Acute effects of intramedullary reaming on bone blood flow in rats

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We examined the acute effects of increasing degree of intramedullary reaming on bone blood flow in 27 male Wistar rats by use of the microsphere method. A marginal reduction in total bone and cortical bone blood flow was seen when the femoral canal was reamed to a diameter smaller than the medullary cavity (1.5 mm). Reaming equal to the antero-posterior diameter (1.8 mm) halved total bone flow and reduced cortical blood flow by one third. Reaming equal to the transverse diameter (2.1 mm) reduced total bone flow to one third and cortical bone flow by one third.

Intramedullary reaming of the tibia to 1.5 mm reduced total blood flow about 50 percent whereas cortical flow in the proximal half was unchanged. We conclude that modest intramedullary reaming has little effect on total and cortical blood flows, whereas reaming which involves destruction of the endosteal cortex reduces both total bone and cortical blood flows.

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In some dynamic blood flow studies it has been found that modest intramedullary reaming does not seriously decrease bone circulation (Whiteside et al. 1978, Grundnes and Reikerås 1992a). This finding seems to contradict microangiographic studies in which avascularity and necrosis of the inner part of the medullary cavity have been demonstrated after reaming (Trueta and Cavadias 1955, Gøthman 1961, Dankwardt-Lilliestrøm 1969). Previous studies on this topic are, however, not specific as to the extent of reaming in relation to the dimensions of the medullary cavity. Therefore, we evaluated the acute effects of increasing degree of intramedullary reaming on bone blood flow in rats.

Material and methods

The study was performed in 27 male Wistar rats (Møllegård Avlslaboratorium, Eiby, Denmark) weighing 346 (328–364) g. The animals were randomly divided into 3 groups (A–C). Another 10 rats were killed prior to the experiment to provide initial data on bone dimensions. In these animals osteotomy was made at the midshaft of the femur. The inner antero-posterior and transverse diameters as well as the cortical thickness were measured by a sliding caliper (accuracy 0.01 mm). At the tibia osteotomies were made at the point of the tuberositas and at the midshaft.

The antero-posterior diameter of the medullary cavity at the femoral midshaft was 1.80 (1.75–1.84) mm and the transverse diameter was 2.23 (2.18–2.30) mm. The cortical thickness was 0.71 (0.65–0.77) mm. The proximal tibia has a triangular shape, and the antero-posterior distance of the medullary canal was 1.77 (1.70–1.84) mm and the transverse distance 1.60 (1.56–1.66) mm. At the midshaft the tibial cavity is circular with a diameter of 1.48 (1.46–1.51) mm. The thickness of the cortex was 0.65 (0.59–0.73) mm.

During intraperitoneal anesthesia (pentobarbital 5 mg/100g body weight) the left trochanter area was exposed. From the trochanteric groove the medullary cavity was entered by an awl, and successively reamed to 1.5 mm in Group A, 1.8 mm in Group B and 2.1 mm in Group C, using steel burrs mounted on an electrical drill. On the right side the same skin incision and exposure of the trochanter area were made, however, no reaming was done. For reaming of the tibia, a longitudinal skin incision was made over the left tuberositas tibia. The medullary cavity was entered by an awl proximal to the tuberosity, and successively reamed to a diameter of 1.5 mm. A sham operation was made on the right side. 3 animals in each group were reamed, both in the femur and tibia.

For blood flow measurements, radioactive microspheres (New England Nuclear, Boston, MA, U.S.A.) labeled with 85-Strontium of 15.5 ± 0.1 μm diameter were used, and each injection consisted of 750,000 spheres homogeneously suspended in 0.9 percent

Table 1. Acute effects of intramedullary reaming with different dimensions on bone blood flow (mL/min x $100g^{-1}$) in rat femora. Bone weight (g) and weight of diaphyseal segment (g) are given. Values are medians and 25–75 percentiles (n 9)

