Closed versus open medullary nailing of femoral fractures

Blood flow and healing studied in rats

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In rats, bilateral closed femoral fractures were produced. On the left side, closed intramedullary nailing was done, and on the right side, the nail was inserted by an open procedure. The healing process of the fractures was evaluated at 4, 8, and 12 weeks, bone and muscle blood flows were also determined. Reaming had no acute impact on bone blood flow, while reaming and fracture halved total bone flow ($P < 0.04$), and reduced cortical diaphyseal flow to approximately one quarter ($P < 0.01$). No differences were found between the open and closed methods. At 4 weeks, the bending moment, rigidity, and fracture energy of the fractures treated by closed medullary nailing were greater than those treated by open nailing. The fracture energy was still greater at 8 weeks, while no differences were seen in bending moment and rigidity. At 12 weeks, however, there were no differences in the mechanical parameters. Bone blood flows in both the cortical diaphysis and callus area were increased at 4 and in the callus area at 8 weeks in bones treated by the open method. No differences were found at the end of the experiment. Muscle blood flow was not different in the two limbs, and was constant during the experimental period.

We conclude that femoral fractures treated by closed nailing heal better in the initial phase compared with those that have been openly nailed. This difference cannot be explained by an impaired muscle or bone blood flow due to open surgery.

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This study in rats was undertaken to compare the healing of closed femoral fractures treated by open or closed intramedullary nailing. Results were evaluated by mechanical testing of the healing fractures and by blood flow measurements of the bone and musculature.

Material and methods

40 male Wistar rats (Møllegård Avlslaboratorium, Eiby, Denmark) weighing 326 (313–340)g were used. Under intraperitoneal anesthesia (fentanyl-fluanixone, 0.1 mL/100 g body weight), the left trochanteric area was exposed. From the trochanteric groove, the medullary cavity was gradually reamed to a diameter of 1.5 mm prior to fracture. Fracture was produced by first percutaneously driving an awl transversely through the bone at the midshaft of the femur to weaken the bone and to avoid comminution of the fracture. The bone was then manually broken. Closed medullary pin insertion was performed on the left side by closed reduction with one hand while driving a 1. 6 mm steel pin mounted on an electric drill from the trochanteric area into the fragments. Fixation was achieved without radiographic control. Proper pin placement was confirmed later by radiographs taken at the end of the experiment.

Open intramedullary nailing was performed on the right side. Reaming and fracture were done as in those treated with the closed method. The incision was then elongated and the fracture area was exposed subperiosteally between the lateral vastus and the hamstrings muscles. A steel pin with a diameter of 1.6 mm was introduced from the fracture site, and by use of the electrical drill it was driven through the greater trochanter. The fracture was then reduced, and the pin was driven into the distal fragment. Bone-debris from reaming and blood cloth were rinsed out, and the wounds were closed in two layers.

Bone and muscle blood flows were measured by use of the microsphere technique. Microspheres (New England Nuclear, Boston, MA, USA), labeled with ^{141}Ce and ^{85}Sr, of 15.5 ± 0.1 µm diameter were used, and each injection consisted of 5×10^5 spheres suspended in 0.9 percent saline. To assure a homogeneous suspension, the vial was vortexed on a whirl mixer for two minutes prior to injection. A heparinized polyethylene catheter (PE-50) was led through the carotid artery and placed in the aortic root for injection of microspheres. The caudal artery was cannulated with a heparinized polyethylene catheter (PE-10) and connected to a Harvard infusion-withdrawal pump for reference sampling set at a flow rate of 195 μL/min. Withdrawal started 15 sec prior to injection of the microspheres and continued for 30 sec after the injection was finished.

Ten rats were assigned to each of the three groups 4, 8, and 12 weeks in the chronic study. A separate group of 10 animals was used to examine the acute effects on bone blood flow as a result of reaming and fracture. In these rats, the first injection (^{141}Ce) was done 10 min following reaming, and the second (^{85}Sr) 20 min after open or closed fracture. Correction for spillover between the two isotopes was made when these bones were counted. For measurements of blood flow at 4, 8, and 12 weeks after fracture, the use of one isotope (^{141}Ce) was sufficient.

