Acta Orthop Scand 57, 368–372, 1986

Effect of compression on fracture healing

Plate fixation studied in rabbits

Bilateral osteotomies in rabbit tibiae were secured with six-hole rigid plates, using axial compression on the right and no compression on the left side. Histological, histomorphometric and torsiometric analysis was performed up to 24 weeks postoperatively. Histological analysis showed end-to-end primary bone healing regardless of treatment. The fracture gaps tended to be smaller in the compression osteotomies, but union was achieved within the same time on both sides, and at 6 weeks torsiometric analysis of the paired specimens revealed similar mechanical properties. By the time the fracture had united both groups of bones showed similar degrees of subendosteal resorption. As a result of this porotic transformation the strength of the cortical bone was slightly impaired from 6 weeks onward, whether or not compression had been applied.

The results suggest that axial compression does not augment fracture healing of plated cortical bone.

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Introduction

It is agreed that axial compression increases the mechanical stability of plate osteosynthesis, but there is no firm evidence that compression stimulates or promotes fracture healing (Perren et al., 1969). Fixation with a rigid plate induces porotic transformation of the underlying cortical bone whether compression is used or not (Gördes et al. 1975, Paavolainen et al. 1978, Slätis et al. 1978, Terjesen & Benum 1983), and semirigid plates cause less porosity (Tonino et al. 1976).

Mechanical studies on the strength of healing fractures in cortical bone treated with various fixation methods with and without compression have been made (Laurin et al. 1963, Anderson 1965, Lettin 1965, Wolff et al. 1981) comparing the strength of bones from different animals. There are only a few experimental series which compare the paired bones of the same animal (Laurin et al. 1963, Wolf et al. 1981).

We assessed the effect of axial compresion on the mode of repair and on the mechanical properties of healing bilateral osteotomies.

Materials and methods

Sixty-five adult rabbits of different species weighing from 2400 to 4650 g were used. On both tibiae a midshaft osteotomy near the tibio-fibular junction was made with a circular saw; the line of osteotomy was cooled with saline. On the right tibia, the osteotomy was fixed anterolaterally with a stainless steel (ASI 316L) six-hole dynamic compression ASIF plate measuring 57.2 × 6.9 × 2.0 mm (AO Catalogue No. 244.06). The maximum compression achievable was applied between the screws nearest to the osteotomy line; they were driven in with a tension-calibrated screwdriver. The other two pairs of screws were tightened into a neutral position. On the left tibia, a similar plate was attached with all the screws in a neutral position to avoid axial compression at the osteotomy line.

Postoperatively, the animals were housed in separate cages and were allowed to move freely with water *ad libitum* and a standard laboratory diet. No exteral splints or bandages were used.

The loss of experimental animals was considerable. Twenty-nine animals had to be discarded because of fractures under the plates (eight in the right, ten in the left, and eleven in both legs) and another sixteen animals because of postoperative infection.

The remaining twenty animals with macroscopically faultless bilateral union of the osteotomies were accepted for the final analysis. The animals were killed 3, 6, 12, and 24 weeks postoperatively, giving four subgroups. Forty-eight hours before being killed each rabbit was given an intramuscular injection of oxytetracycline (Vendarcin®, Gist-Brocades), 20 mg/kg body weight, for intravital staining of newly formed bone. The tibio-fibular bones were exarticulated and freed from soft tissue; the per-

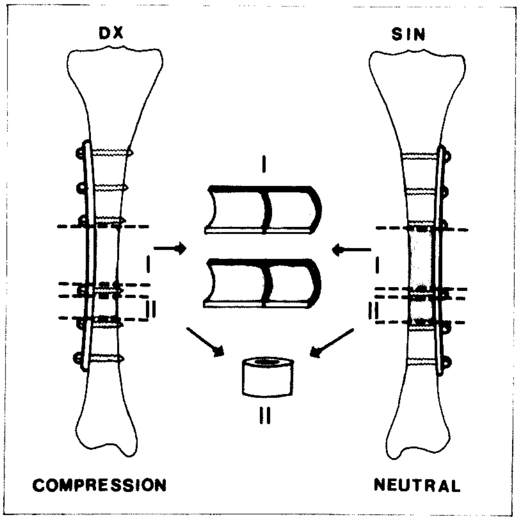

Figure 1. Sections of plated osteotomized rabbit (tibio-fibular) bone. Section I, which contained the osteotomy site, was bisected longitudinally for histologic analysis. Section II, taken from the bone under the plate, was used for histomorphometric analysis.

iosteum was preserved intact. The specimens were tested in a torsiometer and samples were taken (Figure 1). Transverse sections of tubular bone were taken from predetermined levels. Each section was embedded in methylmethacrylate. Section I was sawn longitudinally and Section II transversely, and the slices were ground with carborundum paper to a thickness of 80 μ for fluorescence microscopy and morphometric analysis.

