

# THE ACUTE VASCULAR RESPONSE TO INTRAMEDULLARY REAMING

## MICROSPHERE ESTIMATION OF BLOOD FLOW IN THE INTACT OVINE TIBIA

I. L. H. REICHERT, I. D. McCARTHY, S. P. F. HUGHES

*From the Royal Postgraduate Medical School, Hammersmith Hospital, London, England*

**The tibial nutrient artery supplies 62% of cortical blood flow in the diaphysis and normal blood flow is centrifugal (Willans 1987). Intramedullary reaming destroys the nutrient artery and injures the endosteal surface of the cortex. Trueta (1974) suggested that the direction of blood flow can reverse from centrifugal to centripetal after loss of the endosteal supply.**

**We examined this hypothesis by measuring cortical and periosteal blood flow after intramedullary reaming of the tibia in eight sheep, using <sup>57</sup>Co radiolabelled microspheres. The unreamed contralateral tibiae served as a control group.**

**Thirty minutes after reaming there was no significant change in cortical blood flow, but a sixfold increase in the periosteal flow. Our study confirms Trueta's hypothesis; after trauma or in other pathological states, flow can become centripetal.**

*J Bone Joint Surg [Br] 1995;77-B:490-3.*

*Received 28 April 1994; Accepted after revision 17 August 1994*

The diaphyses of long bones obtain their arterial blood supply from three sources: the nutrient artery, the metaphyseal arteries and the periosteum (Brookes 1971). In 1972, Rhinelander demonstrated that the nutrient artery supplies the inner two-thirds of the cortex and is the chief blood supply to cortical bone, and in 1979 Trias and Fery confirmed this, using Indian ink in mature canine bone. Willans (1987) estimated, by an indicator fractionation technique, that the endosteal blood supply is responsible for up to 62% of cortical blood flow in the intact bone. The cortical circulation is normally centrifugal (Brookes et al 1961).

Intramedullary reaming destroys the nutrient artery and the endosteal surface of the diaphysis (Küntschler 1958), thus depriving the diaphyseal cortex of its centrifugal arterial blood supply. Trias and Fery (1979), however, showed that there were anastomoses between the periosteal and endosteal systems in the middle layers of the cortex and argued that, anatomically, blood could flow either centrifugally or centripetally, depending on the prevailing physiological conditions. Brookes et al (1961) and Rhinelander (1974) had both suggested that the blood supply of a healing fracture may be derived from non-endosteal sources and Strachan et al (1990) confirmed that after plate fixation of a fracture there was no reduction in cortical blood flow when the nutrient artery was ligated.

The possibility of reversal of blood flow had been suggested by Trueta (1974) when he referred to an "undescribed law of compensation" in the vascular response to the interruption or suppression of normal sources of blood supply.

Our aim was to examine Trueta's 'undescribed law' in the intact ovine tibia immediately after intramedullary reaming. We used intact rather than fractured tibiae so that the results would not be influenced by the vascular changes caused by a fracture and its fixation. We compared the blood supply of the reamed intact tibia with that in the non-operated contralateral limb. Blood flow was quantified using an indicator fractionation technique with radiolabelled microspheres. This method is well established in the experimental animal to provide estimations of blood flow to specific areas and to differing types of tissue, under

---

I. L. H. Reichert, MD, Orthopaedic Research Fellow  
I. D. McCarthy, PhD, Senior Lecturer  
S. P. F. Hughes, MS, FRCS, Professor of Orthopaedic Surgery  
Department of Orthopaedic and Trauma Surgery, Royal Postgraduate Medical School, Hammersmith Hospital, Du Cane Road, London W12 0NN, UK.

Correspondence should be sent to Dr I. L. H. Reichert.

---

©1995 British Editorial Society of Bone and Joint Surgery  
0301-620X/95/3944 \$2.00

different perfusion conditions (Morris and Kelly 1980; Gross, Marcus and Heistad 1981; Tothill 1984).

## MATERIAL AND METHODS

We used eight mature full-teethed female Suffolk-crossbred sheep ( $66 \pm 2.3$  kg; mean  $\pm$  SEM) to determine tibial blood flow immediately after reaming the medullary canal.

In these animals, the tibia was  $21 \pm 3.45$  cm long and the external diaphyseal isthmus was  $15.2 \pm 3.5$  mm wide in the anteroposterior plane at the narrowest point. A surgical approach proximal to the tibial tuberosity, similar to clinical practice, allowed for reaming with pneumatic equipment.