The animals were killed in a CO_2 chamber at 4, 8, and 12 weeks following fracture. The superficial muscles of both hindlimbs were carefully removed, and an approximately 3–5-mm-thick and 12–15-mm-long biopsy specimen from the deep musculature surrounding the fracture site was used for muscle blood flow measurement. Both femurs were then dissected free from all soft tissue, wiped dry and weighed. Anteroposterior and transverse diameters of the callus mass were measured by 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 radiographically examined.

The healing fractures were tested in a cantilever bending machine. The proximal end was fixed with a clamp, a metal pin was used as a fulcrum at the fracture site, and the bones were tested 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. Fracture energy was defined as the energy absorbed during loading to fracture. For blood flow estimations, the bones and muscle biopsies were placed in counting vials and together with the reference samples counted in a Packard Auto-Gamma Scintillation Spectrometer. After the total bone flow was calculated, the bones were separated into a proximal diaphyseal segment and a callus area. The medullary cavity was rinsed out prior to recounting to get cortical flow estimations. Blood flow alterations following reaming and fracture were examined in the total bone and in a 10 mm bone segment adjacent to the fracture site.

Table 1. Cross-sectional area of callus mass (mm^2), bending moment (Nm x 10^{-1}), bending rigidity (Nm/rad) and fracture energy (Nm x rad x 10^{-1}) of open and closed nailed femoral osteotomies at 4, 8, and 12 weeks after osteotomy. Medians and 25–75 percentiles

	4 weeks n 9	8 weeks n 10	12 weeks n 10
Callus area			
Closed	43.4	36.8	33.6
	33.8–57.4	32.9–44.5	25.7–44.8
P	0.10	0.05	0.12
Open	64.1	45.2	41.4
	31.8–83.9	36.5–92.4	30.6–50.9
Bending moment			
Closed	5.78	7.77	9.48
	5.23–6.17	6.41–11.1	7.85–11.7
P	0.01	0.07	0.39
Open	2.52	6.09	7.85
	1.55–3.39	2.36–8.53	6.75–11.0
Bending rigidity			
Closed	1.64	2.84	3.47
	1.40–2.26	2.35–3.82	2.66–4.19
P	0.04	0.28	0.39
Open	1.20	2.57	3.40
	0.57–1.84	1.44–4.17	2.74–3.80
Fracture energy			
Closed	0.45	1.13	1.38
	0.30–0.66	0.75–1.59	0.98–1.83
P	0.01	0.04	0.12
Open	0.18	0.59	0.99
	0.15–0.48	0.25–0.99	0.73–1.45

Data are presented with medians and 25–75 percentiles. For statistical evaluation we used the Wilcoxon signed-rank test. $P < 0.05$ was considered significant.

Results

All the rats tolerated the operation well and resumed normal activity within a few days. One rat in the 4-week group died due to exsanguination during catheter insertion, the other cases were successful. Radiographic examination revealed that all fractures healed without signs of infection, and by the production of external callus. A nonsignificant difference (*P* 0.10) was found in the callus area between the two limbs at 4 weeks. Significant differences were seen at 8 weeks, but not at the end of the experiment (Table 1).

The bending moment at 4 weeks was 2.3 times greater in the limb treated by closed intramedullary pin insertion, and the fracture energy was 2.5 times higher. At 8 weeks, the fracture energy still was different in

Table 2. Acute effects on total bone and diaphyseal cortical bone blood flows (mL/min x 100 g^{-1}) of intact bone, reamed bone and reaming followed by open or closed femoral fractures. Medians and 25–75 percentiles. N 10

	Total flow	Diaphyseal flow
Intact bone	10.2	5.64
	7.18–14.0	4.00–8.38
P	0.47	0.38
Reamed bone	9.79	6.40
	7.10–10.8	3.76–7.11
P	0.04	0.01
Reamed and fractured		
Open	4.70	1.47
	2.48–7.83	0.76–4.06
P	0.31	0.43
Closed	5.35	1.72
	3.08–8.99	0.45–2.81

Table 3. Total bone, diaphyseal and callus blood flows (mL/min x 100 g^{-1}) of open and closed nailed femoral fractures at 4, 8, and 12 weeks. Medians and 25–75 percentiles