Contact microradiographs of the undecalcified specimens were made on high-resolution x-ray film, and photographic enlargements at × 100 showed details of the bone structure. The porotic transformation of cortical bone was estimated by the random point sampling technique (Slätis et al. 1978). The degree of cavitation in the cortical bone under the plate was expressed as the mean porosity.

The specimens were kept moistened in physiologic saline at room temperature before the test. After resection of the fibular bone the ends of each tibia were embedded in nuts with epoxy resin, leaving a constant length (8.5 cm) of bone for testing (cf. Paavolainen 1978). The specimens were then fitted into the sockets of the torsiometer and subjected to external rotation until failure at a constant deformation speed of 3.6 degrees/s; the load-deformation curve was constructed with the aid of a conventional x-y-recorder (Hewlett-Packard, type 7015 A); the curve depicted the torque applied as a function of the angular deformation of each specimen. The following mechanical properties were calculated:

M_t = maximum torque at fracture (Nm)
Θ = maximum angle of deformation at fracture (degree)
W_t = energy absorbed before fracture (Nm) = $M_t \cdot d\Theta$
G = torsional rigidity (Nm/degree) = $\frac{dMt}{d\Theta}$

At 3 weeks the bond between the bone ends was too soft for torsiometric analysis. Further, in one animal union had not occurred at six weeks, and the specimen was discarded from the mechanical analysis. There remained 14 animals (28 specimens) for further study representing bone healing at 6 weeks (4 animals), 12 weeks (5 animals) and 24 weeks (5 animals).

The means and their standard deviations were calculated for each subgroup. The effects of plating with and without compression were compared at different time intervals after the operation. The significance of the differences between the paired bones was assessed by the Wilcoxon signed-rank one-tailed test for paired samples. Comparisons between the various subgroups were made by statistical analysis of two means. $P > 0.05$ was taken to be non-significant.

Results

At 3 weeks the osteotomy gap had filled with mesenchymal stroma forming the precursor of transverse osteons. Although anatomical reduction of the osteotomy seemed to be slightly better with compression than without, the difference was negligible. Tetracycline fluorescence of newly formed bone was predominantly concentrated in the osteotomy gap and in the periosteal callus around the bone (Figure 2). At 6 weeks cutter-heads were seen forming longitudinal osteons, extending across the osteotomy. Subperiosteal bone-forming activity had subsided. At 12 and 24 weeks the osteotomy was barely visible, and the fluorescence had diminished.

Abundant resorption of the cortical bone and widening of the Haversian canals in the bone under the plate had started at 3 weeks, and were clearly visible from 6 weeks onwards. This porotic transformation of the bone under the plate was identical after both types of plating. The end-to-end opposition of the bone ends secured swift union of the osteotomies, but after twelve weeks it was associated with suben-

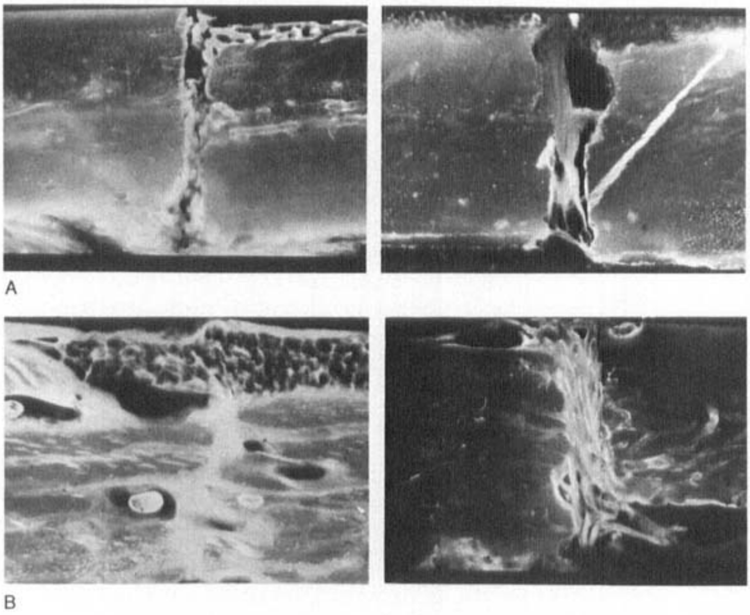

Figure 2. Fluorescence micrographs of the osteotomy under the plate. Osteotomy plated with compression on the left and without compression on the right (× 50).

