Effects of instability on bone healing

Femoral osteotomies studied in rats

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Instability was induced in transversally osteotomized rat femora by means of intramedullary nails with various degrees of interlocking. Osteotomies that were stably pinned healed with less callus than those unstably pinned; no differences were found between *rotational stable and unstable pinned osteotomies*. Mechanical testing revealed that osteotomies treated by rotational stability and axial telescoping healed better than stably fixed and rotational unstable osteotomies. No differences were found between osteotomies treated by rotational instability and rigidily fixed fractures. We conclude that instability favors fracture healing as compared to rigidity. However, *rotational instability in addition to telescoping impairs* callus formation.

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Although it has been well established that fracture healing is influenced by the mechanical environment, the optimal parameters have so far not been established. With increasing instability, the production of callus is increased, with greater strength at the fracture site (Mølster et al. 1982, Reikerås 1990), while rotational instability seems to be detrimental for fracture healing (Mølster 1984). We have compared the healing of rigidly fixed fractures with that of unstable fractures with and without rotational stability.

Material and methods

30 male Wistar rats (Møllegård Avlslaboratorium, Denmark) with a median weight of 352 g (338–397 g) were used in this study. The animals were anesthetized with pentobarbital (5 mg/100 g body weight) intraperitoneally. All the rats were operated on in the same way. The left femur was exposed through a lateral incision between the lateral vastus and hamstring muscles. The soft tissues were detached subperiosteally and protected with a periosteal elevator. A transverse osteotomy at the midshaft of the bone was made with a fine-toothed circular saw blade mounted on an electrical drill. The saw blade was 0.25 mm thick and had a diameter of 25 mm. The medullary cavity was then successively reamed from the osteotomy site using steel burrs mounted on the electrical drill. The proximal fragment was reamed to a diameter of 2.0 mm, the distal fragment to a diameter of 2.2 mm. Three different nails were constructed (Mechanical Workshop, Institute of Medical Biology, University of Tromsø) to give different degrees of stability. The nails consisted of two hollow steel tubes which fitted into each other. The proximal part had an outer diameter of 1.8 mm and the distal part of 2.0 mm. Bone cement (Surgical simplex®, Howmedica Int. Ltd.) was used to fixate the two parts of the nail, and to avoid any movement between the nail and the femur. At the fracture site all nails were stabilized by the proximal part of the nail with a median bending rigidity of 1.36 Nm/rad as measured by the bending test. This is comparable to the bending rigidity of intact femur in rats of this size (Mølster et al. 1982, Grundnes and Reikerås 1992).

Group 1 was given a nail of both rotational and axial instability (Figure 1). Following reaming, the distal part of the femur was filled with cement and the distal part of the nail was then introduced to its correct position. The cement was allowed to harden before any further manipulation of the bone. The proximal part of the femur fragment was then filled with bone cement, the nail was driven in a proximal direction from the fracture site and the fracture was reduced. The proximal part of the nail was then driven as far as possible into the distal fragment, and then redrawn some millimeters to allow axial compression at the fracture site. The bone was kept immobile during the hardening time of the composite.

In group 2, rotation was avoided due to a notch of 1.0 × 1.5 × 1.0 mm in the proximal nail which fitted

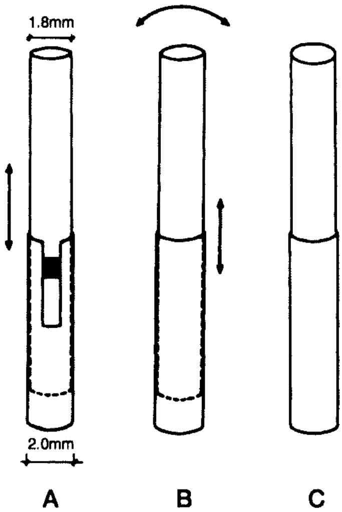

Figure 1. Nails for different degrees of instability.
A. Rotational stability and axial instability.
B. Rotational and axial instability.
C. Rigid nail.

into a 5-mm-long track in the distal nail. Median rotation was measured to 8 degrees. The operation was done as for the rats in group 1, special care being taken to avoid any bone cement in the track of the distal nail. Axial movement was possible, as in group 1.

Rigid osteosynthesis was performed in the third group, as one hollow nail was used. In this group, application of bone cement, introduction of the nail, reduction of the fracture and proper placement of the nail into the distal fragment was done consecutively without any delay. The wounds were closed in two layers.

Unprotected weight bearing was allowed as soon as the animals recovered, and all rats tolerated the operation well and resumed full activity within a few days. Macroscopic rotation was observed in group 1 the first week, but the function of the limb was regained without observable delay. At 60 days the animals were killed in a CO_2 chamber, and the femurs were carefully dissected free from all soft tissue. The external frontal and transverse diameters of the callus mass were measured by a sliding caliper (accuracy of ± 0.01 mm). The quantity of the callus was expressed as the cross-sectional area, assuming it to be an ellipse. The bones were then examined radiologically and the pins were carefully distracted. 7 animals were excluded during the experiment due to wound problems which we considered as a sign of infection, leaving 8 rats in group 1, 7 rats in group 2, and 8 animals in group 3. The healing osteotomies were tested in a cantilever bending machine by dorsal deflection of the distal half of the femur, as described by Engesæter et al. (1978). The load values were transferred to a chart recorder displaying the load-deformation curve. The strength was calculated as the bending moment necessary to produce fracture. The bending rigidity was determined from the slope of the linear elastic part of the curve, and the fracture energy was determined as the area below the curve.

