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Mechanical effects of function on bone healing

Nonweight bearing and exercise in osteotomized rats

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The effects of different degrees of function and weight bearing on the healing of femoral osteotomies were studied in rats. A transverse osteotomy of the left femur was stabilized by intramedullary pinning. The rats were allocated to three groups: (1) tenotomy of the left achilles tendon to avoid weight bearing, (2) unrestricted weight bearing, and (3) a 4-week training programme 4 weeks after the osteotomy. After 8 weeks, the rats were killed; and callus production, bending moment, bending rigidity, and fracture energy at the osteotomy site were evaluated. There were no differences in the area of external callus. The bending moment was less in the nonweight-bearing rats. Bending rigidity and fracture energy were marginally less in the nonweight-bearing rats. There were no significant differences between the weight bearing and exercised rats. The results indicate that normal weight bearing stimulates bone healing, whereas activity above normal neither accelerates nor impairs this process.

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The function of muscles and joints around a fracture site seems to be an important stimulus to the bone-healing process (Sarmiento et al. 1977, van der Linden and Larsson 1979, Terjesen and Svenningsen 1986, 1988). It is, however, uncertain as to what extent different degrees of functional activity and weight bearing influence the speed and quality of fracture healing. The present study, therefore, was undertaken to address these questions.

Material and methods

The study included 30 male Wistar rats (Møllegård Avlslaboratorium, Eiby, Denmark) weighing 328 (312–348) g. After intraperitoneal anesthesia (fentanyl-fluanisone, 0.5 mg/100 g body weight), the left femur was exposed through an incision between the lateral vastus and the hamstrings muscles. A partial transverse osteotomy of the midshaft of the bone was made with a fine-toothed circular saw blade mounted on an electric drill, and the femur was then manually broken. The medullary cavity was successively reamed from the osteotomy site proximally and distally to a diameter of 1.5 mm using steel burrs mounted on the electric drill. A steel pin with a diameter of 1.6 mm was introduced from the fracture site; and by using the electric drill, the pin was driven through the greater trochanter. The osteotomy was then reduced, and the pin was driven into the distal fragment. The wound was closed in two layers.

The rats were randomly assigned to three groups. To prevent weight bearing in one of the groups, the ipsilateral achilles tendon was cut just proximal to its insertion site. Thus, the rats in this group were permitted full mobility of the limb, whereas weight bearing was impossible. These rats were observed once daily to be certain of the effect of the tenotomy. To prevent the achilles tendon from regaining its function, the rats were given a short-acting anesthetic 4 weeks after the first operation, after which the tenotomies were repeated.

In the second group of rats, unrestricted weight bearing was allowed. The third group comprised the exercise group.

After 4 weeks, the osteotomies were considered stable, and these rats started their training programme on a treadmill set at a 10-percent inclination in a dark room. Both the treadmill speed and the duration of training were gradually increased until the rats were running 2 h/day at a speed of 20 m/min. Exercising continued for the remainder of the experiment.

The tenotomized rats moved their limb with ease. As intended function, and hence weight bearing, was, however, insufficient throughout the experimental period. The other rats resumed partial weight bearing a few days postoperatively, and normal function of the limb, including full weight bearing, was regained within 2 weeks.

Table 1. Cross-sectional area of callus mass (mm^2), bending moment (Nm × 10^{-1}), bending rigidity (Nm/rad), and fracture energy (Nm × rad × 10^{-2}) of nailed femoral osteotomies in nonweight-bearing, weight-bearing, and exercised rats at 8 weeks after osteotomy. Medians and 25–75 percentiles in parentheses

	Nonweight-bearing rats		*P*	Weight-bearing rats		*P*	Exercised rats		*P*
Callus area	78.7	(52.9–92.7)		79.7	(70.5–105.5)		60.8	(52.5–81.7)	0.41
Bending moment	1.58	(1.13–1.90)	0.02	2.89	(1.97–3.91)	0.45	2.71	(2.22–5.07)	0.02
Bending rigidity	0.84	(0.59–1.78)		0.98	(0.84–2.17)		2.17	(1.41–2.90)	0.09
Fracture energy	1.15	(0.93–2.32)		3.09	(2.31–4.63)		2.22	(1.08–3.71)	0.06

