

## STUDIES ON MECHANICAL STRENGTH OF BONE

### II. *Torsional Strength of Cortical Bone after Rigid Plate Fixation with and without Compression*

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Biomechanical properties of intact rabbit tibio-fibulae were investigated with torsional loading 1 day to 36 weeks after fixation using 4-hole stainless steel ASIF/DCP plates with and without compression.

During the first 12 weeks energy absorption and torque moment increased slightly as a result of subperiosteal new bone formation following application of the plates. There was a concomitant increase in the yielding properties of the bone, reflecting progressive porotic transformation. Thereafter, up to 36 weeks postoperatively, the values for energy absorption, torque moment and angular deformation gradually declined in both groups of bones. The differences between normal control bones and plated bones at 36 weeks were 70.1, 53.0 and 26.3 per cent, respectively. The decay of torsional strength was the same whether or not compression was used in the plate fixation.

The results suggest that even in normal bone rigid plates induce a considerable loss of strength due to the cancellous transformation they are known to cause in cortical bone.

*Key words:* bone; bone plates; fracture fixation; experimental measurement of bone strength

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Rigid plate fixation of fractured bones initially provides conditions conducive to primary bone healing, but protection of the bone from normal loading stress may induce atrophic changes and a decrease in the mechanical strength of the bone during the later stages of repair. Refractures have been reported after removal of the plates (Richon et al. 1967, Dietschi & Zenker 1973, Solheim 1974).

Both adverse effects on bone tissue as a structure (Schenk & Willenegger 1967, Uhthoff & Dubuc 1971, Gördes et al. 1975a, 1976) and reduction of the bone mineral mass

(Gördes et al. 1975b, Strömberg & Dalen 1976) have been reported in cortical bone after immobilization with a rigid plate. The magnitude of the bone changes seems to depend on the stiffness of the plate since structural alterations have been less marked after the use of plates with mechanical properties resembling those of bone (Akeson et al. 1975, Tonino et al. 1976, Woo et al. 1976). The axial compression applied to the plate and conveyed to the underlying bone does not appear to alter the mechanism of fracture repair (Lettin 1965, Perren et al. 1969), but scant attention has been paid to the effect of

compression on the mechanical properties of normal bone.

The object of this study was to measure the changes in torsional strength at different time intervals after application of rigid plates to normal rabbit tibio-fibular bones, and to assess the effect of additional axial plate compression on the changes observed.

## MATERIAL AND METHODS

### *Operative procedure*

Plates were applied to the tibio-fibulae of 40 adult rabbits weighing from 2400 to 3850 g. The bone was exposed through a straight lateral incision, and a commercial stainless steel four-hole dynamic compression plate (ASIF/DCP) was attached firmly to the anterolateral face of the tibia. The tibio-fibular junction served as a landmark for the exact positioning of the midpoint of the plate. On the right tibia, compression was applied between the most proximal and the most distal screw and the two middle screws were tightened in a neutral fashion. The entire tubular segment between the two outermost screws was thus subjected to compression. On the left tibia, a similar four-hole plate was attached to the bone without compression.

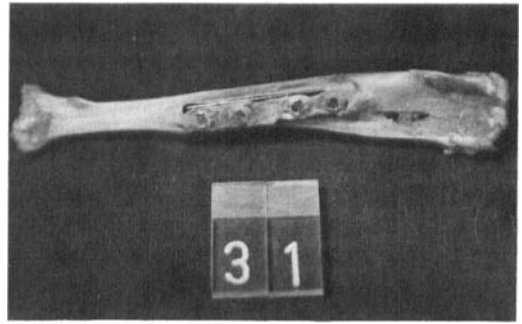
Postoperatively, the animals were housed in separate cages in which they could move freely. Seven animals were excluded from the analysis because of infection (1) or subsequent fracture under the plate (6). In one animal a fracture occurred in the right leg, in one animal in the left, and in four animals in both legs.

### *Testing of the mechanical properties*

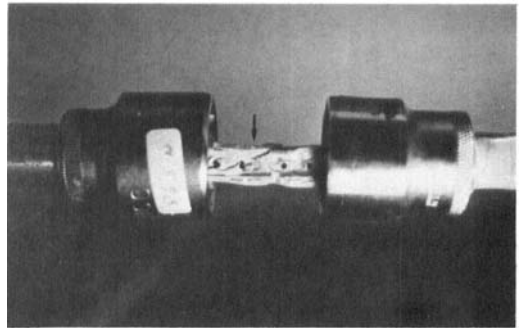
The animals were killed 1 and 3 days, and 1, 3, 6, 12, 18, 24 and 36 weeks after the operation. The tibio-fibular bones were exarticulated and freed from any soft tissue, but the periosteum and any callus tissue were preserved intact.

Prior to the test procedure the bones were radiographed before and after removal of the plates. Examination of the radiographs excluded three more animals from the analysis because of faulty positioning of the plate or fractures at the level of the screw holes. In order to eliminate the stabilizing effect of the fibula, this was severed distally at the tibio-fibular junction, leaving a proximal remnant of 1-2 mm. The specimens were kept in physiological saline at room temperature before the test.