Dimension	Reamed bone		P	Control bone	
	Weight	Flow		Flow	Weight
Total bone flow					
1.5 mm	0.89 (0.84–0.93)	16 (11–25)	0.5	21 (12–30)	0.87 (0.80–0.92)
1.8 mm	0.80 (0.77–0.86)	10 (8.0–14)	0.008	22 (11–27)	0.84 (0.79–0.89)
2.1 mm	0.82 (0.80–0.87)	6.9 (5.9–11)	0.008	18 (8.8–24)	0.86 (0.84–0.91)
Cortical bone flow					
1.5 mm	0.13 (0.10–0.17)	17 (12–20)	0.3	19 (12–24)	0.12 (0.10–0.14)
1.8 mm	0.12 (0.11–0.13)	10 (6.1–12)	0.008	16 (11–20)	0.12 (0.10–0.14)
2.1 mm	0.12 (0.11–0.13)	7.4 (5.9–11)	0.008	12 (8.9–17)	0.13 (0.11–0.14)

saline. The spheres were vortex on a whirl mixer for 2 min prior to injection. A heparinized polyethylene catheter (PE-50) was introduced via the carotid artery and placed in the aortic root for injection of microspheres. The microspheres were injected over a period of 30 sec, and the catheter was then flushed with 0.5 mL saline. The caudal artery was cannulated with a heparinized polyethylene catheter (PE-10) and connected to a Harvard infusion-withdrawal pump for reference sampling. The flow rate in the reference organ was set at a 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. Blood flow measurements started 30 min following intramedullary reaming of the femur.

After the animals were killed in a CO_2 chamber, both hind limbs were dissected, soft tissues removed from the femurs and tibias, and the bones were then wiped dry and weighed. For blood flow estimations, the bones were placed in counting vials and together with the reference samples counted in a Packard Auto-Gamma Scintillation Spectrometer. Specimens were counted for 15 min which gave a counting error less than 1 percent. After the total bone flow was calculated, a diaphyseal segment of the femur was separated, the tibia was cut just proximally to the tuberosity and at the midshaft. The medullary cavity was rinsed out, and the bone segments were weighed and counted together with their reference samples for cortical flow estimations.

Data are presented as medians and 25–75 percentiles. For statistical evaluation we used the paired Wilcoxon sign-rank test for comparisons between limbs. The Kruskal-Wallis test was used to evaluate differences between the 3 groups, and the non-paired Wilcoxon rank-sum test was used when statistical differences were found. The same test was used to evaluate differences between the femoral and tibial bone blood flows. $P < 0.05$ was considered significant.

Results

Reaming of the femoral canal to a diameter of 1.5 mm reduced total bone flow by 22 percent in relation to control flow. Cortical blood flow was reduced by approximately 18 percent. Neither of these reductions was significant. After reaming to 1.8 mm, total bone blood flow was approximately halved, and cortical blood flow was reduced by one third. Reaming to a diameter of 2.1 mm reduced total bone blood flow by 62 percent and cortical blood flow by about 40 percent (Table 1).

In Group A total bone blood flow was greater in the reamed bones as compared to corresponding bones in Group B (P 0.005) and Group C (P 0.001). When cortical blood flow was analyzed, flow in Group A was greater than in Group B (P 0.03) and than flow in Group C (P 0.009). Reaming of the medullary canal to a diameter of 2.1 mm reduced total bone blood flow, as compared to reaming to 1.8 mm (P 0.045), while there was no difference in cortical blood flow between these 2 groups (P 0.45). There were no differences between the 3 groups in control total bone blood flow (P 0.4) or in cortical flow (P 0.1).

The different degrees of intramedullary reaming of the femur did not have any impact on tibial bone blood flow (P 0.9). Total flow in intact tibia was compared to total flow in corresponding femurs and was about 75 percent of femoral flow, while tibial cortical blood flow was about 1.5 times cortical flow in the femur. Reaming of the tibial canal to 1.5 mm reduced total bone blood flow to approximately half of the control flow, while cortical flow was not significantly reduced by 22 percent (Table 2).

