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TORSIONAL STRENGTH OF CORTICAL AND CANCELLOUS BONE GRAFTS AFTER RIGID PLATE FIXATION

PEKKA WARIS

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

Mechanical properties of cortical and cancellous interposition grafts in rabbit tibiofibular bones fixed with 6-hole DCP/ASIF plates were tested with torsional loading after intervals of 3 to 52 weeks postoperatively.
In the cortical grafts maximum torque moment at fracture, energy absorption capacity and rigidity increased from 3 to 12 weeks, while the cancellous grafts were more plastic with lower rigidity, higher angular deformation and higher energy absorption.
From 12 to 52 weeks maximum torque moment at fracture, energy absorption, rigidity and angular deformation decreased in grafts of both types, the respective means at 36 weeks being 39, 34, 57 and 82 per cent of the control values for the cortical grafts, and 26, 17, 42 and 58 per cent of the control values for the cancellous grafts. The differences between the torsional properties of the two graft types decreased with time.

Key words: bone grafts; bone plates; bone strength; fracture fixation

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The differences in the repair of cortical and cancellous autogenous bone transplants have been described mainly on a morphological basis (Abbott et al. 1947, Siffert 1955, Deleu & Trueta 1965). Irrespective of the type of transplant, repair occurs through the process called creeping substitution. In cortical grafts the existing matrix necrotizes and is removed before new bone formation takes place in the resorption cavities (Enneking et al. 1975). When cancellous bone grafts are used, the internal removal of the original matrix and the formation of new bone on the framework of the original bone trabeculae is simultaneous and rapid (Siffert 1955, Boyne 1970).

Few studies have been made on how the repair of orthotopic bone grafts is affected by rigid internal fixation. After rigid plating both cortical and cancellous interposition grafts seem to mend through the process of primary bone healing, without noteworthy formation of external callus (Olerud & Danckwardt-Lillieström 1971, Hutzschenreuter 1972, Düker et al. 1975). The presence of a rigid metallic implant may, however, provoke unwanted changes in the underlying bone. The protection from stress afforded by the rigid plate tends to induce porotic transformation in both intact (Akeson et al. 1976, Woo et al. 1976, Slätis et al. 1978, Strömberg & Dalen 1978) and osteotomized bones (Bradley et al. 1979, Paavolainen et al. 1979b). In both grafts this protection may affect the remodelling of the graft.

The purpose of the present study was to investigate some of the mechanical properties of cortical and cancellous grafts used to bridge a 6-mm

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defect in rabbit tibio-fibular bone subjected to rigid plating for as long as 1 year.

MATERIAL AND METHODS

Animals

A total of 130 adult rabbits weighing from 2450 to 5100 g were used. Cortical grafts were implanted in the tibio-fibular bone of one leg of 70 rabbits and cancellous grafts were placed correspondingly in the other 60 rabbits. In the cortical graft series, 20 rabbits had to be excluded because of fracture or dislocation, and 5 rabbits in the cancellous graft series could not be used for the same reasons.

Tibio-fibular specimens of the grafted and control legs of 21 rabbits in the cancellous graft series and of 19 rabbits in the cortical graft series were submitted to the mechanical testing procedures. Three additional specimens were discarded because of technical failure. The rest of the specimens were kept for morphological studies, to be reported later (Waris et al., to be published).

Operative technique

On the right tibia a standard, 6-mm long segment of bone was removed by osteotomy with a double-bladed circular saw. During this process the osteotomies were cooled with saline, and the periosteum was left *in situ*. The osteotomies were located just below the tibio-fibular synostosis.

In the cortical transplant series the cut segment was turned through 180° and replaced in the defect, while in the cancellous graft series the defect was filled with a 6-mm long cortico-cancellous graft taken from the anterior iliac crest (A and B in Figure 1). Osteosynthesis was achieved with a stainless steel (ASI 316 L) 6-hole DCP/ASIF plate applied with five (cortical graft series) or six screws (cancellous graft series). The screws were secured with a calibrated torque wrench to ensure a standard compression force. In the cancellous bone this force resulted in pressure on the bone trabeculae and loss of compression force; in the cortical graft, axial compression was exerted on the tubular graft.