	4 weeks n 9	8 weeks n 10	12 weeks n 10
Total bone flow			
Closed	25.7	18.8	15.9
	18.9–47.1	15.8–46.3	14.0–31.9
P	0.04	0.48	0.09
Open	49.5	35.0	26.1
	32.0–58.6	15.7–43.2	19.2–34.9
Diaphyseal flow			
Closed	19.2	14.0	10.2
	13.7–36.5	7.92–21.4	7.25–14.2
P	0.01	0.11	0.19
Open	32.9	18.3	16.6
	20.9–47.8	14.4–36.9	10.1–19.1
Callus flow			
Closed	52.6	29.4	19.7
	48.3–134	22.3–37.6	13.8–27.2
P	0.03	0.03	0.34
Open	131	70.1	27.3
	82.1–157	33.3–81.7	21.2–28.8

Table 4. Blood flow (mL/min x 100 g^{-1}) in musculature near the callus of open and closed nailed femoral osteotomies at 4, 8, and 12 weeks after osteotomy. Medians and 25–75 percentiles

	4 weeks n 9	8 weeks n 10	12 weeks n 10
Closed	14.7	11.9	13.0
	12.6–19.9	8.44–19.8	10.0–22.3
P	0.30	0.42	0.32
Open	19.3	11.5	15.1
	15.2–26.4	9.11–20.5	14.3–20.2

the two limbs, while bending moment was not. Neither of these variables was different at 12 weeks. Bending rigidity was greater in the closed treated limb at 4 weeks, but not later in the experiment (Table 1).

Reaming did not seem to have any negative effect on bone flow, as both total bone flow and cortical flow were unchanged compared with the respective flows in control bone. Reaming and fracture did, however, significantly decrease both total bone flow and cortical flow. Only marginal differences in flow were seen between closed and open methods (Table 2).

At 4 weeks, total bone flow in the limb treated by open intramedullary nailing was about twice that which was found in the closed treated side. This difference was reflected by a significant increase in diaphyseal blood flow and a 2.5 fold increment in callus flow. At 8 weeks, neither total bone flow nor cortical diaphyseal flow was different in the two limbs, however, callus flow was still increased in the open treated fracture compared to the closed one. At 12 weeks, only marginal differences in flow between the two bones were seen (Table 3). Total bone flow 4 weeks following fracture was increased about 2.5 times in the closed treated side and about 5 times where open nailing was done when compared with control-bone flow at day 0 ($P < 0.01$ and $P < 0.005$). The increases in cortical flow were about 3.5 and 6 times in closed and open treated fractures, and in the callus 9 and 23 times, respectively. Total bone flow, cortical flow in the diaphysis, and callus flow gradually diminished as the osteotomies healed.

Surgical manipulation from open intramedullary nailing did not change muscle blood flow as no differences between the two sides were recorded. However, a 30 percent (N.S.) increment in median muscle blood flow in the openly treated limb was seen at 4 weeks. At 8 and 12 weeks, median muscle flow was practically equal in the two limbs (Table 4). In contrast to the bone blood flow, muscle blood flow was unchanged during the experimental period.

Discussion

This study shows that femoral fractures treated by closed intramedullary nailing heal faster in the initial phase than those treated by open nailing. At 12 weeks, however, there were no significant differences in mechanical characteristics. At this time the bones usually have regained nearly normal mechanical strength (Mølster 1984, Reikerås 1990).

Measuring the bone blood flow immediately after intramedullary reaming and fracture provided information about the changes in circulation in the acute period following surgical manipulation of the bone. Our findings do not eliminate the possibility of further damage to bone circulation caused by progressive thrombosis as a result of these procedures. Smith et al. (1990) found bone blood flow to be 50 percent of normal flow 10 min after osteotomy, and 29 percent at 4 hours in the dog. However, it is unlikely that the process of thrombosis should be more pronounced in one of the two limbs in our study.

The microsphere method is well documented for bone blood flow analysis (Morris and Kelly 1980, Li et al. 1989). We used a medium large dose of 500,000 microspheres in each injection (1.5 x 10^6 spheres/kg body weight). Li et al. (1989) found reliable data when the number of microspheres per sample was more than 150 in the dog. In the present study, no specific number of counts/sphere was done, however, the number of spheres in each bone segment of the control femurs was estimated to 150–250. This would indicate some inaccuracy in the results concerning the acute study as some of the specimens contained a rather small number of microspheres.