Eight weeks after the osteotomy, all the rats were killed with an overdose of an intraperitoneally administered anesthetic. The left femur was carefully dissected free from all the soft tissue, and the intramedullary pin was removed. The outer anteroposterior and lateral diameters of the callus mass were measured using a sliding caliper (accuracy of ± 0.01 mm), and the quantity of the callus was expressed as the cross-sectional area, assuming it to be an ellipse. The bones were then examined radiographically. The healing osteotomies were tested in three-point bending as described by Engesaether et al. (1978). A standard hydraulic testing machine was run at a constant rate of 0.04 rad/s. 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. Fracture energy was defined as the energy absorbed during loading until fracture.

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 two-sample test. $P < 0.05$ was considered significant.

Results

The starting weight in the exercise group was 326 (315–340) g, which was not significantly different from the other rats (330 [312–348] g). The weight gain in the exercised rats was 151.5 (132–172) g, which was 31 percent less than what was found in the other animals ($P < 0.05$).

The osteotomies healed by the formation of external callus. No differences in callus production was found between the three groups (Table 1).

The bending moment at the osteotomy site in the weight-bearing and exercised rats was nearly equal, and approximately twice that found in the nonweight-bearing group ($P < 0.02$, Table 1).

The bending rigidity of the femurs in the exercised rats was 1.8 times greater than in the weight-bearing rats and twice the values of the the nonweight-bearing rats (Table 1). The differences between the three groups were, however, not significant ($P = 0.09$).

The fracture energy in the weight-bearing rats was slightly greater than in the exercised rats (Table 1). The values were respectively 2.9 and 2.0 times greater than in the nonweight-bearing group. These results were, however, not statistically discernible ($P = 0.06$).

Discussion

In rats the increase of mechanical properties of fractured femurs stabilized by intramedullary pinning takes about 12 weeks (Reikerås 1990). At 4 weeks, however, the fractures usually are consolidated, so the return of strength is most rapid from 4 to 8 weeks after the osteotomy. We therefore exercised one group of rats during this period. The weight gain in the exercised rats was one third less than in the control rats. In agreement with previous studies, we interpreted this finding as proving that the training program produced physiologic effects (Wardzala et al. 1982, Forwood and Parker 1986, Sommer 1987).

The osteotomies were stabilized by intramedullary pinning, but not rigidly, so they healed by the production of external callus. This experimental model, then, mimics the clinical situation in which a fracture of the lower limb is treated by intramedullary nailing. The bending rigidity of a 1.6-mm steel pin is about the same as the bending rigidity of intact femoral bones of the rats used in our study (Mølster and Gjerdet 1984).

Both experimental and clinical observations suggest that using the lower limb accelerates fracture healing (Sarmiento et al. 1977, van der

Linden and Larsson 1979, Terjesen and Svenningsen 1988). In these studies, however, immobilization of the fractured limb was effected by casting. From these studies it is, therefore, difficult to evaluate which factor, weight bearing or muscle function, is an effective stimulus to fracture healing.

In the present study, internal fracture stabilization was the same in all the groups. The nonweight-bearing rats moved their fractured limb freely, but they did not put weight on it, but tended to drag it. Our results, then, indicate that unrestricted weight bearing stimulates bone healing. Increased axial stress and compression at the fracture site may be one reason for the more rapid healing in the weight-bearing group as compared with the nonweight-bearing group.

In a previous study, Mølster et al. (1982) found increased strength in the fractured rat tibia with flexible as compared with rigid intramedullary nails. They raised the question whether or not increased axial stress across a fracture speeds up the bone-healing process. Additionally, it may be assumed that the increased loading of a limb induces a more normal function of the muscles and joints, which generally increases the circulation and metabolic state of the limb (Saville and Whyte 1969, Tøndevold and Bülow 1983).

On the other hand, increased function by exercise did not lead to any gain in mechanical properties at the fracture site when compared with weight bearing only. However, the degree of rotational instability is crucial to fracture healing (Mølster 1984, Mølster et al. 1984). In the present study, there was rotational instability at the fracture site. It is possible that the exercising increased the rotational forces, and thereby influenced fracture healing in a negative way, which counteracted a positive stimulus of increased function.

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