Acta Orthop. Scand. *58*, 66–70, 1987

Fracture repair during external fixation

Torsion tests of rabbit osteotomies

Bone repair was studied in the rabbit tibiofibular bone after a midshaft transverse osteotomy stabilized by external fixation and heavy compression. Both subendosteal and subperiosteal callus formation with concomitant contact healing were observed within 3 weeks, and were further succeeded by subendosteal resorption and increased porosis resulting in atrophy of the cortical bone. Subjected to the torsion test, the bones exhibited restoration of strength within 3 weeks, with maximal energy absorption and elasticity at 6 weeks. The failure of the osteotomy in the torsion test, with radiographic visibility of the osteotomy, characterized the soft-tissue type of behavior of the bones. Hard-tissue like behaviour of the bones with resistance to torsion at the osteotomy site and radiographic obliteration of the osteotomy line occurred by 12 weeks, indicating complete union of the osteotomy. Our experiments demonstrate that elastic external fixation is preferable to the rigid compression plate.

Kari Aalto
Teddy Holmström[1]
Erkki Karaharju[2]
Jaakko Joukainen[3]
Pekka Paavolainen[3]
Pär Slätis[4]

Department of Surgery, Aurora Hospital, Nordenskiöldinkatu 20, 00250, Helsinki 25, Finland, [1]Department of Pathology, University of Helsinki, [2]Department of Orthopedics and Traumatology, Helsinki University Central Hospital, [3]Division of Orthopedic Surgery and Traumatology, Surgical Hospital, University Central Hospital, Helsinki, and [4]The Orthopedic Hospital of the Invalid Foundation, Helsinki, Finland

After compression-plate osteosynthesis, obliteration of the fracture line has been reported as a sign of healing by interfragmentary bone ingrowth (Rüedi & Allgöwer 1974). This does not, however, necessarily mean that the preinjury strength has recovered (McKibbin 1978). Greiff (1979) found no correlation between the degree of union and the radiographic and histologic appearance after compression-plate osteosynthesis. Compression is achieved also by external fixation in order to prevent interfragmentary movement. Contrary to the findings of Matzen (1955), Yamagishi & Yoshimura (1955), and Laros (1974), who noted fracture repair via callus formation in the rabbit tibia, Mayer (1981) reported callus-free contact healing in the osteotomy of sheep tibia after heavy compression by external fixation.

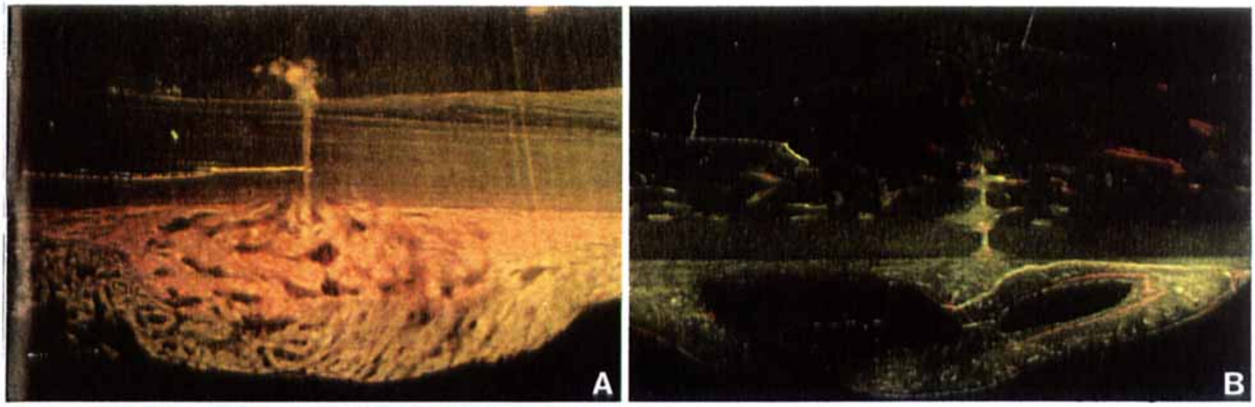
In order to clarify the role of compression for fracture repair and restoration of bone strength, we have studied external fixation of osteotomies in rabbits.

Materials and methods

Thirty-six adult rabbits weighing between 2,600 and 4,200 grams were subjected to osteotomy of the right tibiofibular bone. The bone was exposed through an anterolateral incision, and the osteotomy was performed transversely with a circular saw just distal to the tibiofibular junction. A Rezaian-Karaharju external fixation device with four transfixation pins and two bilateral adjustable side-bars was used for fixation. The distortion of the device was 0.003 (0.001) mm/N in axial loading, 1.7 (0.2 S.D.) deg/Nm in torsion. Compression was applied with a moment wrench calibrated with mechanical scales; 100 N was chosen as the maximum compression that the bones could tolerate.