Data are expressed as medians with 25 and 75 percentiles. For statistical evaluations we used the nonparametric Kruskal-Wallis test comparing several means. When significant differences were found, differences between each group were calculated using the Wilcoxon rank-sum test. $P < 0.05$ was considered significant.

Results (Table 1)

Radiographically the rigidly fixed osteotomies healed with minimal callus production, in contrast to the healing of the unstable osteotomies. No differences in cross-sectional callus area were found between the rotationally stable and rotationally unstable osteotomies. Rigidly fixed osteotomies had less cross-sectional callus area than both the rotational stably- and rotational unstably-fixed osteotomies.

The bending moment at the osteotomy site was approximately three times greater in the osteotomies that had been fixed with axial movement and minimal rotation, compared to both the stable osteotomies and the totally unstable ones. In the osteotomies that had been fixed with rotational instability, the bending moment was not different from that in the rigidly fixed osteotomies.

Median bending rigidity in telescoping and rotationally stable osteotomies was about double that of rotationally unstable osteotomies, and of rigid osteotomies. There were no differences between highly unstable and rigidly fixed osteotomies.

Fracture energy was lowest in the osteotomies that healed by primary union, and highest in the osteotomies with rotational stability and axial movement, but the differences between these groups were not significant.

Discussion

The consequences of different degrees of motion between fracture ends for regaining mechanical strength are not fully clarified. It is a matter of dispute whether regain of strength is more rapid with stable

Table 1. Cross-sectional callus area (mm²), bending moment (Nm x 10^{-1}), bending rigidity (Nm/rad) and fracture energy (Nm x rad x 10^{-2}) in telescoping, rigidly and highly unstable nailed femoral osteotomies at 8 weeks after osteotomy. Values are medians and 25–75 percentiles

				P-values		
	A	B	C	A vs B	B vs C	A vs C
Callus area	50.6 48.5–58.5	29.3 22.3–41.5	44.4 34.8–66.4	0.02	0.05	0.73
Bending moment	3.61 1.85–4.54	1.32 0.82–1.93	1.22 0.84–1.95	0.04	0.92	0.03
Bending rigidity	1.09 0.88–1.47	0.48 0.15–1.09	0.41 0.31–0.72	0.05	0.99	0.02
Fracture energy	3.12 1.32–4.37	0.88 0.46–1.85	1.46 0.58–1.99	0.10	0.10	0.10

A Rotational stable and axial unstable
B Stable
C Rotational and axial unstable

than with unstable fixation. It has been suggested that rigid fixation results in a functionally better healing than unstable fixation, but this view has been opposed by others (Rahn et al. 1971, Rand et al. 1981, Mølster et al. 1982).

In the present study, the osteotomy in one group of rats was stabilized by intramedullary pins that were cemented in distal and proximal fragments. In this way rigid fixation was obtained, as evidenced by healing with minimal production of callus. The healing of these fractures was compared to the healing of fractures that had not been rigidly fixed. These healed by the production of external callus.

Femoral fractures heal during the course of about 3 months. After 3–4 months they have regained normal strength and biomechanical characteristics. In the present study the healing osteotomies were evaluated after 2 months, as this is the time interval when healing femoral osteotomies in rats regain strength most rapidly (Reikerås 1990, Grundnes and Reikerås 1992). Intramedullary nails cause some stress-shielding of bone which may influence the biomechanical characteristics. However, as the bending rigidity of all nails at the fracture site was equal in the three groups, we assume that this factor did not influence the results.

Goodship and Kenwright (1985) found an improvement in fracture healing associated with induction of controlled axial micro-movement in experimental tibial fractures, and Kenwright et al. (1986) confirmed this beneficial effect in human fractures. On the other hand, great instability in rotation seems to be detrimental to the process of fracture healing (Mølster 1984). In the present study there was telescoping instability, but rotational stability in one group of rats. In this situation there was mainly axial stress across the fracture site. In another group of animals, there was both axial and rotational stress. As compared to the healing of the rigidly fixed fractures, healing by external callus production seemed to be preferable. Healing without rotation was, however, significantly better than with rotation. Rotational instability provokes shearing forces across the fracture site, which may be considered detrimental to fracture healing. Our results, then, are in agreement with previous authors who have suggested beneficial effects of compression and distraction across the fracture site, while shearing forces provoked by rotation seem to impair bone union.

We found no differences in cross-sectional callus area between the two groups with different degrees of instability. Bending moment and rigidity were, however, greater in the group with only axial instability. Thus, the differences in mechanical characteristics must be due to a prolonged maturation of external callus caused by rotational instability. Rigidly fixed osteotomies healed by primary fracture healing, since only minor callus was seen in this group. Biomechanically these were inferior to the osteotomies which healed in an unstable situation. This may indicate a delayed maturation in primary bone healing. On the other hand, the shape of the external callus is considered more favorable for resisting external bending forces at the fracture site, and this phenomenon may account for some of the differences in mechanical characteristics between rigidly and unstably fixed osteotomies.

In conclusion, the present study indicates that instability at a fracture site is conducive to fast healing as compared to rigidity. Rotational instability in addition to telescoping instability impairs, however, the process of callus healing.

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