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THE HEALING OF EXPERIMENTAL FRACTURES BY COMPRESSION OSTEOSYNTHESIS

I. *Torsional Strength*

PEKKA PAAVOLAINEN, PÄR SLÄTIS, ERKKI KARAHARJU &
TEDDY HOLMSTRÖM

Division of Orthopaedic Surgery and Traumatology, Surgical Hospital,
University Central Hospital, Helsinki, Finland

Biomechanical properties of osteotomized rabbit tibio-fibular bones fixed with 6-hole stainless steel AO/DCP plates were investigated with torsional loading 3 to 24 weeks postoperatively.

During the first 9 weeks maximum torque capacity, energy absorption and torsional rigidity increased, reflecting progressive bony union between the fractured bone ends. From 9 to 24 weeks the values of torque capacity and energy absorption decreased, whereas torsional rigidity seemed to reach a steady state without further significant changes. For the three parameters considered, the mean percentage differences between the osteotomized plated bones and their paired sham-operated controls were 69, 64 and 80 per cent, respectively.

The results suggest that internal fixation of fractured bones provides conditions for undisturbed fracture healing, but that subsequently the rigid nature of the implant has an adverse effect on the cortical bone, which slowly loses strength. Thus the optimal time for removal of the plate seems to be shortly after the fracture has healed and before the bony tissue has been weakened by secondary changes, such as cancellous transformation and spatial rearrangement of the tubular bone.

Key words: bone; bone plates; fractures; fracture fixation

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The use of rigid metallic plates in the treatment of fractured cortical bones leads to union by a histologically characteristic pattern of events known as primary fracture healing (Schenk & Willenegger 1964, Andersson 1965, Olerud & Danckwardt-Lillieström 1968, Rahn & Perren 1971). The morphological description of this mode of fracture healing, however, does not take into account the mechanical strength of the bond between the fractured bone ends. This property of the fracture union can be quantified only by measuring the rate of recovery of normal strength and rigidity in the healing bone.

Rigid plates applied to tubular bone involve the risk of morphologically untoward changes in the underlying cortical bone. Porotic transformation induced by the stress protection properties of the rigid plate has been reported by some investigators (Uhthoff & Dubuc 1971, Gördes et al. 1975, Woo et al. 1976, Paavolainen et al. 1978b). Uniform morphological changes have been reported after

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fixation of the plates in both intact and osteotomized bones, indicating that the main factor producing these untoward changes in the bone is not the fracture healing, but the rigidity of the implant (Slätis et al. 1978).

The effect of rigid plates on the healing of experimental fractures has been studied by Lettin (1965) and by Henry et al. (1968), who reported reduction of mechanical strength in the osteotomized bones as compared with their intact controls. In osteotomized canine femora, Braden et al. (1973) reported recovery of only 36.7 per cent of the original torsional rigidity at 10 weeks postoperatively, when the fracture was fixed with compression plates. According to Jäger et al. (1976), plate fixation of the fracture in healing rabbit tibiae caused a loss of bending strength of 70–80 per cent 16 weeks postoperatively.

The aim of the present study was to investigate the changes in the torsional strength of osteotomized rabbit tibio-fibular bones in a time-related series after rigid plate fixation of the fracture.

MATERIAL AND METHODS

Operative procedure

Thirty-five adult rabbits weighing from 2800 to 4400 g were used. On the right tibia a midshaft osteotomy was made close to the tibio-fibular junction with a circular saw; during sawing the line of osteotomy was cooled with saline. The osteotomized bone was plated with a stainless steel (AISI 316 L) six-hole dynamic compression plate (AO/DCP). The length of the plate was 53 mm, width 7 mm and thickness 1.5 mm. The plate was attached to the anterolateral face of the tibia and compression was applied between the most proximal and most distal screws. The two pairs of middle screws were tightened in a neutral fashion (Figure 1).

On the left tibia a sham operation was carried out, exposing the periosteum without touching the bone. No external splints or bandages were used after the operation and the animals were allowed to move freely in separate cages. They were provided with water *ad libitum* and the standard laboratory diet.