A. Three weeks after the operation. Note the closer contact between the bone fragments on the side plated with compression. The osteotomy gap is filled with bone derived from the periosteum and endosteum.

B. Six weeks after the operation. Note the appearance of longitudinal osteons traversing the osteotomy gap predominantly on the side plated with compression.

dosteal cortical resorption which subsequently led to structural changes.

The data obtained by random point sampling analysis of the transverse sections of tubular bone were computed according to the time lapse after the operation (Table 1).

A gradual increase in the porosity of the cortical bone under the plate could be observed throughout the experiment. No differences were detected between the bones plated with and without compression. When the values for the two modes of treatments were pooled, the differences between measurements of porosity at 3 and at 24 weeks were highly significant ($p < 0.001$).

Torque and torsional rigidity of the bones plated with and without axial compression in the various subgroups were compared (Table 2). The values obtained reached their peak values at 6 weeks, reflecting firm bony union between the fractured bone ends. Thereafter, these values decreased gradually until the end of the experiment. *Torque* decreased equally in each group between 6 and 24 weeks ($p < 0.01$). *Energy absorption* decreased during the corresponding time by 53 per cent after compression ($p < 0.01$) and by 58 per cent ($p < 0.02$) after fixation without compression. The difference between the values for *angular deformation* at

Table 1. The areas of resorption in cross-sections of the cortex, estimated by random point-samling analysis and expressed as percentage (SEM) of the total area.

Time after operation	Number of animals	With compression	Without compression
3	5	6 (2.7)	6 (2.4)
6	5	20 (7.3)	17 (9.3)
12	5	24 (11)	27 (11)
24	4	47 (10)	53 (9.5)

Table 2. Torque (Nm) and torsional rigidity (Nm/deg) of the osteotomized rabbit tibio-fibular bones after plating with (+) and without (−) compression.

Time after operation	No of animals	Nm (SEM)		Nm/deg (SEM)	
		+	−	+	−
6	4	0.86 (0.40)	1.02 (0.41)	0.14 (0.05)	0.15 (0.04)
12	5	0.87 (0.23)	0.82 (0.20)	0.19 (0.05)	0.19 (0.04)
24	5	0.62 (0.18)	0.65 (0.36)	0.15 (0.05)	0.15 (0.06)

6 and at 24 weeks was significant ($p < 0.05$) in both groups. The value for *torsional rigidity* showed a slight but significant increase ($p < 0.05$) between 6 and 12 weeks; thereafter, the values decreased, but the changes were not significant. In the paired osteotomized bones secured with plates, the mechanical properties were the same at successive time intervals regardless of whether compression was used or not.

Discussion

The heavy loss of animals reflects the difficulties encountered when bilateral osteotomies are made in rabbits. In spite of the use of a six-hole plate, the osteotomies were easily refractured, especially during the first postoperative weeks. A high number of fractures under similar conditions was also reported by Wolf et al. (1981).

The effect of compression on bone healing has been shown to decrease with time; the main effect on the fracture is the stabilizing of the plate in the early phases of healing (Schenk & Willenegger 1967, Olerud & Danckwardt-Lilliestrom 1968, Perren et al. 1969). There was no evidence that lack of compression caused delayed bone union in the osteotomy. Greiff (1979) made similar observations although he followed the healing process for only 4 weeks.

In our study, healing osteotomy specimens had great torsional strength after 6 weeks (cf. Paavolainen et al. 1979), and at this stage no differences could be observed between the bones plated with and without compression.

When solid union had been achieved, resorption continued in the cortical bone under the plate, but very little new bone was laid down (cf. Uhthoff et al. 1971, Gördes et al. 1975, Terjesen & Benum 1983). Similar resorption activity can be seen when intact, non-osteotomized bones are plated (Slätis et al. 1978). Interestingly, in our study, the axial compression did not diminish or augment the resorption. This suggests that compression applied to the plate might have diminished or disappeared during later stages of the experiment (Perren et al. 1969). Twenty-four weeks postoperatively nearly half of the original cortex had been resorbed in all plated bones, whether or not compression had been applied. This severe resorption may be due to the large plate used (cf. Terjesen & Benum 1983). Porotic transformation of cortical bone seems to be important after rigid plate fixation since bone resorption is associated with a loss of strength.

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