Postoperatively, the animals were allowed to move freely in separate cages; they wore no external splints.

The animals were killed 1, 3, 6, 12, 24, 36 and 52 weeks after the operation. Both tibio-fibular bones were removed, with the periosteum and any callus tissue intact. Radiographs were taken immediately after transplantation and again immediately before and after removal of the plate (Waris et al. 1980). The specimens were wrapped in a paper towel moistened with saline and kept at room temperature; they were tested in the torsiometer within 1 hour.

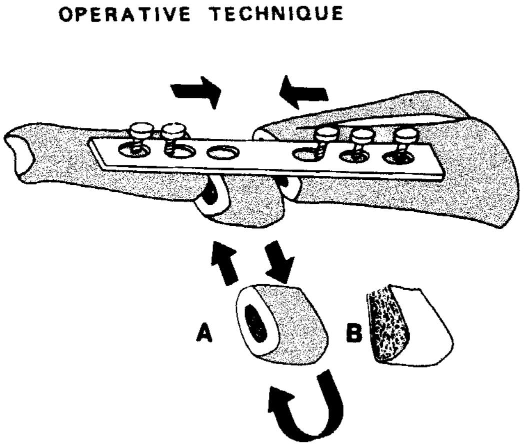

Figure 1. Operative technique.

Mechanical tests

After the plate was removed, nuts were attached to the ends of the bones with the aid of epoxy resin. A constant length (8.5 cm) of bone, with the graft in the middle of it, was fixed rigidly to the torsiometer. The specimen was subjected to torsion at a constant angular velocity of 3.6 degrees/second. The precision of the testing equipment has been reported by Paavolainen (1978).

The ultimate torsional load at fracture and the angular deformation were recorded simultaneously on a paper recorder.

Calculations

From each load-deformation curve the following mechanical properties were calculated at the point of fracture:

M_t = maximum torque moment at fracture (Nm)
Θ = maximum angle of deformation (degrees)
W_t = energy absorption until fracture (Nm)
G = torsional rigidity (Nm/degree)

The strength of each grafted bone was compared with that of the contralateral intact bone. For each parameter the value obtained for the grafted bone was expressed as a percentage of the value obtained for the control bone. Means and standard deviations were calculated for each postoperative group. The statistical significance of the differences of the ratios between the grafted and control bones were tested intraindividually with the t test using logarithmic transformation. The results for the different groups were compared by Student's t test for independent samples. In all tests, the 5 per cent level of probability was taken to imply a significant difference.