The animals were anaesthetised with intravenous thio-pentone sodium 2.5% (May and Baker Ltd, Dagenham, UK), and this was maintained after intubation with a mixture of NO<sub>2</sub> (2 l/min), O<sub>2</sub> (2 l/min) and halothane 2%. The cortex was opened proximal to the tibial tuberosity with an awl. After initial hand reaming, we used flexible AO reamers from 7.0 to 10 mm in diameter with 0.5 mm increments, over a 4 mm AO guide wire, driven by an AO pneumatic drill (Synthes; STRATEC Medical Ltd, Welwyn Garden City, UK).

Blood-flow measurements used radioactive microspheres of  $15.0 \pm 0.1$   $\mu$ m diameter (Du Pont, Wilmington, Delaware) labelled with <sup>57</sup>Co. Each injection consisted of 100 000 microspheres per kg body-weight homogeneously suspended in a mixture of 0.9% saline and 0.01% Tween 80 (Du Pont, Wilmington, Delaware). Before injection, the suspension was placed in an ultrasonic bath (Jencons, Leighton Buzzard, UK) for 20 minutes.

The carotid artery was cannulated with an angiographic heparinised polythene catheter passed to the left ventricle to facilitate injection. Its position in the left ventricle was confirmed by the typical pressure wave on a Hewlett-Packard (Boeblingen, Germany) pressure monitor. The radial artery was also cannulated with a heparinised polythene catheter and connected to an infusion-withdrawal pump (B. Braun Melsungen AG, Melsungen, Germany) which drew blood into a heparinised syringe for reference sampling. The withdrawal rate was 1 ml/min starting 60 seconds before microsphere injection and continuing for 90 seconds after completion.

Microsphere injection took 10 seconds and flushing of the syringe and catheter with 0.9% normal saline 20 seconds. The blood-flow measurements were performed 30 minutes after completion of intramedullary reaming.

The animals were then killed with an overdose of saturated KCl and both tibiae were removed with attached soft tissues. Other soft tissues were then cleared to leave only the periosteum. The tibial diaphyses were sliced into rings 1 cm thick and cleaned of endosteal debris. Any muscle fibres left on the periosteum were carefully removed using a fine scalpel.

The cortex and periosteum were separated, weighed and

then prepared for radioactivity counts in preweighed scintillation vials. The weight of the diaphyseal cortex of the control and experimental bone was compared to determine the percentage of tissue loss during reaming.

An automatic gamma scintillation spectrometer (Model 5360; Canberra-Packard, Pangbourne, UK) was used to make counts of radioactivity for <sup>57</sup>Co for the reference sample and for each cortical and periosteal ring. Blood flow was then determined from the following equation:

Blood flow (ml/min/g) = (microsphere activity in tissue/microsphere activity in reference blood)  $\times$  (withdrawal rate of reference blood/tissue weight).

Statistical comparisons were made by the two-tailed paired Student's *t*-test and 95% confidence intervals for the mean differences were calculated.

## RESULTS

The results are expressed as blood flow in ml/min/100 g of tissue  $\pm$  SD.

**Weight.** The weight of the cortical bone was significantly reduced by reaming from  $39.2 \pm 2.7$  g to  $35.9 \pm 1.4$  g ( $p = 0.0003$ ;  $n = 8$ ). The confidence interval for the mean of the differences was 2.1 to 4.5 g, representing a loss of 8.4% of bone mass.

### Blood flow

**Cortical bone.** Reaming of the tibial medullary canal did not significantly alter blood flow in the cortical diaphysis. This was  $0.94 \pm 0.51$  ml/min/100 g in the unreamed specimens, and  $0.96 \pm 0.58$  ml/min/100 g in the reamed cortical diaphysis ( $p > 0.05$ ;  $n = 8$ ; Fig. 1a). The confidence interval for the mean of the differences was  $-0.22$  to  $+0.25$  ml/min/100 g.

**Periosteum.** There was a significant increase in periosteal blood flow in the reamed tibia as compared with the intact control periosteum. The flow rates were  $15.48 \pm 12.20$  ml/min/100 g and  $99.46 \pm 75.43$  ml/min/100 g respectively ( $p < 0.01$ ;  $n = 8$ ), showing a sixfold increase (Fig. 1b). The confidence interval for the mean of the differences was 27.66 to 140.30 ml/min/100 g.

## DISCUSSION

The vascular system of bone and its reaction to injury are important for fracture healing and have been reviewed recently by Kelly, Montgomery and Bronk (1990). The measurement of cortical blood flow is difficult because the vascular structure of bone is complex with multiple arterial supplies and venous outflows. Many methods have been used to estimate this blood flow, including the measurement of venous outflow, uptake or clearance techniques, and fractionation of diffusible tracers. None of these allows accurate repeated measurements of total or regional flow. The microsphere technique does allow the analysis of regional blood flow in cortical bone (Tothill 1984).