Our results concerning intramedullary reaming resemble those of Whiteside et al. (1978), who outlined the acute effects of different surgical manipulations on blood flow in rabbit tibial bone. They found that separate periosteal stripping or separate medullary reaming of diaphyseal bone did not alter bone blood flow significantly. Although no differences in bone flow as a result of opening at the fracture site were found, devascularization of the fracture ends due to periosteal stripping may still have been critical for ischemic bone cells. As already mentioned, the present model is too insensitive to elucidate small differences in low perfused bone areas when small animals like rats are used. However, from this study it seems that surgical interventions do not add any significant trauma to the vascular supply which should be responsible for the impaired healing at the initial phase.

One of the factors influencing the rate of periosteal bone formation in the early post-fracture period, may have been the periosteal blood supply. In secondary union, production of external callus is mainly developed from the periosteal system (Macnab and De Haas 1974). Several authors have noted the difference in soft tissue attachment between the femur and tibia (Brookes 1963, Smith et al. 1990). There is reason to believe that the more abundant the soft tissue coverage at a fracture site, the less effects of surgical manipulation will be seen. In our study, total bone flow, diaphyseal, and callus blood flows were significantly increased on the side that had been surgically opened. This finding may result from reactive hyperemia on the surgically manipulated side. However, this contention is highly unlikely since no hyperemia was recorded in muscle blood flow. On the other hand, callus flow gradually subsides as the fractures heal (Paradis and Kelly 1975), and a close correlation between increasing mechanical properties and decreases in callus flow has been demonstrated (Grundnes and Reikerås 1992). Therefore, it may be that the richer vascularization in the callus mass in the openly treated group is due to the fact that the callus mass is more immature.

The importance of the arterial reaction in the surrounding soft tissue has been shown (Gøthman 1962). Holden (1972) demonstrated delay in union when ischemic muscles surrounded the fracture site. We were not able to record any differences in blood flow to the musculature adjacent to the fracture site. Thus, the differences in mechanical parameters between the two methods can hardly be explained by changes in soft tissue vascularization. However, differences may be overlooked as, due to the tissue reaction, it was difficult to take identical specimens. Further, the muscle biopsy might have been too large and the possibility exists of not discovering small differences in the vicinity of the fracture site.

Kernek and Perry (1981) compared open versus closed intramedullary pin fixation in rat tibia. They found differences between the two methods in low energy fractures, but not in severe, dislocated fractures. They concluded that the greater the periosteal stripping caused by the fracture, the less noticeable was the effect of further trauma of surgical exposure. Macnab and De Haas (1974) demonstrated that when the periosteal seal was destroyed, fibrous tissue derived from the soft tissue infiltrated between the bone ends with fibrous union as the inevitable outcome. In the present study the periosteal seal obviously was destroyed by the open procedure. However, both open and closed treatments were fully displaced, with destruction of the periosteal seal as the most likely outcome.

Further, it has been claimed that reaming-particles left in place, as well as fracture hematoma, have bone inductive potential (Mizuno et al. 1990). However, at this acute stage of fracture healing, the hematoma is by no means organized and may well reproduce rapidly. On the other hand, it may be that even if no single factor is responsible for the impaired healing by the open procedure, additional trauma by surgery compromises several factors in fracture healing, which may account for the differences in mechanical properties found in this study.

High rates of union are reported with closed medullary nailing of femoral fractures (Raschyer et al. 1972). It has, however, not been proven that closed fixation is better than open fixation in clinical practice. Rokkanen et al. (1969) reported minor differences in the results of closed and open nailing of femoral fractures, but advocated that closed nailing was slightly better, while Hamza et al. (1972) preferred open nailing of tibial fractures. From the present study it seems that the healing of femoral fractures that have been openly nailed, is impaired in the initial phase as compared to those that have been treated by closed nailing. The end results, however, seem to be similar. Which one of the potentially active factors, destruction of the periosteal seal, removal of the fracture hematoma or impairment of marginal circulation, that impair the early phase of fracture healing by opening at the fracture site, is not possible to evaluate from the present study.

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