THE ROLE OF THE TibIAL NUTRIENT ARtery

MICROSPHERE ESTIMATION OF BLOOD FLOW IN THE OSTEOATOMISED CANINE TibIA

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There has been a long-standing debate as to whether medullary or periosteal flow is the dominant vascular supply during the healing of diaphyseal fractures. We used radioactive microspheres to quantify blood flow to the canine tibia two weeks after an osteotomy.

There was a significant contribution from the periostea to the blood supply of healing cortical bone after nutrient artery ligation, with a reversal of flow from a centrifugal to a centripetal direction. Our study has confirmed the qualitative observations of Trueta (1974) regarding the significant recruitment of vessels from surrounding soft tissue during fracture healing. We have not studied the later stages of healing.

Following a fracture, the vascular response provides a homoeostatic mechanism for the supply of solutes to a healing fracture. Tothill (1984) has reviewed the various methods of measuring bone blood flow and the ways in which the tibial nutrient artery has been used to study this by direct injections. These have included clearance of bone-seeking tracers (Copp and Shim 1965) and washout studies of diffusible tracers (McCarthy and Hughes 1983).

Trias and Fery (1979) using injections of indian ink, have reported that arterial flow in the mature animal bone is predominantly centrifugal, whereas venous drainage is mainly centripetal. They also demonstrated anastomoses between periosteal and endosteal systems in the middle layers of the cortex and argued that blood can flow in either direction depending upon physiological conditions. Rhinelander (1972) describes the tibial nutrient artery as supplying the inner two-thirds of the cortex and being the chief blood supply of cortical bone. Indeed, it has been estimated by Willans (1987) that in intact diaphyseal bone the endosteal supply is responsible for providing at least 65% of cortical blood flow.

The question then arises as to the situation following fracture; it is here that controversy arises. Trueta (1974) noted that after a fracture “the main bulk of new vessels comes from the periosteal side” and that “the suppression of intramedullary flow increases the vascularity of the periostea”. Rhinelander (1972), who also used a microangiographic technique, considered that in early fracture repair, an extra-osseous arterial supply derived from surrounding soft tissues provides the blood for external callus formation. However, he also stated that by five weeks after fracture “the medullary supply has repaired and has a dominant role”. However, Rhinelander, like Trias and Fery, also observed that reversal of flow might occur in various physiological conditions. Brookes et al (1961) also suggested that a reversal of the normal centrifugal flow follows a fracture.

The aim of our study was to attempt to quantify the relative contributions of the different afferent supplies to a healing osteotomy two weeks after surgery, and to make a comparison with the supply in an intact bone. Morris and Kelly (1980) and Gross, Marcus and Heistad (1981) have established that systemic injections of radiolabelled microspheres can provide repeated estimations of bone blood flow to specific areas, and to different types of tissue under different perfusion conditions.

METHODS

In eight adult greyhounds, tibial blood flow was determined two weeks after the creation of a mid-diaphyseal transverse osteotomy across approximately 80% of the shaft, leaving the fibula intact. The osteotomies were held using neutralisation plates, the osteotomy being centred on a 4.0 cm central section without screws. After recovery, the animals were allowed to take full weight. Six control animals had plates applied without an
osteotomy. All 14 intact contralateral tibiae were also studied.

Blood flow to the tibiae was measured by cannulating the carotid artery and inserting microspheres into the left ventricle. Blood was withdrawn from the brachial artery into a syringe at a fixed rate, the syringe then acting as the reference organ for calculation of the cardiac output. The nutrient artery of the tibia, in the operated leg only, was exposed in preparation for ligation.

Thirty seconds after starting withdrawal of blood at 1.5 ml/min, Cobalt-57 labelled microspheres (New England Nuclear Inc) were injected into the left ventricle, and blood was withdrawn for a further 90 seconds. After ligation of the nutrient artery on the osteotomised leg, a similar procedure was repeated, but this time injecting Tin-113 labelled microspheres (New England Nuclear Inc).

The dogs were then killed and both tibiae removed. A 3 cm section of bone centred on the osteotomy, and an equivalent section on the control side were removed. These sections were further divided into bone, marrow and callus. Counts of radioactivity for cobalt and for tin were made for each section, using an automatic sample scintillation counter (L K B Wallac). Blood flow was then determined from the following equation:

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\text{Bloodflow (ml/min/g)} = \frac{\text{Microsphere activity in tissue}}{\text{Microsphere activity in reference blood}} \times \frac{\text{Withdrawal rate of reference blood}}{\text{Tissue weight}}
\]

RESULTS

The results are expressed as blood flow in millilitres per minute per gram of tissue; Figure 1 shows the results for normal limbs, plated controls and plated osteotomies. Plain white or black bars show blood flow to the various tissues before ligation of the nutrient artery; cross-hatched bars show blood flow after ligation. Statistical comparison was by paired t-tests.

