

STRESS-PROTECTION AFTER EXTERNAL FIXATION ON THE INTACT RABBIT TIBIA

TERJE TERJESEN & PÅL BENUM

Department of Orthopaedic Surgery, Trondheim University Hospital, Trondheim, Norway

Bone loss due to the stress-protecting effect of a metal plate on intact bone is a well-known phenomenon. The purpose of the present study was to find whether a similar effect is caused by external fixation.

External mini-fixation was applied on the intact rabbit tibial diaphysis of one leg. The other tibia served as control. The animals were sacrificed after 6 or 12 weeks, and both tibiae biomechanically tested in three-point bending. The bone mineral content was measured by photon absorptiometry.

No significant changes in bone strength, stiffness or mineral content were found after 6 weeks. The strength and stiffness were significantly reduced after 12 weeks. The median strength and stiffness at that time were 87 and 88 per cent, respectively, in relation to the control bones. The mineral content in the bone segment which had been stabilized by external fixation was significantly reduced after 12 weeks (median 90 per cent of the values for the control bones). No significant change in the mineral content occurred at a level in the tibial diaphysis distal to the external fixation device.

It is concluded that the stress-protecting effect caused by external mini-fixation on the rabbit tibia occurs later, and is less pronounced, than that caused by metal plates.

Key words: bone mineral content; bone strength; external fixation; stress-protection

Accepted 21.i.83

Application of a rigid metal plate on intact, diaphyseal bone leads to bone loss and reduced strength in the plated bone segment (Uthoff & Dubuc 1971, Paavolainen et al. 1978, Låftman et al. 1980). This results from the partial protection from functional stress afforded to the bone due to load sharing with the plate. The purpose of the present *in vivo* investigation was to find whether a similar stress-protecting effect is caused by external fixation. The mineral content and the biomechanical qualities of the bone were examined after external fixation on the intact rabbit tibia.

MATERIALS AND METHODS

Operative procedure

Eighteen Chinchilla rabbits of both sexes weighing from 2230 to 4120 g were used. The rabbits were anaesthetized with intramuscular injections of Hypnorm® Vet (Leo). All operations were performed under strictly sterile conditions. The right or left leg was operated, while the other served as control. A straight anterior incision was made over the middle part of the tibia, and the lateral aspect of the bone exposed by retracting the tibialis anterior muscle. The external mini-fixation (Jacquet Orthopedie S.A., Geneva) was applied on the middle part of the intact tibial diaphysis. The tibio-fibular junction, which represents the mid-

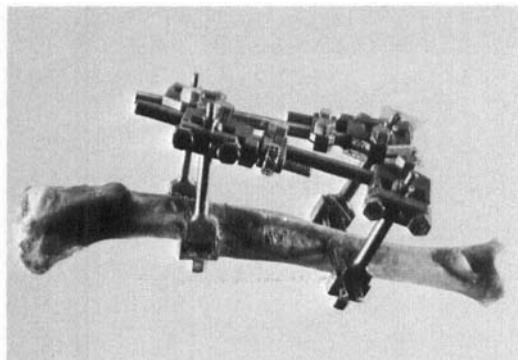


Figure 1. The picture shows how the external mini-fixation frame was mounted. Smooth, transfixing pins were used.

point of the tibia, served as a landmark for the positioning of the pins. 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 plane, and the external frame mounted (Figure 1). The fascia and skin were sutured with Dexon®. Both legs were radiographed immediately after the operation (Figure 2).

Postoperative treatment and complications

The rabbits were kept in separate cages in which they could move freely. They received adequate food and water supply, and were observed daily. Most rabbits tolerated the external fixation well, and after a few days full weight-bearing was resumed. No pin hole infections occurred.

Six animals were excluded from the study because of postoperative complications (five cases) and technical failure during the biomechanical testing (one case). A fracture occurred through the proximal or distal pin holes in four cases, probably because the projecting parts of the fixation frame was stuck into the holes of the cage floor, and the animals tried to wrench themselves free. To avoid this complication the frame had to be bandaged with a padded dressing. In one case the screws of the fixation frame worked loose, and the frame disconnected.