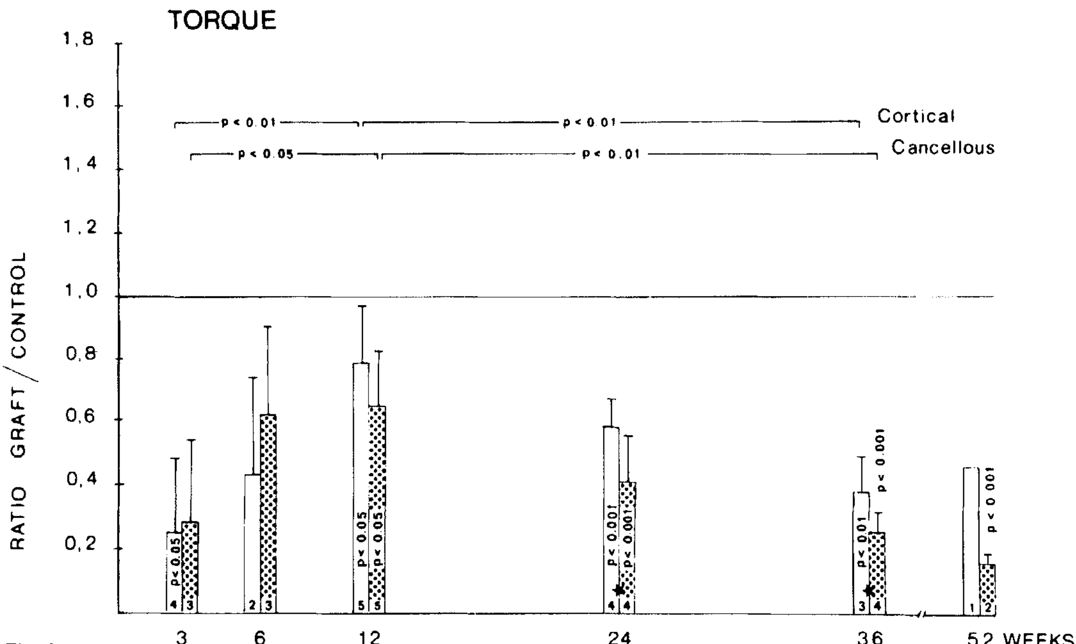

Fig. 2a

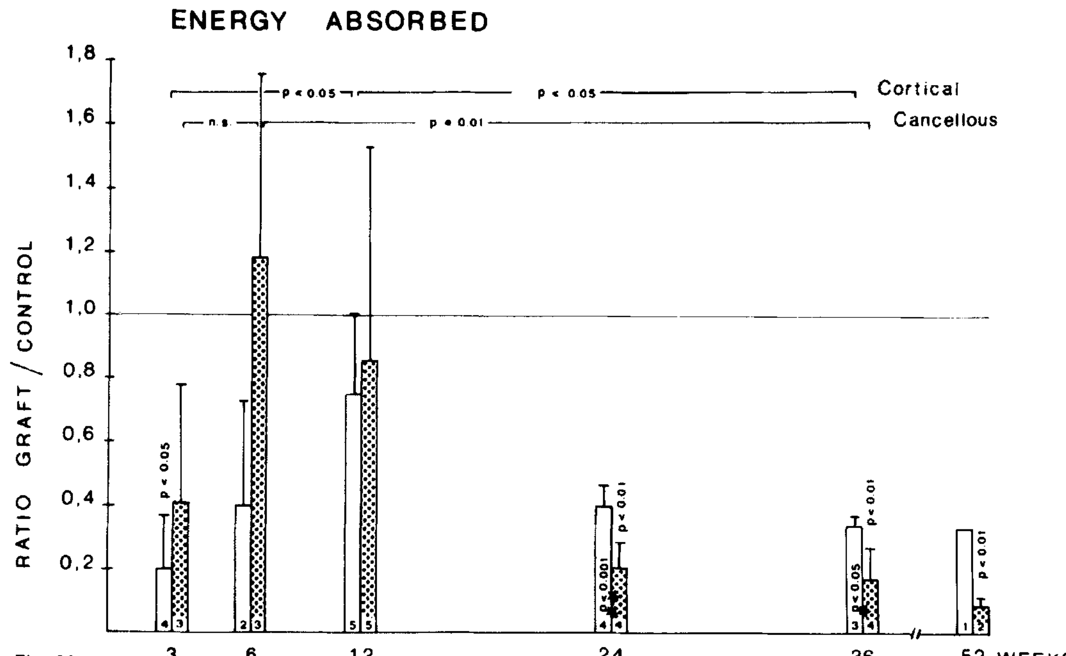

Fig. 2b

Figure 2a–d. Mechanical properties of cortical (white columns) and cancellous (stippled columns) interposition grafts in rabbit tibio-fibular bone 3 to 52 weeks after rigid plating. (Vertical line = standard deviation; number at base of column = number of specimens; P value (x = < 0.05, xx = < 0.01, xxx = < 0.001): within column = comparison with control value (t test); between columns = comparison between values of respective columns; top of figure = comparison between values for time intervals indicated).

