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Loss of bone strength after intramedullary nailing

Torsion tests of tibial osteotomies in rabbits

Rigid intramedullary nailing was used in 75 rabbits to stabilize a transverse osteotomy of the midshaft of the tibia. In 36 additional rabbits intramedullary nailing was performed without osteotomy. No additional external immobilization was used postoperatively. After removal of the nail the mechanical strength of the tibiofibular bones was tested torsiometrically in 30 osteotomized and 18 non-osteotomized animals from 3 to 24 weeks after the operation. At 3 weeks the torsional load fractured all osteotomized bones through the osteotomy line. At later stages a spiral fracture occurred either crossing or close to the osteotomy area, usually distal to the tibiofibular junction. The increase in mechanical strength of the osteotomized bones reached a maximum at 6 weeks and then decreased. The strength of the non-osteotomized nailed bones also decreased slightly. The results suggest that rigid intramedullary nailing, although providing good conditions for early consolidation of experimental osteotomy, leads secondarily to deterioration of the mechanical properties of tubular bone.

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We have studied the strength of cortical bone after intramedullary nailing of the rabbit tibiofibular bone with and without an osteotomy.

Material and methods

A total of 111 mature rabbits weighing 2.4–4.8 kg were operated on. In 75 rabbits a midshaft transverse osteotomy was performed with a circular saw on the right tibia close to the tibiofibular junction. Subsequent osteosynthesis was achieved with a stainless steel intramedullary nail after reaming the medullary canal to 3.2 mm. The intramedullary nails were flanged at both ends to obtain rotational stability at the osteotomy site. In another 36 animals identical intramedullary nailing was performed without preceding osteotomy. The operative technique used has been described in detail by Kaartinen et al. (1985). In the osteotomy series, 23 of the 75 animals had to be excluded from the analysis because of death, fracture, non-union or infection. In the non-osteotomy series nine of the 36 animals were excluded because of death or fracture.

The animals were killed 3–24 weeks after the operation, and both tibiofibular bones were prepared for further investigation. During the preparation the periosteum and any callus were left intact, and the specimens were kept moist with saline at room temperature until torsiometric testing, which took place within 1 h. The intramedullary nails were removed prior to testing and both tibiofibular bones of each animal were radiographed. The tibiofibular bones of 30 animals in the osteotomy series and of 18 animals in the non-osteotomy series were then subjected to mechanical testing, the remaining bones being prepared for both histologic and densitometric analysis.

Mechanical tests. Three-point bending tests carried out on nailed non-osteotomized bone specimens revealed a 30 per cent increase in load tolerance before the bone broke. Before torsiometric testing, each bone was adjusted to a constant length of 8.5 cm by removing the proximal part of the fibula and both condylar ends of the tibia. Nuts were then cemented (Simplex®) to the ends of the bones. The mounted specimens were subjected to torsion with a constant angular velocity of 3.6 degrees/s until the bone broke. The load-deformation curves were simultaneously recorded. Each bone was photographed before and after testing, and the type of fracture was recorded (Paavolainen 1978).

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

M = maximum torque at fracture (Nm)
Θ = maximum angular deformation (degrees)
W = energy absorption to fracture (Nm)
G = torsional rigidity (Nm/degree)

The strength of each nailed bone was compared with that of the contralateral intact bone. Each parameter was expressed as a percentage of the value obtained for the control bone. Means and standard deviations were calculated for each postoperative group.

The significance of the difference of the ratios between the nailed and control bones was tested intraindividually with Student's t-test using logarithmic transformation. The results for the different groups were compared using Student's t-test for independent samples.

Results

At 3 weeks the torsional load fractured all osteotomized bones through the osteotomy line, but only one in six at 6 weeks. At later stages the breakage occurred as a spiral fracture either traversing the ostotomy area or in an adjacent part of the bone, usually distal to the tibiofibular junction. The non-osteotomized bones regularly broke distal to the tibiofibular junction.

The *maximum torque* (Table 1) for the osteotomized bones reached a peak at 6 weeks but remained less than the corresponding value for the controls. A further reduction in torque was observed at 12 and 24 weeks, when it was only 55 per cent of the control value. The maximum torque of the non-osteotomized bones was higher than that of the osteotomized bones. At 24 weeks the torque of the nailed non-osteotomized bones was less than that of the control bones.

The mean *angular deformation* of the osteotomized bones varied within narrow limits throughout the experiments. It was highest at 3 weeks (89 per cent of the control value) and lowest at 12 weeks (77 per cent). A similar trend was seen in the non-osteotomized bones, where the highest value was noted at 12 weeks and the lowest at 9 weeks. No differences were observed between the two nailed groups.

The recorded *energy absorption* in the osteotomized bones was lower than in the control specimens. The peak value for the osteotomized bones was found at 6 weeks. The nailed non-osteotomized bones absorbed more energy at 9, 12 and 24 weeks than did the osteotomized bones; the values were close to those of the control bones.

