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Effects of fixation stiffness on fracture healing

External fixation of tibial osteotomy in the rabbit

In rabbit tibial osteotomies, the effects on bone healing of three different degress of stiffness of external fixation were investigated. Redislocation occurred in one third of the osteotomies with the least rigid fixation, and the amount of external callus was greater in this group. At 6 weeks there were no significant differences between the groups regarding bending strength and stiffness of the bones.

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The stability of the original Hoffman external fixator was greatly improved by the introduction of transfixing pins and a double external frame (Adrey 1970). However, it is questionable whether greater rigidity of an external fixation frame is desirable. Burny (1979) reported good results with an elastic fixator of the unilateral type using half-pins, and maintained that there was no indication for the double frame, for it gives too great a rigidity. Apart from the recent study of Wu et al. (1984), there is a lack of experimental data on the optimal degree of stiffness of external fixation. We have studied how the quality and speed of diaphyseal bone healing under external fixation is related to the degree of rigidity.

Materials and methods

Increasing the diameter of the transfixing pins has been shown to be one of the most efficient means for increasing the stiffness of an external fixator (Briggs & Chao 1982). In the present study, three different diameters of the pins were used.

The stiffness of the fixation of transverse, midshaft osteotomies was measured in vitro. External minifixation (Jaquet Orthopedie S.A., Geneva) was used, with two smooth, transfixing pins in each fragment, inserted in the frontal plane or slightly oblique to this. The pin-group separation was 3 cm. Three different degrees of stiffness were obtained by using pin diameters of 1.0, 1.5 or 2.0 mm. In each group of 1.0 and 1.5 mm pins, three bones were tested, and in the 2.0 mm group, four bones.

The stiffness of fixation was tested in the anteroposterior (AP) and lateral directions in bending in an Instron testing machine (Terjesen & Benum 1983a). The overall bending stiffness was calculated as the mean of the AP and lateral stiffnesses.

Twenty-seven Chinchilla rabbits of both sexes, weighing from 2470 to 3470 g, were used for the study of bone healing. They were anesthetized with intramuscular injections of Hypnorm® Vet (Leo). One leg was operated on, while the other served as a control. The procedure was similar to that previously described (Terjesen 1984). Compression of the osteotomies was not applied. Full weightbearing was allowed postoperatively, and was apparently resumed after a few weeks.

because of complications. In the group with the least rigid fixator, one animal had a peroperative fracture through one of the pin holes, and three animals had a redislocation of the osteotomy leading to angulations of 17°, 24° and 30°. A refracture through one of the distal pin holes resulting in gross angulation occurred in one animal with a pin diameter of 1.5 mm. In those with the most rigid fixator, one animal had a peroperative fracture trough the pin holes, and in another loosening of the distal pins and gross dislocation occurred.

The animals were killed with Mebumal after 6 weeks. The fixator was removed, and the bones were dissected free of soft tissues, and radiographed. The tibiae were wrapped in towels soaked with Ringer's solution and stored at −18°C until testing.

Evaluation of bone healing

The outer AP and transverse diameters at the osteotomy site and at the corresponding level of the control bone were measured with a caliper. The amount of periosteal callus was expressed as the percentage of the sum of these diameters for the test bone related to that for the control bone. The angulation of the bone fragments was evaluated from the AP and lateral radiographs taken after 6 weeks.

The tibiae were tested in 4-point bending in the AP direction in an Instron testing machine. The load was applied at the osteotomy site. The deformation was measured with a linear variable differential transformer (Terjesen & Benum 1983a). From the load-deformation diagram, the bending strength and elastic stiffness were obtained. The Wilcoxon two-sample test (two-tailed test) was used to calculate the statistical differences between the groups. Differences were considered significant at p-values below 0.05.