The animals were divided into two groups. Each group consisted of six animals, which were sacrificed with injections of lethal doses of mebupal after 6 and 12 weeks, respectively.

After sacrifice the external fixation frame was unscrewed, and both tibia dissected free of all soft tissue, and the fibulae removed. The bones were radiographed (Figure 3), and then wrapped in towels soaked with Ringer's solution, and stored at -18°C until testing.

Measurement of bone mineral content

The tibiae were thawed to room temperature before testing. The bone mineral content was measured by photon absorptiometry (Cameron & Sorensen 1963). A commercially available scanning device with 60 keV gamma radiation from ^{241}Am was used (AB Gambio, Lund). Scanning was performed across the bones at two levels: Through the middle of the bone segment between the pin groups, and 1 cm distal to the distal pin hole. The mineral content was expressed in g/cm, and the value for the bone with external fixation expressed as the percentage of the value for the control bone.

Biomechanical tests

The bones were tested in three-point bending in the antero-posterior direction in an Instron testing machine as previously described (Terjesen & Benum 1983a). The deformation of the bone segment between the pin groups was measured with a linear, variable, differential transformer (LVDT). The load was applied halfway between the proximal and distal pin holes. All tibiae were loaded to fracture, which occurred at the same

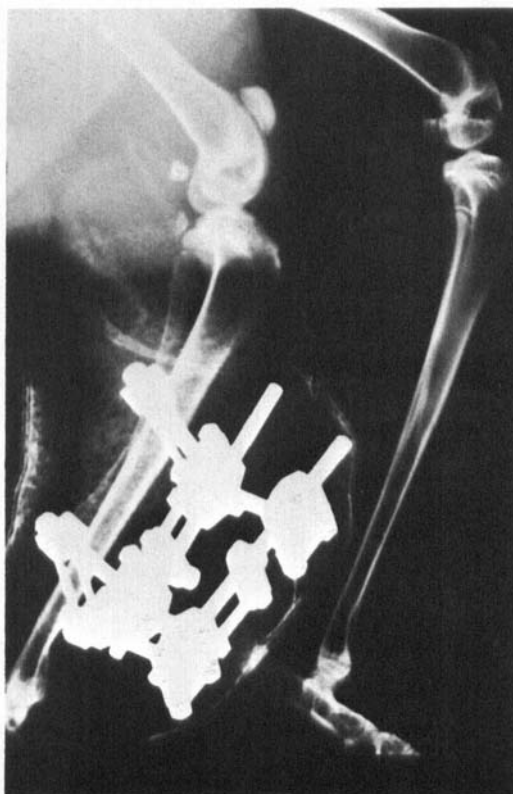


Figure 2. Postoperative radiograph showing the external mini-fixation mounted on one tibia.