As previously described (Paavolainen 1978), the



*Figure 1A. Rabbit tibio-fibular bone 36 weeks after application of a rigid steel plate. Note the formation of new subperiosteal bone round the plate.*



*Figure 1B. A typical spiral crack passing through a screw-hole at the tibio-fibular junction (arrow) after torsional loading of the bone specimen 36 weeks postoperatively. Note the porotic cavitation of the cortical bone under the plate.*

ends of the bones were embedded in nuts with epoxy resin, leaving a constant length (8.5 cm) of bone for testing. The specimen was then fitted into the sockets of the torsionmeter and subjected to external rotation at a constant deformation speed of 3.6 degrees/second.

### *Calculations*

From the load-deformation curve obtained, which represents the torque moment as a function of the angular deformation of each specimen, the following biomechanical properties were measured.

$M_t$  = maximum torque moment (Nm)

$\theta$  = maximum angle of deformation (degree)

$W_t$  = energy absorbed until fracture (Nm)

$G$  = torsional rigidity (Nm/degree)

As reported earlier (Paavolainen 1978), the mechanical properties of the rabbit tibio-fibular bone, apart from angular deformation, are

critically dependent on the body weight of the animal. Hence, the data obtained for each bone specimen were corrected for the weight of the animal. Using linear regression curves for body weight in relation to torque moment, energy absorption and torsional rigidity in the control series, the biasing effect of body weight was reduced by multiplying the test values obtained by a constant which standardized them for the mean body weight (3275 g) of the control group.

Mechanical properties of 57 specimens were analysed successfully; three specimens had to be discarded because of technical failure. The 57 specimens were divided into five groups according to when the animals were killed: 1-3 days (4+4 specimens), 1-3 weeks (9+9 specimens), 6-12 weeks (7+8 specimens), 18-24 weeks (5+5 specimens) and 36 weeks postoperatively (3+3 specimens). The means and their standard deviations were calculated for each of these. Statistical analysis of the influence of compression was made in paired bones, and of the influence of time after plating in the different groups. The statistical significance of the differences between the paired bones was assessed with a paired *t*-test. Between the various groups statistical analysis for two means was made.  $P > 0.05$  was taken to be non-significant.

#### *Sources of error*

The experimental error for biomechanical differences between paired bones of the same animal, expressed as SEM values for the percentage deviations of the paired variables measured from the mean value, was as follows: torque moment at fracture 6.3 per cent; deformation at fracture 5.7 per cent; energy absorbed at fracture 10.0 per cent; torsional rigidity 7.1 per cent. There was no statistically significant right-to-left dominance between the pairs of bones (Paavolainen 1978).

## RESULTS

The biomechanical properties of the bones plated with and without compression in the various age groups are shown in Figure 2. During the first three postoperative days, the torque moment of both the compression and neutrally plated bones fell by almost one standard deviation compared with the values for normal bones, reflecting the weakening effect of the screw-holes in the tubular bone. At 6-12 weeks postoperatively, the torque

moment had increased almost significantly ( $P < 0.05$ ) in the plated bones, whether the plates were applied with or without compression. Thereafter, however, the torque moment declined continuously up to the 36th week postoperatively. In both types of plating the differences between the initial postoperative values and those obtained at 36 weeks were statistically significant ( $P < 0.01$ ).

Energy absorption, i.e. the magnitude of the work needed to deform the bone up to the point of failure, increased steadily for 6-12 weeks postoperatively. At this stage the values approached the values of energy absorption measured in normal bones. Thereafter, however, the values of energy absorption in both groups of bones gradually declined. The difference between the initial postoperative values and those at 36 weeks was highly significant ( $P < 0.001$ ) whether or not compression had been used at plating.

The changes in angular deformation were closely related to the changes in energy absorption. The values for deformation seemed to reach a peak at 6-12 weeks postoperatively. Thereafter, they declined slightly. The differences between the initial postoperative values and the values at 36 weeks postoperatively were almost statistically significant ( $P < 0.05$ ).

Only slight changes were observed in the values for the torsional rigidity of the bone. At 6-12 weeks postoperatively, the increase in both energy absorption and angular deformation led to diminishing values of torsional rigidity. This means that the slope of the load-deformation curve decreased, although at the same time the maximum torque moment increased, both of which factors led to increased values for energy absorption. At 36 weeks, the values for torsional rigidity seemed to approach the initial postoperative values. The differences between the values immediately after the operation and at 36 weeks were not statistically significant.

There were no statistically significant differences between the bones plated with and without compression.

