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EFFECT OF INSTABILITY ON EXPERIMENTAL FRACTURE HEALING

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Bilateral tibial osteotomy with fracturing of the fibula was performed on ten Wistar rats weighing 300–350 g. Intramedullary nailing was performed with 1.4 mm nails after reaming. On the left side solid stainless rods were used, while on the right side the nails had a middle part made of titanium-nickel wire covered with polyvinylchloride (PVC), giving the nail a high degree of flexibility.

After 8 weeks, nine of the ten flexible nails showed fracture of the central wire. The continuity was, however, maintained by the PVC tube. The bones with flexible nailing always showed hypertrophic callus while there was only scanty callus on the side with rigid nailing.

Strength, deformation at fracture and stiffness were measured in a three-point bending test after removal of the solid nails and the fibulae. The strength of the tibiae was greatest on the side with flexible nailing, as was the deformation at fracture. The mean stiffness was higher in the bones with rigid nails, but the difference here was not statistically discernible.

Key words: callus formation; mechanical properties; osteotomies; rats

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Fracture healing without fixation implies formation of an external callus, consisting primarily of woven bone, at the site of fracture. The bone subsequently becomes more mature and stability increases. Later, remodelling takes place, and the external callus gradually disappears until the bone regains its original strength, shape and internal architecture. This process may be called secondary bone healing.

Danis (1949) and later the ASIF-group (Schenk & Willenegger 1964, Willenegger et al. 1971) and others (Olerud & Danckwardt-Lilliestrõm 1971) have shown that rigid fixation of a fracture with contact allows healing without formation of external callus. New Haversian systems grow directly across the fracture gap. This type of bone healing resembles the rebuilding of normal cortical bone and has been referred to as primary bone healing (Schenk & Willenegger 1971).

External callus seems to be the result of some stimulus, the most constant of which is movements of the fracture ends relative to each other. That instability gives increased production of external callus is considered an established fact. The mechanical properties of callus are, however, a matter of disagreement, as an increasing number of authors seem to find that "a certain amount" of external callus promotes earlier functional bridging of the fracture gap (Uhthoff & Dubuc 1971, Tonino et al. 1976 and Sudmann 1976).

Küntscher (1950) states from clinical experience that "good stability" gives "better" healing. Anderson (1962 and 1965), Göthmann (1961), Rhinelander & Baragry (1962) and the ASIF-

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group (Hutschenreuter et al. 1969, Schenk & Willenegger 1964, Willenegger et al. 1971) demonstrated this in animal experiments finding that increased stability gave better fracture healing. Brown & Mayor (1978 and 1980), however, found in rabbit tibias treated with intramedullary nails that increasing *in*stability gave a faster healing as measured by mechanical testing, and their findings are confirmed by Wang et al. (1981). A very high degree of instability is considered one of the main causes of non-union (Burny et al. 1980). However, a critical value of instability leading to non-union has not been established (Brown & Mayor 1978). The present study was designed to investigate the influence of instability on the amount and quality of callus formation in osteotomies.

MATERIALS AND METHODS

Ten male Wistar rats (300–350 g) were used. The animals were anaesthetized with ether on an open mask.

After shaving of the skin with an electric razor, the tibiae on both sides were exposed through an anterior incision. The soft tissues were detached subperiosteally by means of a curved periosteal elevator. An oblique osteotomy was made using a fine-toothed, circular saw, 0.1 mm thick with a diameter of 19 mm rotating at a speed of 800 rev/min under continuous cooling with Ringer solution. The osteotomy was directed from a level on the anterior aspect of the tibia 4–5 mm distal to the tuberosity, about 30 degrees upwards/backwards. The fibula was fractured manually without being exposed.

The medullary cavity of the tibia was reamed with a cutting reamer to a diameter of 1.4 mm under continuous irrigation with Ringer solution. The reaming was performed proximally and distally from the osteotomy site. An opening for the insertion of the nail was obtained by allowing the reamer to extrude proximally through the anterior tibia between the tuberosity and the knee joint. The nail was inserted proximally from the osteotomy site so far that the osteotomy could be reduced, then the nail was hammered carefully into the distal fragment. The soft tissues were allowed to slip back into place. Penicillin was instilled into the wound, which was closed with a one-layer continuous dexon suture.