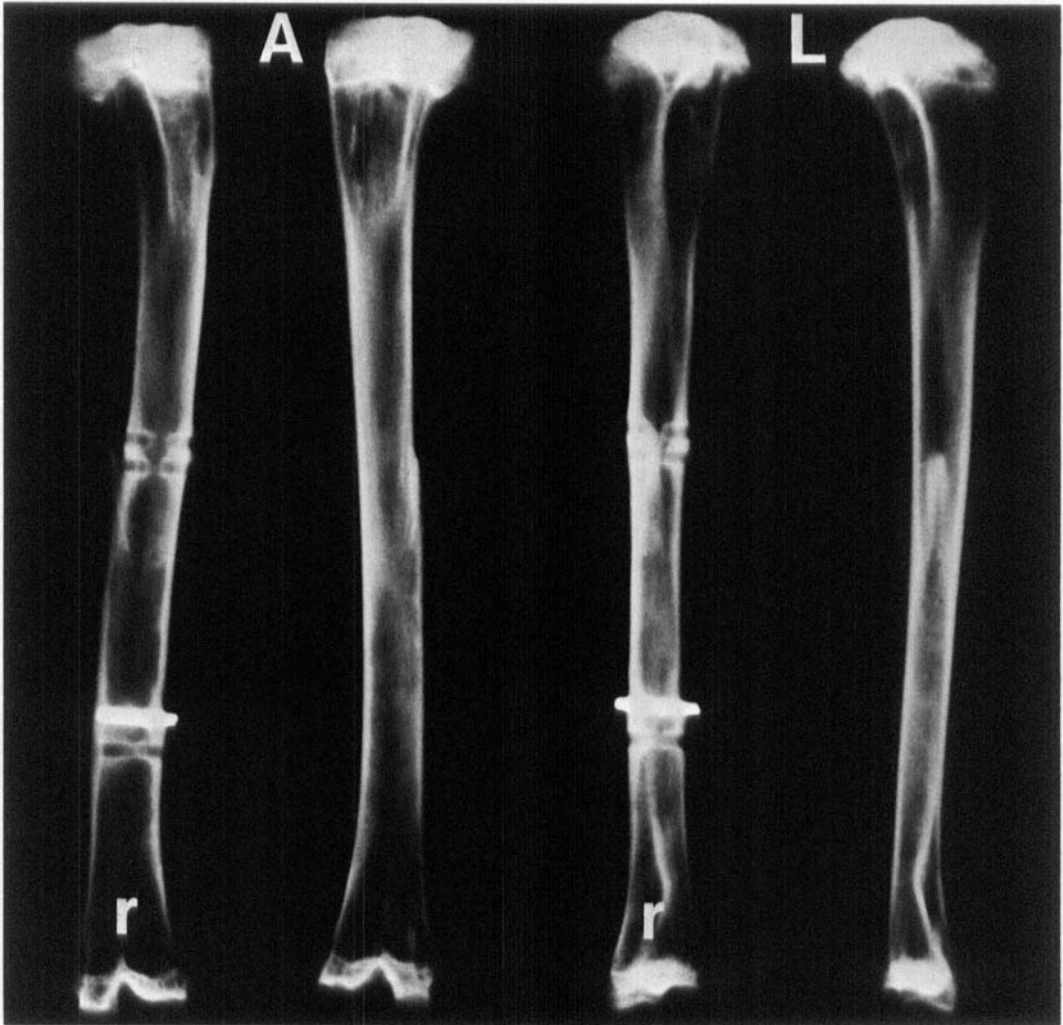


Figure 3. Antero-posterior (A) and lateral (L) radiographs of both tibiae after sacrifice of a rabbit where external fixation had been applied on the right tibia (r) for 12 weeks. One of the distal pins had to be cut because it was firmly anchored to the bone.

bone level as the load was applied. From the load-deformation diagrams the bending strength, elastic stiffness and deformation at fracture were obtained.

Histological examination

The tibiae of one animal from each group were histologically examined, to see whether osteoporosis had occurred in the bones with external fixation. A bone segment of 5 mm length was taken from the mid-tibial diaphysis. The structure of the cross-section of the bone was studied by reflected-light microscopy of sections prepared by a metallographic techniques (Pugh et al.

1972). A point-counting method was used to determine the percentage of intracortical porosity (Weibel 1979).

Studies on paired tibiae of untreated animals

In order to find whether there exists a symmetry between the paired right and left side, both tibiae of 15 rabbits were examined by photon absorptiometry and loaded in bending as previously described. The mean bone mineral content, bending strength and elastic stiffness were 0.6 per cent, 2.7 per cent and 1.1 per cent greater, respectively, for the right tibia compared to the

left. The differences were not significant for any of the parameters.

Statistical analysis

The Wilcoxon signed rank test for paired samples (two-tailed test) was used to calculate the statistical differences between paired bones with and without external fixation. Differences were considered significant at P -values below 0.05.

RESULTS

The median strength of the bones after 6 and 12 weeks with external fixation was 98.6 and 86.5 per cent, respectively, in relation to the control bones (Table 1). The strength of the treated bones was significantly reduced after 12 weeks ($P = 0.032$) but not after 6 weeks. The elastic stiffness and the deformation at fracture are given in Table 2. The stiffness was significantly reduced after 12 weeks ($P = 0.032$), but not after 6 weeks. No significant differences were found regarding the deformation at fracture, either after 6 or after 12 weeks.