In the intact contralateral tibiae there was no significant difference in flow to marrow or bone using the two different sets of microspheres, so the results were from both sets. The mean flow to the cortex was 0.032 ± 0.0067 ml/min/g (n = 14) and to the marrow 0.17 ± 0.034 ml/min/g (n = 14). These figures correspond with those reported by Morris and Kelly (1980) for blood flow in conscious dogs.

Plate application alone increased cortical flow to 0.13 ± 0.030 ml/min/g, p < 0.02 (n = 6). Ligation of the nutrient artery significantly reduced flow to bone to 0.067 ± 0.015 ml/min/g, p < 0.05 (n = 6). Ligation also reduced the blood flow to the marrow significantly from 0.76 ± 0.25 ml/min/g to 0.19 ± 0.076 ml/min/g (n = 6). The high flow found in the external callus was not significantly changed by ligation of the nutrient vessel.

Even after plating alone, blood flow to bone increased by a factor of 3.5 and to the marrow by a factor of 4.5. Nutrient artery ligation appeared almost to halve the blood flow to the cortical bone in every animal and reduced marrow blood flow by a factor of 5.5.

After 80% osteotomy and plating (Fig. 1), flow to bone increased by a factor of 6.5 to 0.22 ± 0.040 ml/min/g, p < 0.01 (n = 8). This was nearly double the increase seen in the plated controls. However, the most interesting finding was that, in contrast to the findings in the plated controls, ligation of the nutrient artery in the plated osteotomies failed to reduce cortical flow significantly, the result being 0.20 ± 0.042 ml/min/g (n = 8). Blood flow to the external callus was 0.77 ± 0.12 ml/min/g and increased following ligation to 0.78 ± 0.13 ml/min/g, p < 0.05 (n = 8), again, an insignificant change. Blood flow to the marrow did fall significantly following ligation from 0.68 ± 0.15 ml/min/g to 0.24 ± 0.06 ml/min/g, p < 0.05 (n = 8). This decrease in marrow flow was less, but not significantly less, after plated osteotomies than in the plated controls.

DISCUSSION

The use of radiolabelled microspheres seems to be a useful and reliable means of quantifying the rates of vascular recovery. One of the principal advantages of using systemically injected microspheres is that detailed analysis of flow to different regions of bone is possible (Smith, Kelly and Bronk 1988). The interpretation of experiments to study fracture healing by tibial nutrient artery perfusion, such as those reported by Hughes et al (1979) must be open to question, since it appears that much of the healing bone is not supplied by the nutrient artery and that the zones perfused by different afferent supplies will change during the period of fracture healing.

Our experiments have provided evidence of significant periostal recruitment of flow, particularly in the plated osteotomy. It appears that the periostal blood supply of cortical bone has a considerable capacity to contribute to high demand by reversing blood flow into a centripetal direction as stated by Brookes (1960). How long this situation might exist in a healing fracture is unclear, as there is strong evidence in the work of Rhinelander (1972) and of Trueta (1974), that it may not be long before endosteal flow is re-established, and begins once more to contribute significantly to the cortical blood supply. Our study gave no data on the timing of such return to the more centrifugal type of flow defined by Brookes and Harrison (1957).

Smith et al (1988) demonstrated that, 14 days after osteotomy, intramedullary nailing reduces the blood flow to the endosteal cortex significantly more than external fixation, but this situation is not maintained at 90 days after osteotomy. Several authors, including Trueta and Rhinelander, mention that disruption of the intramedullary circulation may inhibit endosteal callus formation,
and that when such callus does form it tends to appear in the proximal bone and in the presence of an intact or revascularised nutrient artery.

Workers such as Silberman and Solá (1967) and Richards et al (1987) have used histological methods to show the importance of an intact periosteum during the healing of a fracture. Whiteside and Lesker (1978 a,b) used a hydrogen-washout technique to study blood flow following periosteal damage.

However, debate about the direction of blood flow in bone following fracture has been restricted by a lack of quantitative information. The evidence from our type of osteotomy experiment is that periosteal flow predominates early in the course of healing. However, the timing and extent of the re-establishment of endosteal blood flow is still uncertain. Experiments similar to ours, but quantifying blood flow six weeks after osteotomy are needed to discover if such a reversal of blood flow has occurred by then. Experiments are also needed for different types of fixation, since different mechanical environments may result in different flow responses from the various afferent blood supplies. It may also be the case that damage to periosteum and endosteum will alter the timing and nature of such flow responses.

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