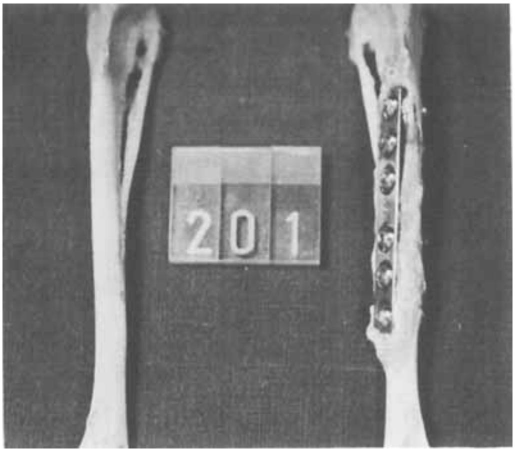

Figure 1. Rabbit tibio-fibular bone 6 weeks after fixation of the midshaft osteotomy with a six-hole AO/DCP-plate (on the right) and its paired control bone (on the left). The fracture has united and the line of osteotomy can no longer be distinguished. Note the formation of new subperiosteal bone around the plate and the increased diameter of the plated bone as compared with the paired control.

Sampling techniques

Fifteen animals had to be excluded from the series because of infection and/or fracturing of the plated bone.

The animals were killed 3, 6, 9, 12 and 24 weeks after the operation with an overdose of sodium pentobarbitone. Both tibio-fibular bones were exarticulated and the soft tissue removed, leaving the periosteum and any callus intact. Radiographs were taken before and after removal of the plate. The specimens were kept at room temperature in a cloth moistened with 0.9 per cent saline. One more animal had to be excluded from the series due to a technical failure in the torsional testing, which left 19 animals for the final biomechanical testing of both tibio-fibular bones.

Measurement of torsional properties

The proximal part of each fibula and the condylar bone ends were removed, leaving a bone specimen of exactly 8.5 cm for the biomechanical assay.

The bones were fixed rigidly to the torsiometer. All specimens were subjected to external rotation with a constant angular deformation of 3.6 degrees/second. The bones were subjected to torsion up to the breaking point and the torque capacity and angular deformation were recorded simultaneously on a paper recorder displaying the load-deformation curve.

The following parameters were calculated from each load-deformation curve where torque was displayed on the vertical axis and the angular deformation on the horizontal axis.

Maximum torque capacity (M_t) was determined from the maximum deflection of the curve (to the nearest 0.1 mm) and expressed in Nm.

Maximum angular deformation (θ) was measured directly from the horizontal axis of the curve and expressed in degrees.

Energy absorbed at fracture (W_t) was calculated from the area under the curve, which was measured with a planimeter (type HAFF 317). The values were expressed in Nm.

Torsional rigidity (G) of the specimen was measured from the slope of the linear portion of the curve and expressed in Nm/degree.

Calculations

The biomechanical strength of each osteotomized and plated bone was compared with that of the contralateral sham-operated intact bone. For each parameter the value obtained for the plated bone was expressed as a percentage of the value obtained for the control bone.

The mechanical properties of the rabbit tibiofibular bone, apart from angular deformation, are critically dependent on the body weight of the animal (Paavolainen 1978). Using linear regression curves for body weight in relation to torque, energy absorption and torsional rigidity in the normal rabbit tibio-fibular bones (Paavolainen 1978), 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 (3500 g) of the operated animals. This made the absolute values obtained from animals of different size and weight more comparable with each other, but naturally did not affect the percentage differences between the paired bones from the same animal.

Means and their standard deviations were calculated for each subgroup according to the postoperative time.

The statistical significance of differences between the plated bones and their controls was analysed by the paired *t* test. $P > 0.05$ was taken to be non-significant.

RESULTS

The results obtained were combined in subgroups according to the time after the operation: 3 weeks (five animals), 6 weeks (five animals), 9 weeks (three animals), 12 weeks (three animals) and 24 weeks (three animals).

Macroscopically all specimens retained their exact reduction under the plate. Manual tests showed that in all specimens solid union was achieved from 6 weeks onwards.