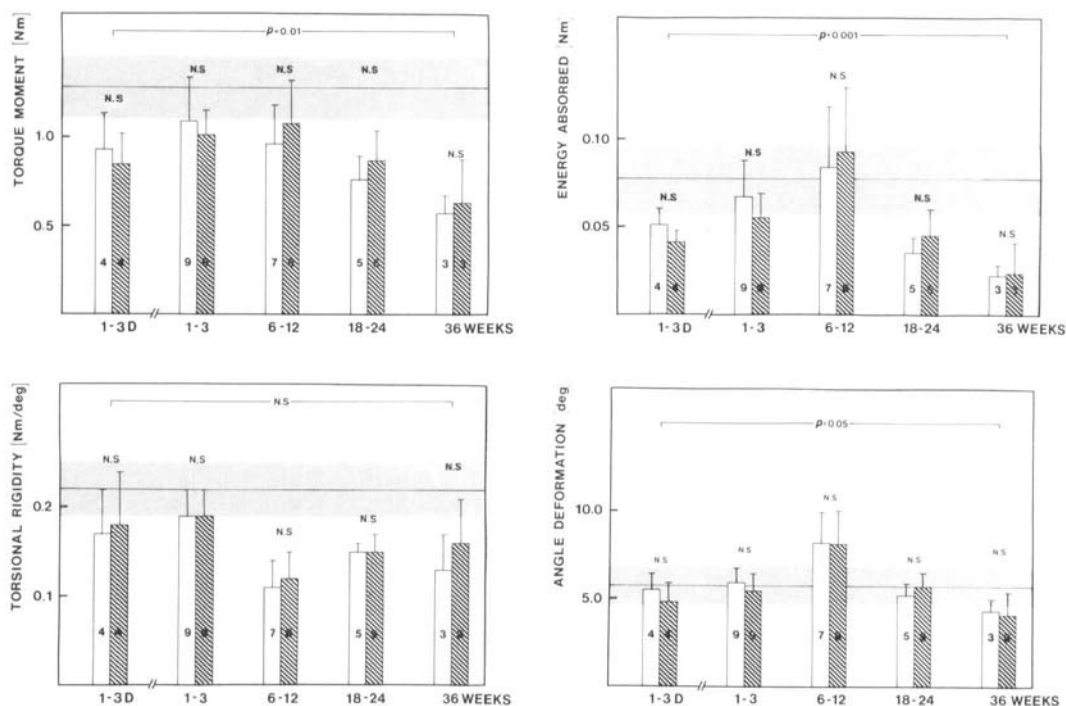


Figure 2A-D. Biomechanical properties of intact rabbit tibio-fibular bones after exposure to rigid plates with (white columns) and without (shaded columns) compression. Vertical bars represent one standard deviation. The figures in the columns denote numbers of specimens. Statistical significance between bones plated with and without compression, and between values measured immediately and at 36 weeks postoperatively are indicated for both types of plated bones. The stippled horizontal area indicates the mean value and two standard deviations for normal rabbit tibio-fibular bones.

## DISCUSSION

Application of rigid steel plates to normal rabbit tibio-fibular bones leads to progressive changes in the affected bone. The alterations are characterized by cancellous transformation of the cortex accompanied by increases in the diameters of the tubular bone and medullary cavity (Paavolainen et al. 1978). The cancellous transformation of the bone is of the same magnitude after compression and after neutral plate fixation (Slätis et al. 1978). Morphologically, the porotic cavitation of the cortex closely resembles the changes observed during primary fracture healing (Schenk & Willenegger 1967, Olerud & Danckwardt-Lillieström 1968, Uthoff & Dubuc 1971, Gørdes et al. 1975a).

The present study reveals that plating causes considerable changes in the biomechanical properties of rabbit tibio-fibular bones. For a few days postoperatively, the screw-holes in the tubular bone caused a reduction in torque moment and energy absorption values (cf. Burstein et al. 1972). After this, the alterations seemed to occur in two phases. In the first phase, 1 to 12 weeks after application of the rigid plate, both the torque moment and the energy absorption values increased to almost normal values, reflecting increasing strength of the bone as a structure. Simultaneously, however, there was an increase in angular deformation and a decrease in torsional rigidity values, reflecting changes in the yielding properties of the bone. The increased strength of the newly plated

bone was obviously due to formation of new subperiosteal bone round the tubular bone (Paavolainen et al. 1978).

The concomitant increase in the yielding properties of bone reflects the increasing cavitation of the cortex as a result of cancellous transformation (Slätis et al. 1978).

In the second phase, 18 to 36 weeks postoperatively, energy absorption and torque moment values decreased considerably. Meanwhile, the angular deformation decreased but torsional rigidity increased slightly. This indicates that in the late stages of adaptation to the plate the bone as a structure loses both strength and flexibility. The alterations during the second phase seem to coincide with progressive porotic cavitation of the cortex, which at 36 weeks amounts to over 40 per cent of the cortical bone (Slätis et al. 1978). There were no significant differences between plate fixation with and without compression regarding the decline of biomechanical properties of the underlying bone. Hence, it seems that the changes observed are due to the rigidity of the plates and not to the compression *per se*.

Strömberg & Dalen (1976) plated intact canine femora with commercially available rigid steel plates and compared the test specimens with control bones perforated with the same number of screw-holes. Seven months later they found a reduction of 18.3 per cent in torsional capacity and of 22.2 per cent in angular deformation. Our results showed reductions of 53.0 per cent in torque moment and 26.3 per cent in angular deformation of the test specimens when compared at 36 weeks postoperatively with normal, intact rabbit tibio-fibulae. The data obtained indicate considerable loss of strength even in normal bones subjected to plating.

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