Full weight bearing was allowed immediately after the operation. Bone growth was labelled with parenteral doses of alizarin red 30 mg/kg, oxytetracyclin 50 mg/kg, and xylenol orange 30 mg/kg, given after half and three quarters of the immobilization period and prior to killing.

Due to infection and fixation failure, 6 rabbits were excluded, leaving 30 rabbits, which were killed



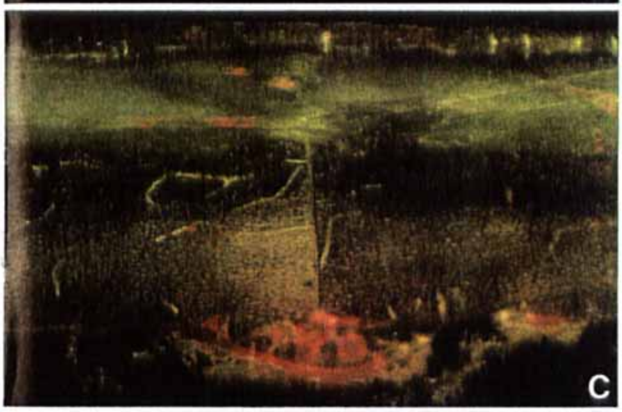
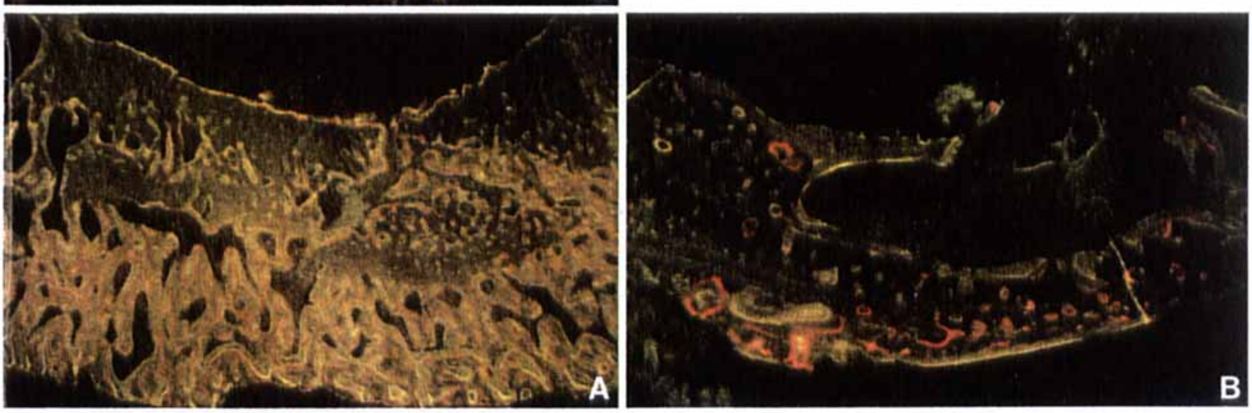


Figure 1. Low power fluorescence photomicrographs of longitudinal sections at the osteotomy site, three (A), 12 (B) and 24 (C) weeks after osteotomy. Note disappearing osteotomy line and maturing subperiosteal callus. At 12 weeks transverse osteons can be seen crossing the osteotomy line.



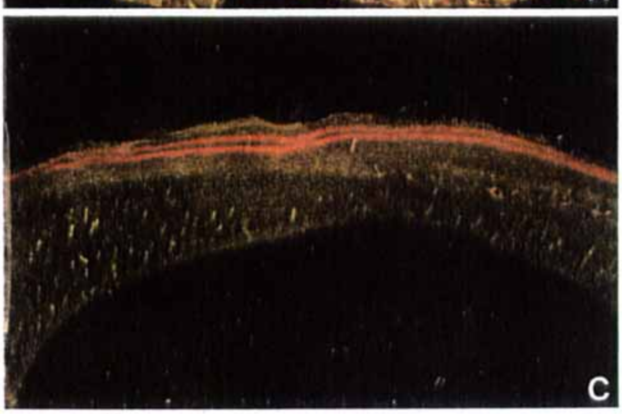


Figure 2. Low power fluorescence photomicrographs of transverse sections at the osteotomy site, six (A), 12 (B) and 36 (C) weeks after osteotomy. Note rather extensive subperiosteal callus formation maturing to lamellar bone. Heavy subendosteal resorption removes original cortical bone which enlarges the medullary cavity.

in subgroups of five, 1, 3, 6, 12, 24, and 36 weeks after the osteotomy. The fixation device was removed and radiographs of the osteotomy were taken in two projections. The tibias were then tested in a torsiometer with an angular speed of 14 deg/sec. The energy absorption and angular deformation of the bones needed for breakage were recorded. The left, intact tibiofibula of each rabbit was similarly tested and served as a paired control.