Table 2. Acute effects of intramedullary reaming on total bone and cortical bone blood flow (mL/min x $100g^{-1}$) in rat tibia. Total bone and diaphyseal segment weights (g) are given. Values are medians and 25–75 percentiles

Dimension	Reamed bone		P	Control bone	
	Weight	Flow		Flow	Weight
Total bone					
1.5 mm	0.61 (0.55–0.68)	7.6 (6.4–11)	0.04	14 (5.7–17)	0.61 (0.58–0.65)
Cortical bone					
1.5 mm	0.10 (0.08–0.11)	17 (14–26)	0.4	22 (13–31)	0.10 (0.08–0.13)

Discussion

In the literature there are controversies as to the effect of intramedullary reaming on cortical bone blood flow. Histologic evidence suggests that the inner two thirds of the diaphysis is supplied by medullary and the outer one third by periosteal vessels (Trueta and Cavadias 1955, Rhinelander 1974). Other studies report that the periosteal ratio in cortical circulation is about one half to two thirds (Pfitzer et al. 1979). Furthermore, a reversal of flow from the periosteal to the endosteal system has been demonstrated (Brånemark 1961), and this phenomenon contributes to changes in the endosteal/periosteal ratio under different conditions. Whiteside et al. (1978) found an unchanged diaphyseal flow rate after intramedullary reaming of the rabbit tibia, while Indrekvam et al. (1992) reamed the femoral canal to 1.8 mm in rats with a weight comparable to our rats and found a 70 percent reduction in diaphyseal flow. However, no cortical flow estimations were done in their study. Obviously, then, controversies as to the effects of intramedullary reaming on bone blood flow may be the results of different methods, species and bones investigated, and the results of our study support this view. We found that blood flow reductions after intramedullary reaming depend on the extent of reaming in relation to the dimensions of the bone.

Measuring bone blood flow immediately after intramedullary reaming provided information about the circulatory changes in the acute period. Analysis between the 3 groups revealed that following reaming, bone blood flow in Group A was significantly greater than in Group B and Group C. However, the possibility of progressive thrombosis as a result of medullary reaming exists. This would further impair bone circulation after some hours and possibly eliminate the differences between the 3 groups.

The microsphere method we used is well established for bone blood flow measurements (Heymann et al. 1977, Morris and Kelly 1980, Li et al. 1989). However, in small animals, such as rats, the number of microspheres in each specimen may be too low to obtain accurate results, and differences in hypoperfused bone areas may be overlooked (Li et al. 1989). In the present study the number of spheres in the bone specimens used for control cortical flow analysis contained about 250 spheres. Thus, the hazard of not finding small differences following reaming exists.

We used the aortic root for injection of microspheres. A theoretical possibility of laminar streaming of spheres in the peripheral arteries exists. However, when peripheral organs, like bones, are examined, intra-aortic injection of microspheres does provide accurate and reliable flow measurements (Tuma et al. 1986).

From experimental data the effect of reaming on fracture healing is controversial. Reikerås et al. (1989) concluded that reaming did not affect the mechanical properties of healing fractures, whereas Bråten et al. (1990) found impaired strength in healing fractures of bones that had been reamed. Revascularization after reaming of the rat femur takes about 1 week; the presence of a nail seems to be of no significance (Indrekvam et al. 1992). Fracture of a long bone is followed by a powerful hyperemic response which reaches a peak of several times the increase in blood flow at 2–4 weeks (Paradis and Kelly 1975, Grundnes and Reikerås 1992b). Therefore, it may be that the differences found between the groups in the present study is of clinical significance only in marginally circulated bones.

It has been suggested that the tibia differs from the femur concerning soft tissue attachments and medullary circulation (Rand et al. 1981). The nutritient artery is particularly vulnerable at reaming with serious implication on bone blood flow in the middle and distal parts. Our results may be an indication of this. However, the present study indicates that femoral and tibial circulations are comparable, and that when modest intramedullary reaming is performed, cortical circulation is not disturbed to any significant degree, neither in the femur nor in the tibia. With an increasing degree of reaming, blood flow decreases significantly.

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