The median bone mineral content at the mid-diaphyseal level (in the bone segment previously stabilized with external fixation) was 98.7 and

Table 1. The bending strength (Newton metres) of rabbit tibiae after external fixation, and of control bones. The table also shows the strength of the bone after external fixation in per cent of the strength of the control bone

	6 weeks <i>n</i> =6	12 weeks <i>n</i> =6
Bones after external fixation,		
Bending moment (Nm),		
median	5.21	4.55
range	3.27–5.39	2.87–6.40
Control bones,		
Bending moment (Nm),		
median	5.28	5.61
range	4.04–6.42	3.13–7.70
Strength (per cent) of the bone after external fixation,		
median	99	87
range	81–110	76–92

Table 2. Elastic stiffness, and deformation at fracture of bones after external fixation, expressed as the percentage of the values for the control bones

	6 weeks <i>n</i> =6	12 weeks <i>n</i> =6
Elastic stiffness,		
median	99	88
range	86–112	86–96
Deformation,		
median	102	99
range	83–115	86–102

Table 3. Bone mineral content (g/cm) at the mid-diaphyseal level of rabbit tibiae after external fixation, and of control bones. The table also shows the mineral content of the bone after external fixation in per cent of the value for the control bone

	6 weeks <i>n</i> =6	12 weeks <i>n</i> =6
Bones after external fixation,		
mineral content (g/cm),		
median	0.185	0.178
range	0.155–0.199	0.110–0.239
Control bones,		
mineral content (g/cm),		
median	0.185	0.206
range	0.164–0.211	0.151–0.267
Mineral content (per cent) of the bone after external fixation,		
median	99	90
range	82–106	73–92

Table 4. Bone mineral content at a diaphyseal level 1 cm distal to the distal pin hole of tibiae after external fixation, expressed as the percentage of the values for the control bones

	6 weeks <i>n</i> =6	12 weeks <i>n</i> =6
Mineral content,		
median	104	105
range	87–123	87–119

89.7 per cent, respectively, in relation to the control bones (Table 3). The mineral content was significantly reduced after 12 weeks ($P = 0.032$),