The resulting fracture was documented radiographically, and any failure of the osteotomy and its radiographic visibility were noted. In the fracture evaluation, even partial failures of the osteotomy line were recorded as failures. The osteotomy line was considered to be obliterated when the fracture ends had become indistinct and faded.

The fractures were reduced and the specimens were embedded in methylmetacrylate. Three transverse and two longitudinal sections, 15 microns thick, were made of each group of five bones for fluorescence microscopy. Longitudinal sections were inspected for callus and appearance of the osteotomy line. In the transverse sections, the amount of cortical bone as a percentage of the total transsectional area, representing the extent of callus formation, was measured by planimetry. The porosity of the cortical bone was calculated from photographic enlargements of the sections by counting the average of five symmetrically placed line samplings crossing each other in the midpoint of the medullary cavity.

Results

In the longitudinal sections the osteotomy line was clearly distinguishable up to 12 weeks; it had almost disappeared at 24 weeks, and it was not visible at 36 weeks. One week after the operation the bone displayed no dye-labelled activity. From 3 weeks on, osteons could be observed crossing the osteotomy gap; a sign of contact healing (Figure 1). Bone formation was observed both subperiosteally and subendosteally 1 week after the osteotomy; labelling showed that it had mainly occurred 1.5 weeks after osteotomy. Within 12 weeks, the new bone gradually matured into normal appearing cortical bone. Concomitantly, subendosteal resorption eroded most of the original cortex leaving a larger, thinner-walled tubular bone (Figure 2).

The vital dyes gave no further information after the most vigorous 6-week uptake period. From 12 weeks on, only weak fluorochrome activity was noted.

Torsion tests

One week after the operation, all the osteotomies were unstable and no testing was possible. At 3 weeks, the strength of the bones, characterized by their energy-absorption capacity, was found to be at the same level as that of the intact paired control bones (Figure 3). Maximum strength was recorded at 6 weeks; it was more than twice that of the controls. It was followed by a period of decreased resistance to torsional stress, about half that of the controls, from 12 weeks to the end of the experiment at 36 weeks. The angular deformation of the osteotomized bones at breakpoint was also greatest at 6 weeks, representing the phase of maximum elasticity (Figure 3). From 12 weeks on, angular deformation also diminished to an even, subnormal level, a sign of increased stiffness and fragility.

Radiographic observation

A rapid change in the radiographic appearance of the osteotomy line was noticed between 6 and 12 weeks. Up to 6 weeks, the osteotomy line was clearly visible, and it was indistinguishable at 12 weeks in 4 of the 5 rabbits, and

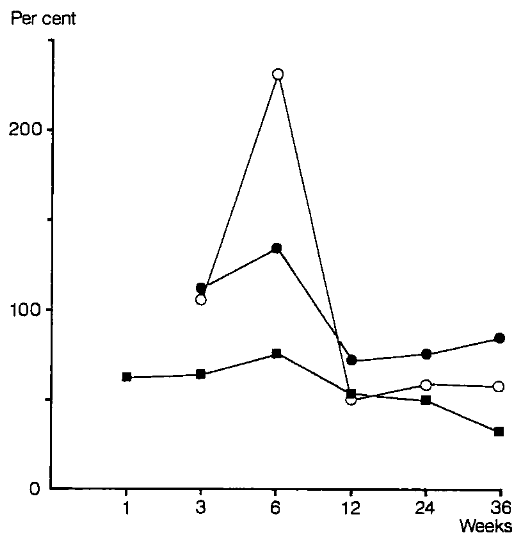


Figure 3. The energy-absorption capacity and angular deformation of the operated bones in the torsion test as a percentage of their contralateral intact pairs. The cortical area is expressed as the percentage of the cortical bone of the total transsectional area of the bone at the osteotomy site. N 30
○ Energy absorption. ● Angular deformation. ■ Cortical area.