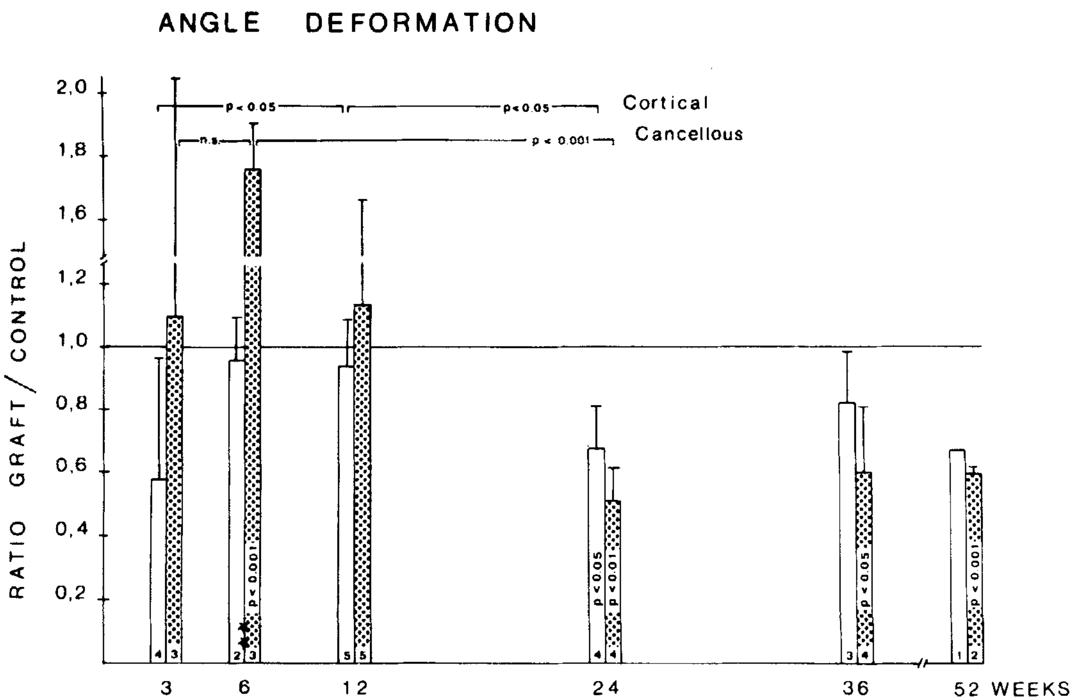
ANGLE DEFORMATION
2,0
1,8
1,6
1,2
1,0
0,8
0,6
0,4
0,2
RATIO GRAFT / CONTROL
p < 0.05
p < 0.05
Cortical
n.s.
p < 0.001
Cancellous
p < 0.001
p < 0.05
p < 0.01
p < 0.05
p < 0.001
4 3
2 3
5 5
4 4
3 4
1 2
3
6
12
24
36
52 WEEKS

Fig. 2c

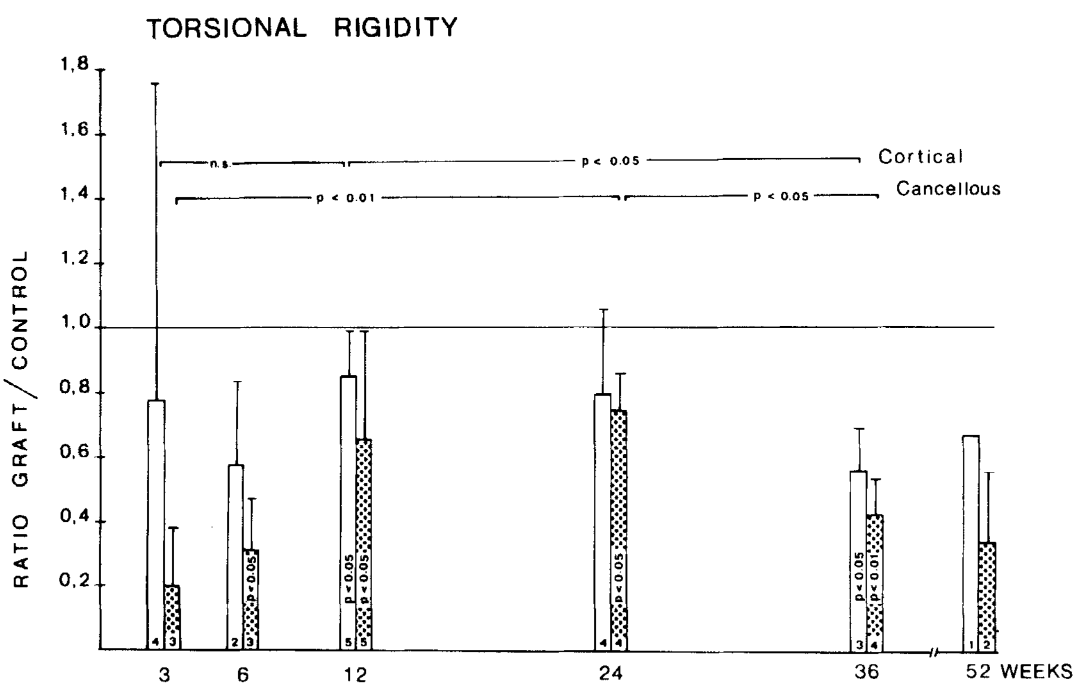
TORSIONAL RIGIDITY
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
RATIO GRAFT / CONTROL
n.s.
p < 0.05
Cortical
p < 0.01
p < 0.05
Cancellous
p < 0.05
p < 0.05
p < 0.05
p < 0.05
p < 0.05
p < 0.01
4 3
2 3
5 5
4 4
3 4
1 2
3
6
12
24
36
52 WEEKS

