainen et al. 1979). However, after the phase of bone union is accomplished, the remodelling of the bone begins; the periosteal and intramedullary callus being resorbed according to Wolff's law. In this later stage the stress-protecting effect of rigid metal plates has an adverse effect on cortical bone (Uthoff & Dubuc 1971, Låftman et al. 1980). This might explain the reduced strength of the healing bones in the late stage of healing found in the present series as well as reported by others (Noser et al. 1977, Paavolainen et al. 1979, Sarmiento et al. 1980). In order to avoid permanent atrophy and weakening of the bone, the rigid plate should be removed as soon as the biomechanical qualities of the bone have reached a certain stage. However, the optimum time for plate removal has not yet been determined.

## Conclusions

1. In the early stage of healing, that is 4–6 weeks, a greater strength of the healing bones was found after metal plate fixation compared to external fixation. In the later stage of healing (12 weeks), no differences were found in biomechanical properties between the two groups.
2. The speed of bone healing of rabbit tibial osteotomies was more rapid after plate fixation than after external fixation.
3. In the late stage of healing, the bones

with plate fixation are secondarily weakened because of the stress-protecting effect of the stiff plate.

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