The *torsional rigidity* of the osteotomized bones reached the control value at 6 weeks and showed no marked decline until 24 weeks. The rigidity of the non-osteotomized bones exceeded that of the paired control bones at 9 weeks, gradually decreasing thereafter to less

Table 1. Mechanical properties of nailed osteotomized (O) and non-osteotomized (N) rabbit tibiofibular bones after intramedullary nailing in relation to paired control bones (mean ± S.D.).

Time after operation (wk)	Group	No. of animals	Maximum torque	Angular deformation	Energy absorption	Torsional rigidity
3	O	8	0.38±0.10*	0.89±0.32	0.35±0.18*	0.52±0.24*
	N	5	0.93±0.27◊	0.96±0.21	0.92±0.40◊	0.93±0.21◊
6	O	6	0.86±0.11*	0.83±0.18*	0.73±0.23*	1.02±0.16
	N	3	0.96±0.13	0.91±0.05	0.88±0.18	0.96±0.08
9	O	5	0.77 ±0.31	0.83±0.13*	0.63±0.26*	0.98±0.36
	N	4	1.17±0.30◊	0.90±0.13	1.04±0.21◊	1.38±0.28*
12	O	5	0.76 ±0.13*	0.77±0.15*	0.62±0.22*	0.92±0.10
	N	3	1.02±0.06◊	0.98±0.23	1.02±0.23◊	1.03±0.05
24	O	6	0.55±0.17*	0.79±0.37	0.47±0.29*	0.75±0.27*
	N	3	0.85±0.09◊	0.96±0.06	0.82±0.12◊	0.86±0.03*

Significant difference ($P < 0.05$), * compared to the control value, ◊ between the values of respective groups.

than the control value at 24 weeks. No differences in torsional rigidity were observed between the two operated groups after 3 weeks.

Discussion

Our results suggest that the osteotomy had healed within 6 weeks. Deterioration of the biomechanical properties of the osteotomized bones was noted subsequently, with a gradual reduction in strength up to 24 weeks postoperatively. Interestingly, a similar but less pronounced weakening of bone was also seen in the non-osteotomized bones 9 weeks after intramedullary nailing. It should be noted that the mechanical strength of the osteotomized bones approached but did not quite reach that of the control bones during the 24-week period of observation. The nailed non-osteotomized bones, on the other hand, reached the control value after only 3 weeks. A reduction in bone strength was, however, observed at 24 weeks in terms of maximum torque and torsional rigidity values (Table 1).

The intramedullary nail used in our study provided a stable fixation firm enough to allow immediate unsupported weight-bearing. The protection afforded by the nail against stress was reflected by a gradual decrease in bone strength after 9 weeks, regardless of whether the nailed bone had been osteotomized or not. Although the intramedullary osteosynthesis provided favourable conditions for swift repair of the osteotomy, the secondary weakening of the bone was considerable.

Studies of intramedullary nails with different moduli of elasticity suggest that the healing conditions are more favourable when less rigid nails are used (Brown & Mayor 1978, 1980, Wang et al. 1981, Mølster et al. 1982, Mølster & Gjerdet 1984, Wang et al. 1985). Christel et al. (1982) noticed no mechanical differences when comparing the results after intramedullary nailing with stainless steel and epoxy carbon nails at 4 months.

Biphasic changes in the biomechanical strength of healing osteotomies have been reported from this laboratory after rigid plate fixation (Paavolainen et al. 1979). The similarity in bone strength alterations after rigid intramedullary nailing and rigid plate fixation is obvious (Figure 1). The data do not suggest that either technique is superior under the experimental conditions used.

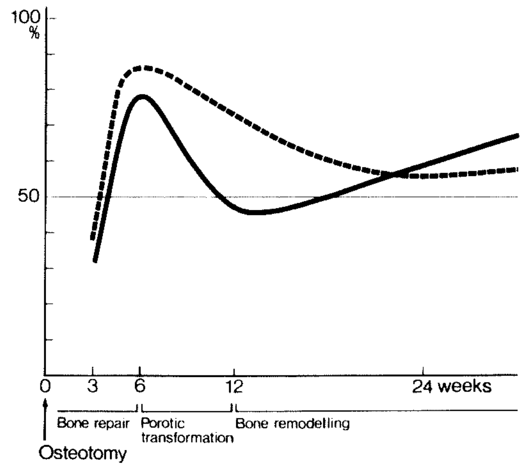

Figure 1. Schematic representation of the changes in the mechanical strength of healing experimental osteotomies after intramedullary nailing ···· and rigid plate fixation ——. The first increasing phase reflects the healing of an osteotomy, and the second decreasing phase the subsequent weakening of the strength with porotic transformation of the bone induced both by the rigidity of the osteosynthesis and by the remodelling of the cortical bone.

Whether the observed reduction in biomechanical strength may be counterbalanced by early removal of the implants remains to be seen. Uhthoff & Dubuc (1971) demonstrated histologically a slow recovery of the bone after implant removal. Preliminary data from this laboratory suggest that the bone strength returns to normal at a rate which corresponds to the length of time the implants have been attached to the bone (Joukainen et al. 1983). The biphasic pattern of the strength of the nailed osteotomy suggests that early removal of the implant would be advantageous.

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