In order to produce different degrees of stability two types of nails were used, type A on the left side and type B on the right side (Figure 1). The stiffness of type A was 392N/mm and that of the middle part of type B 3N/mm, as measured by the bending test. The stiffness of intact tibias is approx. 390N/mm (Mølster 1981, unpublished data).

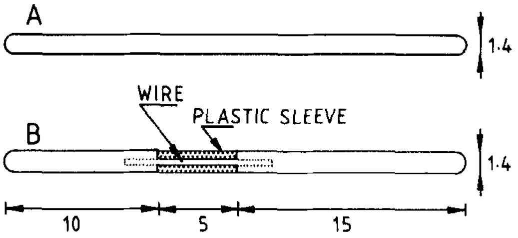

Figure 1. The two types of intramedullary nails. A (above) is made of solid stainless steel. B (below) has a flexible midpart made of titanium/nickel alloy ("Nitinol") covered with PVC.

Full weight-bearing was allowed as soon as the animals recovered from the anaesthesia.

X-rays (front and lateral projections) were taken at 3, 6 and 8 weeks after operation. The quantity of callus was estimated from the X-rays. The largest diameter was measured on the a–p and side views, and the cross-sectional area calculated assuming it to be an ellipse.

Eight weeks postoperatively the animals were sacrificed by an overdose of ether. The tibias were excised and freed of all soft tissues, put in a moisture chamber and tested at room temperature within 3 hours. The rigid nails were removed before testing, while the flexible nails were left *in situ*. This was because of the technical difficulties involved in removal and because of the negligible influence on the test results, as the Nitinol wire at this stage was fractured in all but one case, and only the soft PVC tube held the two parts of the nail together.

A three-point bending test was performed. The tibiae were tested, after excision of the fibula, in a special device (Figure 2), which was attached to a testing machine (Instron 1193). Bending was applied at a

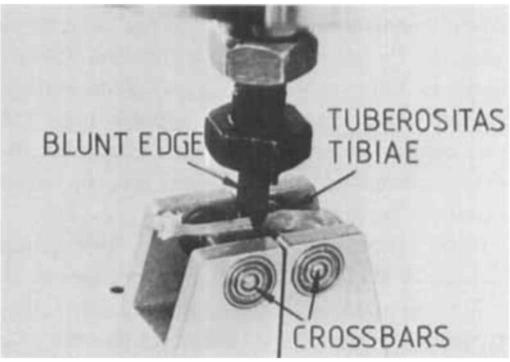

Figure 2. Three-point loading system with specimen in position. The crossbars are mounted in roller bearings. The blunt edge is moved by the cross head of the testing machine.

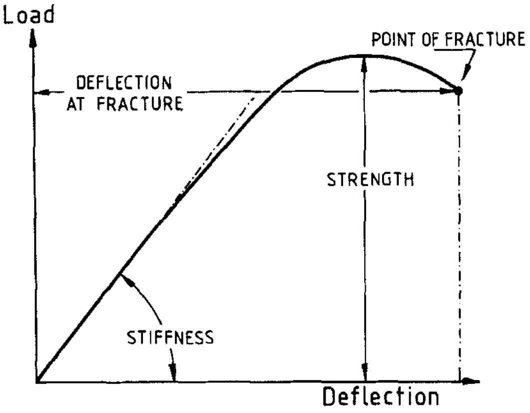

Figure 3. Schematic load-deformation curve showing how the measurements were taken.

speed of 10 mm/min, and continued until fracture occurred. Strength, stiffness and deflection at fracture were taken from the recorded curves (Figure 3).

The maximum load was taken as the strength of the bone at the fracture site.

Stiffness was calculated from the initial, nearly straight part of the recorded curve.

After testing the fragments were repositioned, fixed in formaldehyde, decalcified in formic acid, dehydrated, and embedded in paraffin. Longitudinal 6 μm sections were stained with haematoxylin and eosin.

Statistical evaluations were performed by Student's *t*-test for paired samples (two-sided).

RESULTS

In tibias with flexible fixation, all except one of the titanium/nickel cores were broken after 6 weeks, the continuity of the nail being maintained only by the PVC tubing, and most of the tibias showing some angular deformity. There were no non-unions of the tibias after 8 weeks. Five animals had an atrophic non-union of the fibula on the side with rigid fixation. The others showed healing of the fibula with moderate amounts of callus on the rigidly fixed side, while on the other side the fibula was healed in all cases with great amounts of callus which were not quantified because of overprojection of the tibia on the X-rays (Figure 4).