The type of breakage of the specimen varied with the time after the fracture. At 3 weeks, the site of the osteotomy opened up with a soft give as torque was applied. At 6 and 9 weeks postoperatively, breakage occurred through the osteotomy with increasing resistance. Later, the ultimate failure at torque occurred as a spiral fracture with a cleavage plane of 45 degrees to the long axis of the bone through the previous osteotomy site, the biomechanical properties of the specimen approaching those of intact bone with high rigidity.

Figure 2A–D shows the mechanical properties of the osteotomized plated bones compared with the contralateral intact bones at various time intervals. Maximum torque capacity (Figure 2A) seemed to achieve its peak value at 9 weeks postoperatively. At this stage the difference between plated and control bones was no longer statistically significant (mean 83.3 per cent of the value for the paired controls). After that, however, the values declined. Already at 12 weeks postoperatively, the torque capacity of the plated bones showed a statistically significant reduction ($P < 0.01$) as compared with the intact controls. Subsequently, the reduction was significant ($P < 0.02$) at 24 weeks postoperatively (mean 69.2 per cent of the value for the paired controls).

The energy absorption until failure (Figure 2B) was found to be equivalent to the values for normal control bones at 6 weeks postoperatively. After that, the values for energy absorption gradually diminished. Paired statistics between the contralateral bones

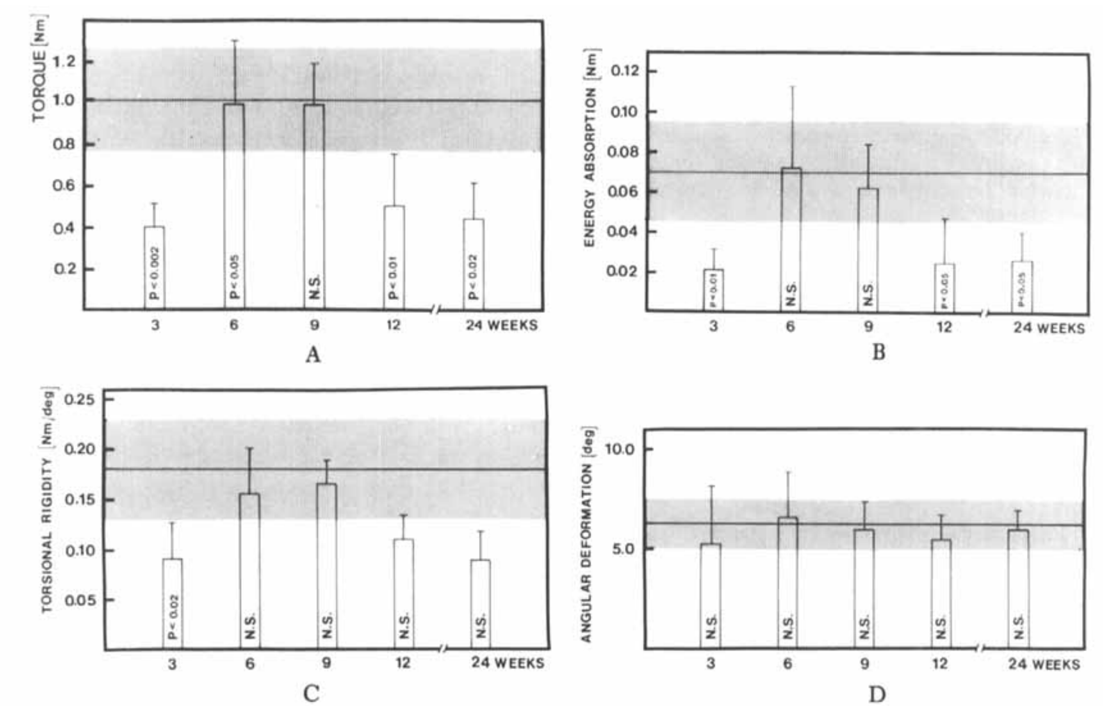

*Figure 2A–D. Biomechanical properties of osteotomized and plated rabbit tibio-fibular bones. The white columns indicate the means of the values measured, the vertical bars representing one standard deviation. Statistical significances of the differences from the paired controls (*t *test) are given inside the columns. The stippled horizontal area indicates the mean value and two standard deviations for all control bones.*

revealed significant ($P < 0.02$) weakening of the plated bones at 12 and 24 weeks postoperatively (mean at 24 weeks 63.6 per cent of the values for the paired controls).