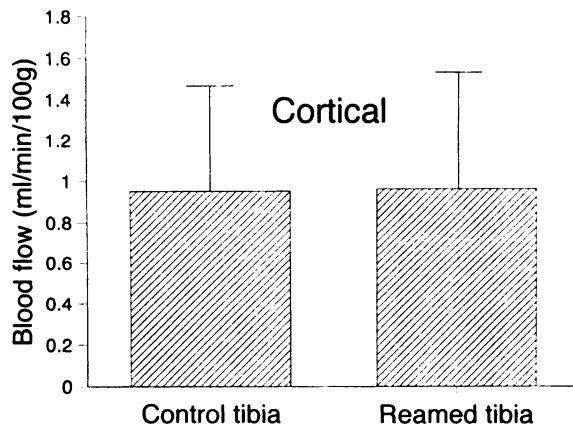


Fig. 1a

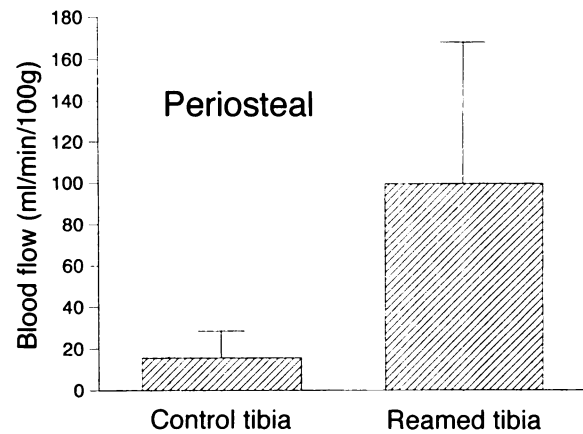


Fig. 1b

Blood flow in the diaphyseal cortices (a) and the periosteum (b) of the non-operated control tibiae and the reamed contralateral tibiae (mean  $\pm$  SD; n = 8).

Our experiments have shown that immediately after intramedullary reaming there was no significant difference in cortical blood flow despite the fact that the dominant afferent supply from the nutrient artery had been destroyed and a proportion of cortical bone had been reamed out.

Cortical blood flow would appear to be affected differently depending on the method and degree of disruption to its normal centrifugal blood supply. Both Tothill et al (1987) and Willans et al (1987) ligated the nutrient artery in the intact canine tibia to suppress the normal centrifugal blood supply to the intact diaphyseal cortex, and found a significant reduction in cortical blood flow. Grundnes and Reikerås (1993) used radiolabelled microspheres to measure blood flow after intramedullary reaming of the rat femur without osteotomy. They found no significant reduction in blood flow in the diaphyseal cortex after reaming to a diameter smaller than that of the medullary cavity, but reported an acute reduction in cortical blood flow after reaming to a diameter which removed cortical bone.

In our experiments the reaming was to a reamer size of 10 mm in the ovine tibia which has an anteroposterior diameter of as small as 6 to 7 mm. This reamed out 8.4% of the endosteal cortex. Thus our results, showing an unchanged cortical flow after reaming, contradict those of Grundnes and Reikerås; this may be due to their use of smaller animals and smaller reaming equipment. Whiteside et al (1978) measured cortical blood flow by the hydrogen washout technique after hand-reaming the medullary cavity of the rabbit tibia without osteotomy. They found no difference in cortical flow, which agrees with our data. Results obtained with the hydrogen washout method, however, must be treated with caution (Tothill 1984).

Our experiments evaluated the effect of intramedullary reaming alone on the haemodynamics in the intact tibia 30 minutes after reaming; we did not examine the effect of subsequent insertion of an intramedullary nail. Klein et al (1990) used a Procein Red intravital stain and image analysis to semiquantify perfusion, and reported 70% non-

perfusion of the canine tibia seven hours after reaming without osteotomy and the insertion of an intramedullary nail. They found, at most, 55% non-perfusion after intramedullary nailing without prior reaming. Further work, using quantitative methods, is required to study cortical blood flow after the insertion of different types of nail.

The microangiographic studies of Trueta and Cavadias (1955) showed the importance of the periosteum for cortical perfusion after intramedullary reaming. Using similar methods, Danckwardt-Lillieström (1969) reported increasing filling of the periosteal blood vessels one day after reaming of the dog femur and rabbit tibia. The introduction of radiolabelled microspheres has made it possible to quantify and evaluate accurately bone blood flow.

Our ability to measure periosteal blood flow for the first time has shown a sixfold increase on the reamed side when compared with the unreamed side in the acute phase after intramedullary reaming. This increased flow in the periosteum must provide the cortex with compensatory blood flow after the loss of the endosteal blood supply. Only compensation resulting from the periosteal response can explain the similarity in the observations of cortical blood flow between the reamed and unreamed sides.