Curves representing the mean data are presented in Figure 5.

The values obtained from the individual test curves are shown in Table 1.

The measurements showed that the mean strength with flexible nails was approximately twice that with rigid nails ($P = 0.03$). The mean deflection at fracture was 2.7 times higher with flexible than with rigid nails ($P = 0.006$).

The mean stiffness of tibias with flexible nails was 1.5 times lower compared to tibias with rigid

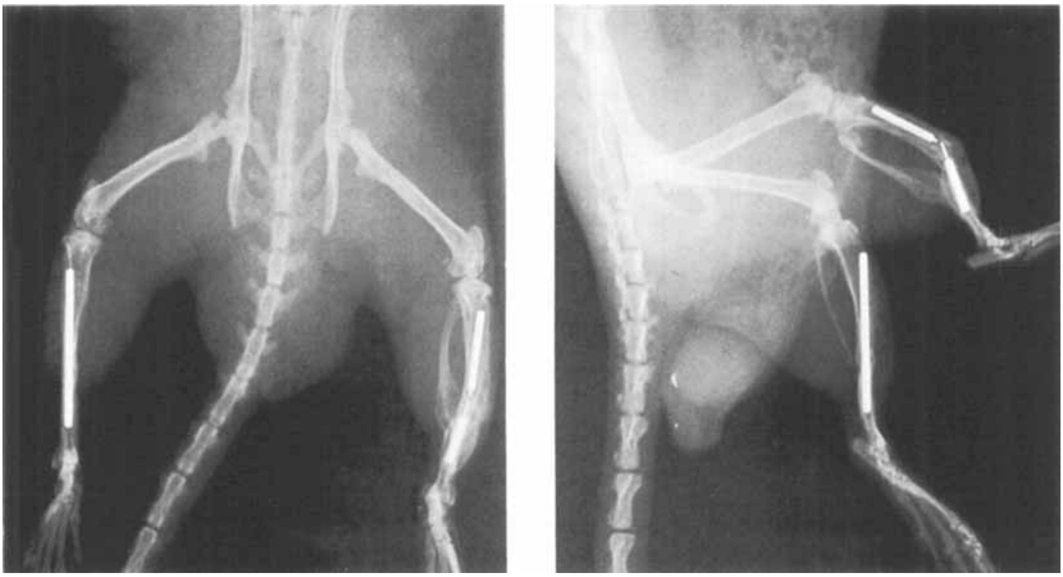

Figure 4. Typical X-ray after 8 weeks. Callus is abundant on the right side, where the central wire is broken. On the left side tibia callus is scanty, and the fibula reveals atrophic non-union.

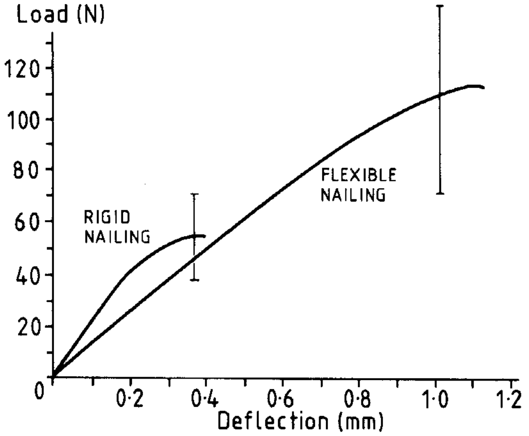

Figure 5. Load-deformation curves representing the mean values in the two types of intramedullary fixation. Vertical lines represent standard deviations.

nails. These values were, however, not statistically discernible ($P > 0.1$).

On X-rays at 3, 6 and 8 weeks, the cross-sectional areas of the callus on the flexible side were more than double those on the rigid side (Figure 6) and the difference was highly significant ($P < 0.001$).

On histologic examination, the callus tissue was less oriented on the flexible side, and mineralization was generally less advanced than on the rigid side.

DISCUSSION

The connection between stability of fixation and rate of healing as measured mechanically, and also between stability/instability and the occurrence of non-union, may be species specific. Our results in the rat, however, seem to be in good accordance with the results of Brown & Mayor (1978 and 1980) and Wang et al. (1981) regarding these factors in the rabbit.