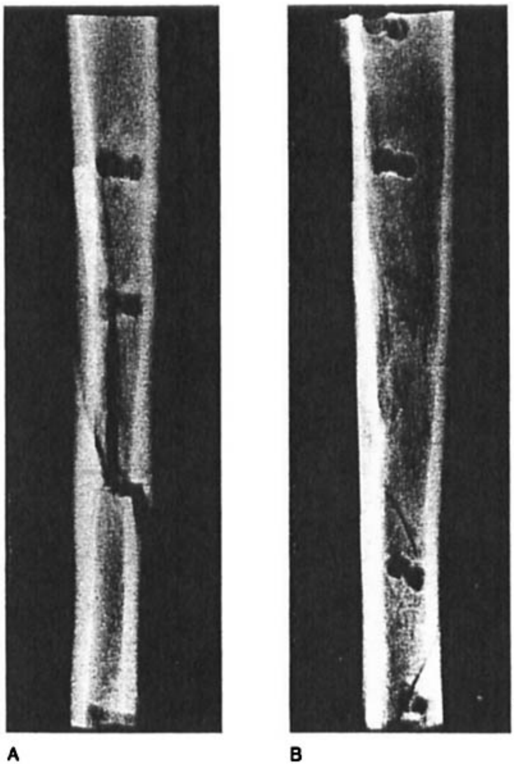


Figure 4. A. The torsional fracture six weeks after the osteotomy with partial failure of osteotomy line.
B. Twelve weeks after the operation the breakage passes through the distal pin holes as a spiral fracture with no failure of the osteotomy line.

from then to the end of the experiment, at 36 weeks.

In the radiographs of the fractures, a total or partial failure of the osteotomy was observed up to 6 weeks (Figure 4). At 12 weeks only one of five osteotomies failed, and subsequently a spiral fracture crossing the osteotomy site was observed in all the rabbits.

Proportion of cortical bone

The proportion of cortical bone appeared to be most extensive from 3 to 6 weeks, representing the phase of maximal callus formation (Figure 3). Due to the remodelling process, a normal proportion of cortical bone was observed from 12 to 24 weeks. Subsequently the cortical bone atrophied with a relative widening of the medullary cavity at the end of the experiment.

Table 1. Porotic transformation of diaphyseal bone during fracture repair after external fixation. Expressed as median percentage (range) of the cortical area. N 30.

Time after operation Weeks	Porosity	
1	8.0	(6.2–8.5)
3	11	(9.7–14)
6	19	(11–28)
12	26	(18–37)
24	27	(12–48)
36	19	(15–24)

Porosity of the left, intact tibiofibular bone, 8.1 (6.9–8.7) per cent.

Changes in the porosity of the cortical bone

No abnormalities were found in the structure of the cortical bone 1 week after osteotomy. At 3 weeks widening of the Haversian canals was observed, resulting in generalized porosis of the cortical bone at 6 weeks (Table 1). The structure of the cortical bone appeared to be normal at 12 weeks, and subsequently porosis was visible as isolated cysts in otherwise normal bone.

Discussion

Mayer's (1981) findings of callus-free contact healing after external fixation and heavy compression could not be demonstrated in our study, where fracture repair proceeded via concomitant callus formation and contact healing, as reported previously also after neutralizing external fixation (Wu et al. 1984) Compression does not seem essential for contact healing; on the contrary, conditions favouring callus-free contact healing cannot be achieved by the use of heavy compression alone, which seems to be more closely related to the stability of the fixation device (Laros 1974, Burger et al. 1977, Wu et al. 1984).

The elasticity of external fixation as a method of osteosynthesis also reduces the stress-protecting effect associated with rigid plate fixation (Terjesen & Benum 1983). Accordingly, porotic transformation of the cortical bone, which, after rigid plate fixation under similar experimental conditions, reached a maximum of 38 per cent (Paavolainen et al. 1979), was 27 per cent in our study.

Stability of the rabbit tibia after diaphyseal osteotomy and external fixation has been demonstrated within 24 days (Matzen 1955). White et al. (1977) distinguished four stages of fracture repair, finding a distinct change in load-deformation behavior at 4 weeks; from a rubbery quality to hard- tissue type. In our study the strength of the osteotomized bones was restored within 3 weeks. The osteotomy, however, still appeared rubbery in the torsion test, which also showed failure of the osteotomy line.

Decisive consolidation of hard- tissue type was found later, at 12 weeks. It was characterized by a normalized cortical bone mass, representing the stage of callus remodelling, as also reported for similar experimental conditions (Terjesen 1984).

Acknowledgements

This study was supported The Academy of Finland and Sigrid Juselius Foundation.

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