Fig. 2d

RESULTS

The site of the fracture in each specimen was examined macroscopically, manually and radiographically. At 3 weeks the distal osteotomy opened softly, whereas the bond of the proximal osteotomy was invariably stronger. In each series of grafts one specimen had not healed, and in one cortical graft specimen firm bony union was already present.

At 6 and 12 weeks the fracture occurred mostly through the distal osteotomy. From 6 to 12 weeks the rigidity of the structure increased, and at 12 weeks the fracture line partially followed a spiral course through the cancellous graft and the distal osteotomy. In the cortical graft series the spiral fracture generally passed between the graft and the callus surrounding it.

Later, from 24 to 52 weeks, fracture occurred in both series as a spiral fracture passing through the graft, the distal osteotomy and the distal screw hole.

The load-deformation curves are depicted in Figure 2 (a–d). The maximum torque moment at fracture (Figure 2a) increased significantly in both the cortical and the cancellous graft series from 3 to 12 weeks, but did not reach the level of the contralateral bone (means 78 and 65 per cent of the values of the paired controls, respectively). At 36 weeks, however, the strength had again decreased significantly ($P < 0.01$) in both series. In the beginning the maximum torque moment at fracture of the cortical and cancellous grafts did not differ, but at 24 and 36 weeks the cortical bone graft withstood higher torque moments at fracture ($P < 0.05$).

The energy absorption curves in Figure 2b indicate differences between the two types of grafts. The cancellous grafts absorbed much more energy at 6 weeks, the level even exceeding the values for the paired controls. Thereafter the energy absorption of the cancellous graft gradually declined throughout the experiment ($P < 0.01$). The energy absorption of the cortical graft increased more slowly and was greatest at 12 weeks. Although the cortical grafts also lost a significant amount of their capacity to absorb energy, they retained more energy than the cancellous grafts at 24 and 36 weeks ($P < 0.01$ and < 0.05, respectively).

The deformation curves in Figure 2c reveal that the cause of the high energy absorption of the healing cancellous grafts at 3 to 12 weeks was their plasticity. At 6 weeks the deformation of the cancellous graft reached a mean value of 176 per cent of that of the paired controls. From 6 to 24 weeks, however, the deformability of the cancellous grafts declined significantly and thereafter remained below normal.

In the cortical grafts deformability was highest at 6 and 12 weeks (means 95 and 93 per cent of the value of the paired controls). By the 24th week it had decreased significantly, and at 36 and 52 weeks it was still below normal. The differences between the means for the cortical and cancellous grafts were statistically significant only at 6 weeks ($P < 0.01$).

The rigidity (Figure 2d) of the cancellous graft increased significantly ($P < 0.01$) from 3 to 24 weeks, when it reached its highest value (mean 76 per cent of the level of the paired controls, $P < 0.05$). Thereafter the rigidity again decreased. The rigidity of the cortical graft increased more rapidly, and was highest at 12 weeks (mean 85 per cent of that of the paired controls, $P < 0.05$). It then decreased significantly up to 36 weeks, when it was only 57 per cent of the level of the paired controls ($P < 0.01$). In spite of the variations in rigidity, there were no statistically significant differences between the means of the cortical and cancellous grafts.