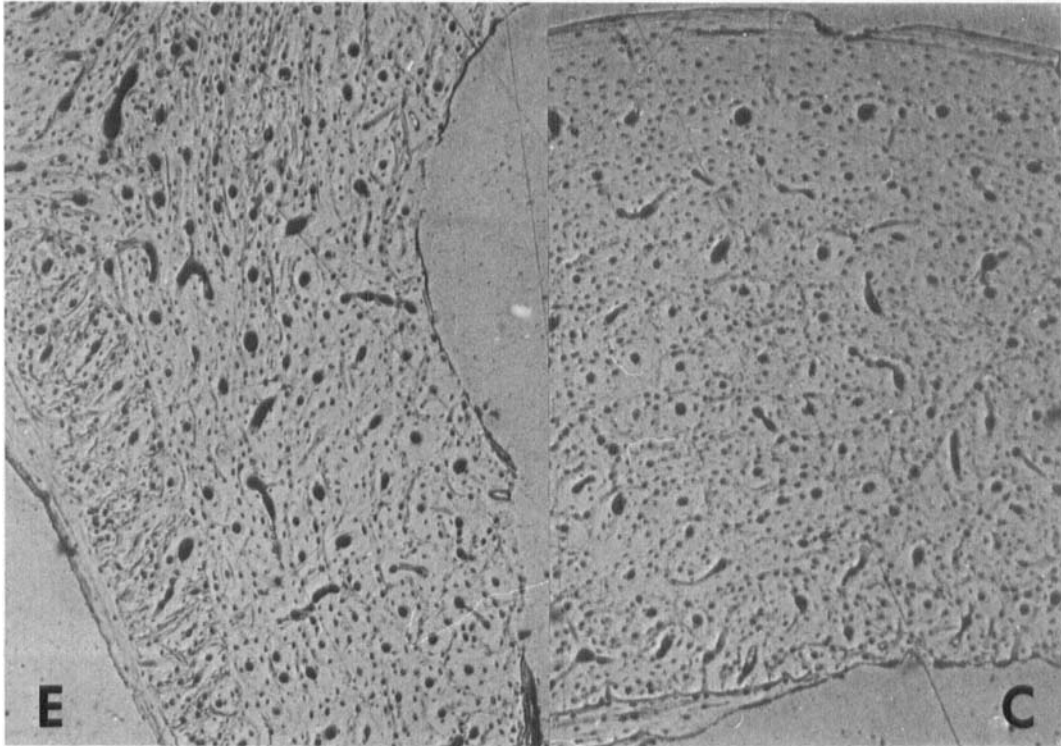


Figure 4. Histological sections (reflected-light microscopy, $\times 37.5$) of cortical bone at the mid-diaphyseal level from a tibia where external fixation had been applied for 12 weeks (E), and from the contralateral control tibia (C). A slightly increased intracortical porosity was found in the bone after external fixation.

but not after 6 weeks. In the tibial diaphysis 1 cm distal to the distal pin the mineral content was not reduced either after 12 or after 6 weeks (Table 4).

The histological examination showed a slightly increased porosity of the tibia where external fixation had been applied for 12 weeks (Figure 4). No increased porosity was found in the tibia with external fixation for 6 weeks.

DISCUSSION

No significant differences were found in strength, stiffness and mineral content between the paired left and right tibia of 15 unoperated rabbits of the same breed as those treated with external fixation. Hence, there is a high degree of symmetry in mechanical properties between paired bones in rabbits, which has also been found in other

studies (White et al. 1974, Paavolainen et al. 1978, Låftman et al. 1980). This justifies the use of one tibia, chosen at random, as test bone, and the other as control in the present investigation.

In a previous study a good accordance between the *in vitro* biomechanical effects of external mini-fixation on intact rabbit tibiae (with the same frame mounting as in the present study) and the Vidal-Adrey double frame on intact human tibiae was found (Terjesen & Benum 1983a). The bones were tested in bending (anteroposterior direction) before and after application of the external fixation device. A median stiffness increase of the stabilized bone segment of 10.2 per cent in human tibiae and of 6.1 per cent in rabbit tibiae were found. Thus, we feel that external mini-fixation on the intact rabbit tibia is a suitable model for studies of the stress-protecting effect caused by external fixation.

After application of external fixation for 12

weeks on the intact rabbit tibial diaphysis, a significant reduction in strength, stiffness and mineral content were found in relation to the control bones. No significant changes regarding the same parameters occurred after 6 weeks. This indicates that external fixation causes a stress-protecting effect on the bone after 12 weeks. An objection to this interpretation might be that the animals were apt to bear less weight on the leg with external fixation, and that this was the reason for the reduced strength and mineral content. However, no reduction in bone mineral content occurred in the diaphysis distal to the pins, which implies that a disuse osteoporosis had not taken place. This is in agreement with the observation that the rabbits resumed full weight-bearing on the operated leg a few days postoperatively.

After application of different plates on the intact femur of dogs, less rigid plates have been shown to cause less bone atrophy (Woo et al. 1976, Moyen et al. 1978). *In vitro* studies of intact human as well as intact rabbit tibiae showed that a greater stiffness increase in the stabilized bone segment was obtained after application of a steel plate than after external fixation (Terjesen & Benum 1983a). Accordingly, a less pronounced stress-protection is likely to occur after external fixation than after plate application. This was confirmed in the present study, as relatively slight bone changes were found. A median reduction in bending strength and stiffness after 12 weeks of 13.5 and 12.2 per cent, respectively, were found, compared to reductions of the same parameters of about 25 per cent after application of a six-hole steel plate of 5×1 mm cross-section (Terjesen & Benum 1983b). Låftman et al. (1980) found a reduction in torsional strength of about 50 per cent after application of a considerably more rigid plate (6×2 mm cross-section) for 12 weeks. Furthermore, the stress-protecting effect occurred even at 6 weeks after plating (Terjesen & Benum 1983b, Låftman et al. 1980). Thus, the stress-protecting effect caused by external mini-fixation on intact rabbit tibiae occurs later, and is less pronounced, than that caused by metal plates.