Simple ligation of the nutrient artery and the consequent suppression of the normal centrifugal blood flow resulted in a significant reduction in cortical blood flow (Tothill et al 1987; Willans 1987). It did not stimulate an effective compensation by the periosteum. This raises the possibility that the acute haemodynamic response in the periosteum after reaming may not result solely from the absence of the dominant centrifugal blood supply, but may, in part, be an indirect consequence of the additional injury to the endosteal cortex caused by reaming. As yet, it is not possible to describe the precise mechanism responsible for inducing the increase in flow, which is separated from the site of injury by cortical bone but is part of the same continuous vascular system.

The normal direction of blood flow in the diaphyseal

cortex is mainly centrifugal (Brookes et al 1961) and anastomoses between the periosteal and centrally supplied blood-flow system have been demonstrated (Trias and Fery 1979). The acute increase in the periosteal blood flow and the compensatory flow to the cortical bone in the absence of any intramedullary blood source indicate an acute reversal of direction of blood flow in cortical bone and show that the vascular system of bone is capable of responding flexibly to injury.

Our results with radioactive-labelled microspheres have shown the compensatory capacity of the periosteum to increase blood flow in the pathological situation. They corroborate Trueta's hypothesis.

This work was supported by Action Research. Dr Reichert was supported by Action Research in conjunction with SPARKS.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

#### REFERENCES

- Brookes M.** *The blood supply of bone: an approach to bone biology.* London: Butterworths, 1971.
- Brookes M, Elkin AC, Harrison RG, Heald CB.** A new concept of capillary circulation in bone cortex. *Lancet* 1961;1:1078-81.
- Danckwardt-Lillieström G.** Reaming of the medullary cavity and its effect on diaphyseal bone. *Acta Orthop Scand Suppl* 1969;128:1-153.
- Gross PM, Marcus ML, Heistad DD.** Current concepts review: Measurements of blood flow to bone and marrow in experimental animals by means of the microsphere technique. *J Bone Joint Surg [Am]* 1981;63-A:1028-31.
- Grundnes O, Reikerås O.** Acute effects of intramedullary reaming on bone blood flow in rats. *Acta Orthop Scand* 1993;64:203-6.
- Kelly PJ, Montgomery RJ, Bronk JT.** Reaction of the circulatory system to injury and regeneration. *Clin Orthop* 1990;254:275-88.
- Klein MP, Rahn BA, Frigg R, Kessler S, Perren SM.** Reaming versus non-reaming in medullary nailing: interference with cortical circulation of the canine tibia. *Arch Orthop Trauma Surg* 1990;109:314-6.
- Küntscher GBG.** The Küntscher method of intramedullary fixation. *J Bone Joint Surg [Am]* 1958;40-A:17-26.
- Morris MA, Kelly PJ.** Use of tracer microspheres to measure bone blood flow in conscious dogs. *Calcif Tissue Int* 1980;32:69-76.
- Rhineland FW.** Circulation of bone. In: Bourne GH, ed. *The biochemistry and physiology of bone.* 2nd ed. Vol. 2. Physiology and Pathology. New York, etc: Academic Press, 1972:2-77.
- Rhineland FW.** Tibial blood supply in relation to fracture healing. *Clin Orthop* 1974;105:34-81.
- Strachan RK, McCarthy I, Fleming R, Hughes SPF.** The role of the tibial nutrient artery. *J Bone Joint Surg [Br]* 1990;72-B:391-4.
- Tothill P.** Bone blood flow measurement. *J Biomed Eng* 1984;6:251-6.
- Tothill P, Hooper G, McCarthy ID, Hughes SP.** The pattern of distribution of blood flow in dog limb bones measured using microspheres. *Clin Phys Physiol Meas* 1987;8:239-47.
- Trias A, Fery A.** Cortical circulation of long bones. *J Bone Joint Surg [Am]* 1979;61-A:1052-9.
- Trueta J.** Blood supply and the rate of healing of tibial fractures. *Clin Orthop* 1974;105:11-26.
- Trueta J, Cavadias AX.** Vascular changes caused by the Küntscher type of nailing: an experimental study in the rabbit. *J Bone Joint Surg [Br]* 1955;37-B:492-505.
- Whiteside LA, Ogata K, Lesker PA, Reynolds FC.** The acute effects of periosteal stripping and medullary reaming on regional bone blood flow. *Clin Orthop* 1978;131:266-72.
- Willans SM.** *Modelling in the analysis of ion exchange between blood and bone.* PhD thesis, University of Edinburgh, 1987.