Torsional rigidity (Figure 2C) was found to accord with that of the control bones 6 weeks after the operation. Although the values at 12 and 24 weeks were lower than the mean value of all control bones, the paired statistics could not reveal any significance between the contralateral bones.

Owing to the elastic nature of the healing osteotomy, the values for angular deformation (Figure 2D) sometimes actually exceeded those of the control bones up to the 9th week postoperatively. Anyhow, there were no statistically significant differences between the paired bones regarding angular deformation in any of the subgroups.

DISCUSSION

Earlier reports indicate that after experimental osteotomy the rabbit tibia achieves bony union between the 6th and 8th weeks postoperatively (Henry et al. 1968, Laros 1974, Lindsay & Howes 1931). The rapidity of fracture healing in cortical bone is seemingly the same after different types of fracture fixation and after healing without any internal fixation (Jäger et al. 1976, Laurin et al. 1963, Lettin 1965).

White et al. (1977) described four biomechanical stages of fracture healing in rabbit tibiae treated with an external compression device after experimental osteotomy. Stage I is characterized by failure through the fracture site with low stiffness; stage II by failure through the fracture site with high stiffness; stage III by failure partly through the original fracture site and partly through the intact bone, with high stiffness, and stage IV by failure entirely through the intact bone, with high stiffness. The types of breakage of our specimens under torsion closely resembled those described by White et al. (1977).

The initial increase in strength followed by deterioration of most biomechanical properties of the bone, as observed in this study, shows that rigid plate fixation of an osteotomized bone leads at first to undisturbed bony union, but that after some weeks the rigid nature of the implant has an adverse effect on the cortical bone. Thus up to 6 or 9 weeks postoperatively, the values of maximum torque capacity, energy absorption and torsional rigidity increased almost linearly, reflecting progressive bony union between the fractured bone ends. From 9 to 24 weeks postoperatively, the values for maximum torque capacity and energy absorption decreased, whereas torsional rigidity seemed to reach a steady state without significant changes after 9 weeks. Similar observations have been reported after rigid plate fixation of intact cortical bone (Strömberg & Dalen 1976, Paavolainen et al. 1978a).

The loss of strength seems to be due to porotic transformation after rigid plate fixation with increased susceptibility to initiation of cracks from internal cavities or flaws in the microstructure of the bone (Uhthoff & Dubuc 1971, Slätis et al. 1978). This interrelationship between mechanical properties and density in composite materials like bone has been well documented by Wright & Hayes (1977) and Carter & Hayes (1977).

Henry et al. (1963) and Lettin (1965) reported reduced mechanical strength of fractures treated by rigid plate fixation, as compared with intact bones or fractured bones united by normal callus formation after non-operative treatment. Jäger et al. (1976) observed a decrease of 70 to 80 per cent in the bending strength of osteotomized rabbit tibiae 16 weeks after rigid plate fixation, as compared with a decrease of only 40 per cent after normal callus formation at the same time. Braden et al. (1973) reported recovery of only 36.7 per cent of normal torque stiffness 10 weeks after plate fixation of canine femora. The tendency towards diminishing strength after internal fixation is the same in the different studies, although the absolute values differ because of the different species and different testing procedures. The commercially available plate used in the present study can be considered slightly over-dimensioned when compared with the rabbit tibio-fibular bone. This may influence the profound structural changes and reduced mechanical strength of the bone specimens in the present study.

Rigid plate fixation obviously induces adverse secondary changes in the underlying bone long after the fracture has healed. The present study reveals a biphasic pattern in the mechanical properties observed at different time intervals after osteosynthesis. Our findings suggest that the optimal time for removal of the plate is shortly after the fracture has healed and before the rigid fixation has induced secondary changes.

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Correspondence to: Pekka Paavolainen, Division of Orthopaedic Surgery and Traumatology, Surgical Hospital, University Central Hospital, Kasarminkatu 11–13, Helsinki, Finland SF 00130.