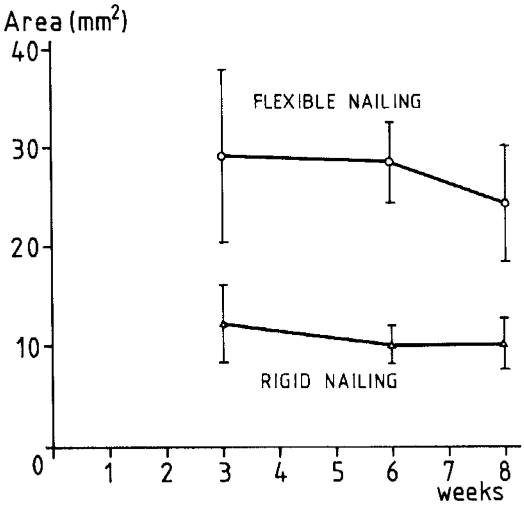

Figure 6. Cross-sectional areas of callus measured in X-rays. Vertical lines represent standard deviations.

The occurrence of atrophic non-unions in the fibulae on the rigid side contrasted with the abundant callus on the flexible side confirms the findings in the tibiae, as is also shown by Aro et al. (1981). The idea of "elastic osteosynthesis" in clinical practice has been forwarded by Burny et al. (1980), who did not, however, use medullary nailing with reaming. The reaming, together with the subperiosteal approach, will leave a large part of the cortical bone avascular (Anderson et al. 1962, Rhinelander & Baragry 1962 and Göthmann 1961). The osteones of a presumed "primary bone healing" will therefore have to penetrate a long distance in avascular bone to

Table 1. Results obtained by testing tibias after intramedullary nailing

	Flexible nailing		Rigid nailing	
	x̄	S	x̄	S
Maximum load (N)	112	46 ($n=10$)	57	31 ($n=9$)
Deflection at fracture (mm)	1.0	0.4 ($n=10$)	0.4	0.2 ($n=8$)
Stiffness $\frac{N}{mm}$	165	99 ($n=10$)	240	109 ($n=8$)

(x̄: arithmetic mean, S: standard deviation) reach the osteotomy site. Therefore, the only source of new bone in the first stages will be the periosteum and parosteal tissues. It is therefore to be expected that healing in the rigid situation, without the stimulus of movements causing external callus formation, will be notably slower than in the flexible situation.

This may explain different findings from experiments made with plate osteosynthesis, where reaming is not performed. However, the findings of analogous trends in the healing process in the fibulae tend to contradict this explanation, as these bones are neither reamed nor denuded.

As to the amount of instability we probably cannot consider even the most rigid of our osteosyntheses as absolutely stable. It is interesting, though, to find that different amounts of instability give callus tissues which seem to adapt their properties to the mechanical environment. Intramedullary nailing with a solid steel rod of about the same stiffness as the normal tibia resulted in less abundant callus formation than flexible nails. An early reduction in callus mass as measured on X-rays may be taken as a sign of early maturation.

As indicated by the measured values of strength and fracture deformation the healing tibias after 8 weeks were weaker after rigid fixation than after flexible nailing. They also broke at a smaller deformation, showing that callus on the rigid side was more brittle than on the flexible side (Panjabi et al. 1979).

Flexibility at the osteotomy site resulted in an increased amount of callus, seeming less mature than that of the rigidly nailed side, but at the same time giving better strength. The histologic immaturity was in accordance with the greater pliance after flexible nailing. Not only quality (pliance) and quantity, but also the geometry of callus in the flexible situation improves its ability to take up energy, as the moment of inertia is greater in the callus with the greater diameter.

A rigid immobilization protects bone from normal loading, and numerous reports have been given that show cancellous transformation and weakening of existing cortical bone after plate osteosynthesis (Tonino et al. 1976, Woo et al. 1976 and Paavolainen et al. 1978). It is probable that the same principle applies to new bone in the process of osteogenesis, stress protection giving a slow rate of healing. One might ask if the mechanical properties of the fractured bone with a rigid nail *in situ* will ever reach normal values. Further experiments are needed to answer this question.

In conclusion, differences in the rigidity of fixation by intramedullary nailing after reaming of oblique osteotomies of the tibiae in the rat result in different callus formation. Rigid osteosynthesis induces a scanty callus with early signs of maturation, but low total strength, and fracturing at a small deformation. On the other hand, flexible osteosynthesis provokes an abundant callus formation giving high strength and pliability.

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