The histological examination showed a slightly increased intracortical porosity after 12 weeks, but no changes after 6 weeks. This corresponds

well with the results of the biomechanical tests and the photon absorptiometry. Aalto (1981) found cortical resorption, but not to the extent that cancellous transformation took place, after external fixation of intact rabbit tibiae. This is in accordance with our findings. It was maintained by Aalto (1981) that the histology reflected the local reaction of the bones to the transfixing pins. The present study did not confirm this, and we are of the opinion that the changes are caused by the stress-protecting effect of the fixation frame on the bone.

The clinical consequences of the findings in this study might be that external fixation should be removed as soon as the fracture healing permits it, in order to avoid the stress-protecting effect. This is especially important with regard to the most rigid frames. Timing of the removal of the external fixator is quite variable in clinical practice (Ordway 1982). In some cases of severe tibial fractures the external fixator is not removed until more than 1 year after the accident (Benum & Svenningsen 1982, Krempe et al. 1979, Edge & Denham 1981). If one of the most rigid frames has been used primarily, it is probably rational to change the treatment after a certain stage of healing has occurred to a frame mounting with less stiffness, or to a tibial brace.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to Materials Technology Division, The Foundation of Scientific and Industrial Research at the Norwegian Institute of Technology, for expert assistance in the mechanical testing. We are indebted to Gallus-Plesner A/S, Oslo and Jaquet Orthopédie S.A., Geneva, for their donation of the external mini-fixation equipment.

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

REFERENCES

- Aalto, K. (1981) Bone changes after external fixation. Proceedings of the Scandinavian Orthopaedic Association. *Acta Orthop. Scand.* **52**, 458.
- Benum, P. & Svenningsen, S. (1982) Tibial fractures treated with Hoffmann's external fixation. *Acta Orthop. Scand.* **53**, 471–476.

- Cameron, J. R. & Sorensen, J. (1963) Measurement of bone mineral in vivo: An improved method. *Science* **142**, 230–232.
- Edge, A. J. & Denham, R. A. (1981) External fixation for complicated tibial fractures. *J. Bone Joint Surg.* **63-B**, 92–97.
- Krempen, J. F., Silver, R. A. & Sotelo, A. (1979) The use of the Vidal-Adrey external fixation system. *Clin. Orthop.* **140**, 111–121.
- Låftman, P., Sigurdsson, F. & Strømberg, L. (1980) Recovery of diaphyseal bone strength after rigid internal plate fixation. *Acta Orthop. Scand.* **51**, 215–222.
- Moyen, B. J-L., Lahey, P. J., Weinberg, E. H. & Harris, W. H. (1978) Effects on intact femora of dogs of the application and removal of metal plates. *J. Bone Joint Surg.* **60-A**, 940–947.
- 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.
- Paavolainen, P., Slätis, P., Karaharju, E. & Holmström, T. (1978) Studies on mechanical strength of bone. *Acta Orthop. Scand.* **49**, 506–511.
- Pugh, J. W., Rose, R. M. & Radin, E. L. (1972) Techniques for the study of the structure of bone. *Microstructures* **3**, 23–27.
- Terjesen, T. & Benum, P. (1983a) A biomechanical study of the in vitro effects of external fixation on intact and osteotomized tibiae. *Acta Orthop. Scand.* (accepted for publication).
- Terjesen, T. & Benum, P. (1983b) The stress-protecting effect of metal plates on the intact rabbit tibia. *Acta Orthop. Scand.* (submitted for publication).
- Uthoff, H. K. & Dubuc, F. L. (1971) Bone structure changes in the dog under rigid internal fixation. *Clin. Orthop.* **81**, 165–170.
- Weibel, E. R. (1979) *Stereological methods*, Vol. 1. Academic Press, London.
- White, A. A., Panjabi, M. M. & Hardy, R. J. (1974) Analysis of mechanical symmetry in rabbit long bones. *Acta Orthop. Scand.* **45**, 328–336.
- Woo, S. L-Y., Akeson, W. H., Coutts, R. D., Rutherford, L., Doty, D., Jemmott, G. F. & Amiel, D. (1976) A comparison of cortical bone atrophy secondary to fixation with plates with large differences in bending stiffness. *J. Bone Joint Surg.* **58-A**, 190–195.

Correspondence to: Terje Terjesen, Department of Orthopaedic Surgery, Trondheim University Hospital, N-7000 Trondheim, Norway.