Table 1. Stiffness of fixation in vitro, expressed as the percentage of the elastic stiffness for the corresponding intact bone. The median value in the antero-posterior and lateral direction of the three groups are shown

	Pin diameter		
	1.0 mm	1.5 mm	2.0 mm
Antero-posterior	4	8	15
Lateral	12	19	40

Results

In relation to the bending stiffness of the intact tibiae, the median stiffness obtained in the three groups of pin diameters were 7, 13 and 29 per cent (Table 1). All frames were more rigid in the lateral direction than in the AP direction.

Radiographic healing had taken place in all 20 osteotomies, although the osteotomy line was still visible in some. Most bones healed either without or with minimal angulation of the fragments, and in no case did the angulation exceed 10 degrees.

The periosteal callus formation (Table 2) was greater in bones with the least rigid frame than in those with the medium and most rigid frame ($p = 0.002$ and 0.001); there was no difference between the least-mentioned groups. In some of the bones in these groups, healing occurred without radiographically visible periosteal callus.

The tibiae regained stiffness more rapidly than strength (Table 2); the stiffness had reached normal values, whereas the median strength was about 60 per cent in all the groups. No significant differences in biomechanical properties between the groups were found.

Discussion

The optimal degree of stiffness in fracture fixation remains controversial. Data obtained from animal studies with known fixation stiffness are necessary to elucidate this problem, and the amount of stiffness used should correspond to the fixation stiffness in clinical fracture treatment. In a previous study (Terjesen & Benum 1983a), good agreement was found between the in vitro bending stiffness of the Vidal-Adrey quadrilateral frame, with a pin diameter of 4 mm on osteotomized human tibiae, and that of external minifixation on rabbit tibiae, using a pin diameter of 1.5 mm and a similar frame mounting as in the present study. Because the stiffness of the least and most rigid frames were approximately 50 and 200 per cent, respectively, related to that previously tested, it was assumed that the degrees of stiffness of the three fixators were so disparate that any possible effect on bone healing should be revealed.

Less rigid fixation involves healing with more abundant periosteal callus, irrespective of the method of treatment (Yamagishi & Yoshimura 1955, Anderson 1965, Nunamaker & Perren 1979), and this was confirmed in the

Table 2. Bending strength, elastic stiffness and amount of periosteal callus of the healed tibiae, expressed as the percentages of the corresponding values for the control bones. Values are median (range)

	External fixator stiffness		
	Low n=6	Medium n=6	High n=8
Bending strength	65 (43–98)	60 (43–80)	57 (34–90)
Elastic stiffness	120 (57–132)	103 (81–168)	100 (66–129)
Periosteal callus	167 (139–207)	129 (117–137)	133 (120–137)

present study. Although the difference between the in vitro stiffness of the least rigid frame and the medium one was small, this range seems to be an important one for the pattern of bone healing. This implies that, in fractures with good bony contact between the fragments, fixators with a bending stiffness of less than approximately 10 per cent of the stiffness of intact bones involve healing with abundant periosteal callus, whereas more rigid frames tend to promote "primary" bone healing.

In a recent investigation comparing the healing of dog tibial osteotomies with two different degrees of external fixator stiffness, greater mechanical properties at 30 days were found in bones with the most rigid fixation (Wu et al. 1984). However, at 120 days no differences were found, although the values tended to be greater in bones with the least rigid frame. The explanation might be that rigid fixation, though advantageous in the initial phase of healing (the first few weeks), is unfavourable in the later stage of remodelling, because it prevents the bone from being exposed to normal functional loads. This stress-protecting effect is most pronounced when using rigid steel plates, but has been found in bones with external fixation as well (Terjesen & Benum 1983b).

The amount of fixator stiffness was relatively immaterial for the speed of fracture healing in the present study. However, the least stiff frame proved inadequate for secure fracture fixation, as redislocation of the osteotomy occurred in one third of the rabbits. The fixators with the medium and greatest degree of stiffness thus seemed to be the most appropriate ones in promoting sound bone healing during the 6-week period.

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