DISCUSSION

Morphological investigations of graft healing have shown that the osteogenic and osteo-inductive capacities of cancellous bone exceed those of cortical bone (Abbott et al. 1947, Siffert 1955, Deleu & Truéta 1965). These investigations did not, however, consider the mechanical strength of the bond between the graft and the host bone. This factor, as well as the later changes in the structural strength of the graft, can be measured only by mechanical testing.

Earlier studies on the mechanical strength of healing fractures have dealt mostly with cortical bone. In these studies bony union of rabbit tibial osteotomies occurred at 6–8 weeks (Lettin 1965, Henry et al. 1968, White et al. 1977, Paavolainen et al. 1979a). The type of fracture fixation does not seem to influence the healing time (Falkenberg 1961, Lettin 1965, Henry et al. 1968, Jäger et al. 1976).

In the present study the type of fracture was as described for simple osteotomies by White et al. (1977). Up to 12 weeks the fracture occurred through the distal osteotomy, although rigidity was increasing. Thereafter cracks seemed to be initiated in the graft as a result of the resorptive remodelling, for the host bone was never the primary site of the fracture.

In the cortical grafts of the present study the increases in maximum torque and energy absorption capacity occurred somewhat more slowly than in the plated osteotomies studied by Paavolainen et al. (1979a), even though the test conditions were identical. These results are consistent with the radiological and morphological studies on the graft specimens, which showed that healing of the distal osteotomy was delayed, seemingly owing to its poorer blood supply (Waris et al. 1980, Waris et al., to be published).

The healing of cancellous grafts showed interesting differences from that of cortical grafts. The slow increase in rigidity and the high deformability of the cancellous grafts possibly reflect the low mineralization and the high collagen matrix content of the healing cancellous grafts (Waris et al. 1981a). These findings are congruent with the hypothesis of Burstein et al. (1975), who, by progressive decalcification, showed that a decrease in bone minerals resulted in a decrease in the elastic modulus of the bone.

In the present study the initial increase in strength and rigidity in both graft types was followed by a similar deterioration in the mechanical properties of the bone. The decrease began after 12 weeks, and was greatest with respect to energy absorption capacity. The cortical graft, however, seemed able to retain greater strength than the cancellous graft after rigid plating.

In a study on simple osteotomies of rabbit tibia Paavolainen et al. (1979a) also found a loss of bone strength. They reported decreases in maximum torque at fracture, energy absorption and rigidity that reached 69, 64 and 80 per cent of the respective control values at 24 weeks. However, the values measured in the present study were significantly greater. At 36 weeks the means for maximum torque at fracture, energy absorption, rigidity and angular deformation for the cortical grafts were 39, 34, 57 and 82 per cent of the values of the control bones, the corresponding percentages for the cancellous grafts being 26, 17, 42 and 58 per cent, respectively.

This deterioration was obviously due to the increasing porotic resorption and remodelling of the whole plated bone and especially the graft (Waris et al. 1980, Waris et al., to be published).

In addition to the protection from stress afforded by the plate, the graft undergoes vigorous internal rebuilding by creeping substitution. Enneking et al. (1975) followed unfixed fibular autografts for 48 weeks, using torsional loading and morphometric calculations. They found a 40 per cent decrease in torque strength from 6 to 24 weeks. The strength was correlated with the amount of porosity of the graft; it reached the normal range again at 48 weeks.

Comparison of the results of Paavolainen et al. (1979a) and Enneking et al. (1975) with the present findings indicates that the effect of rigid plating on the porotic transformation of the graft is additive.

Initially, rigid plate fixation provides the conditions needed for undisturbed union of grafts. Although the torsional properties of cortical and cancellous bone grafts differ at the beginning of the healing process, these differences decrease with time as remodelling progresses. After 12 weeks, however, the grafts lose a significant amount of the strength gained. This loss is obviously a result of reorganization of the graft and of the protection from stress afforded by the plate, and the bone does not normalize as long as it is attached to the plate.

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Correspondence to: Pekka Waris, Division of Orthopaedic Surgery and Traumatology,
Surgical Hospital, University Central Hospital, Helsinki, Finland SF 00130