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# Blood flow in rabbit osteotomies studied with radioactive microspheres

Arterial embolisation with radio-active microspheres was used to measure the proportion of cardiac output to the skeleton and the tibiofibular bone both in unoperated rabbits and in rabbits after tibial osteotomy and subsequent external fixation. The mean uptake of the intact tibiofibula was 0.11 per cent of the cardiac output and, correspondingly, 0.21 per cent after the osteotomy. Maximal uptake occurred 18 days after the operation which was accompanied by a slight decrease in overall skeletal circulation.

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The arterial network in the rabbit tibiofibula is complex, including the principal nutrient artery, metaphyseal arteries and periosteal arteries (Brookes & Harrison 1957). Due to anastomoses between the separate systems, a compensatory circulatory response can be demonstrated after arterial blockage (Trueta & Caladias 1964). The diaphyseal nutrient artery is mainly responsible for the medullary and two-thirds of the cortical blood supply in the rabbit tibiofibular bone (Huggins & Wiege 1939, Brookes & Harrison 1957, Rhinelander & Baragry 1962). Disruption of the nutrient artery causes medullary ischaemia, which starts to resolve on the fourth postoperative day and continues resolving until the 22nd day (Huggins & Wiege 1939).

Using radio-isotopes, Heller et al. (1957) registered immediate mineral uptake, which was at a maximum 20 days postoperatively in the fractured rat tibia. A similar observation of rapid circulatory recovery was made angiographically by Rhinelander & Baragry (1962) after undisplaced fracture in the dog forelimb. After intramedullary reaming, the vascularity in the rabbit tibia seems to be re-established within 4 weeks (Danckwardt-Lilliestrom et al. 1970).

Radio-active microspheres injected into the systemic arterial circulation are trapped in the capillary bed, providing data of the blood flow to various organs (Neutze et al. 1968, Brookes 1970, Tothill & McCormick 1976). This labelling technique can be used to measure the share of cardiac output of individual bones and the entire skeleton.

Using microspheres, Brookes et al. (1970) demonstrated a maximal circulatory increase of 50 per cent in the rabbit forelimb bones after osteotomy and rigid plate fixation of the humerus. No quantitative reports of circulatory changes after osteotomy and external fixation have, however, been published.

## Material and methods

The series consisted of 14 adult rabbits. Ten animals were subjected to transverse diaphyseal osteotomy of the right tibia by circular saw immediately distal to the tibiofibular junction. The osteotomy was stabilized by an external fixation device with four transfixation pins. Axial compression of 10 kiloponds was accomplished by adjustable side bars. Four unoperated rabbits served as controls.

Rabbits with osteotomy were killed in groups of two, 6–30 days after the operation. Prior to sacrifice, arterial embolisation with radio-active microspheres was performed on all animals using the following technique.

Under general anesthesia the right carotid artery was cannulated with a plastic tube with an outer diameter of 0.038 inches. The soft rounded tip of the catheter was eased into the ascending aorta and the embolisation was performed immediately with a single dose within 30 s. Three minutes after the microsphere injection, the animals were killed with an overdose of i.v. barbiturate.

The size of the particles was 15 ± 3 μm(3M Tracer microspheres®) and the isotopes used were $^{46}Sc$ and

*Table 1. The percentage of skeletal distribution of cardiac output in four unoperated rabbits*

| Skeleton total | Right tibiofibula | Left tibiofibula |
|---|---|---|
| 6.44 | 0.18 | 0.20 |
| 7.07 | 0.11 | 0.10 |
| 6.26 | 0.07 | 0.07 |
| 7.03 | 0.08 | 0.10 |
| Mean 6.70±0.41 | | 0.11±0.05 |

$^{85}$Sr. Each dose contained about $10 \times 10^7$ microspheres vigorously shaken in saline (2–4 mCi).

Measurements of radio-activity were carried out using a well-type scintillation counter.

Both tibiae were prepared, including the callus in the operated one. The carcass was boiled for removal of all soft tissues and the radio-activity of the tibiae and the skeleton was measured after being divided into parts, each about 20 g weight.

The residual radio-activity in the syringe and the catheter was measured and subtracted from the primary dose, the result representing the bolus of microspheres the animal actually received.

## Results

The ten rabbits with osteotomy recovered with no complications. The entire share of the cardiac output in the four unoperated animals averaged 0.11 ± 0.05 per cent, and, correspondingly, the entire skeleton including both tibiae, 6.70 ± 0.41 per cent (Table 1).

After tibial osteotomy, the local perfusion of the tibia was higher, on average 0.21 ± 0.10 per cent (Table 2). Maximal uptake after osteotomy was reached at 18 days, the ratio of operated tibia to the paired control tibia averaging 3.22:1. A slightly elevated level of radioactivity uptake was seen thereafter, the ratio being 1.75:1.

The overall skeletal uptake after osteotomy was less than normal, as compared to the unoperated control animals, on average 5.68 ± 0.88 per cent (N.S.). A mean normal uptake of 6.50 per cent was gained at 18 and 24 days; it was subsequently followed by diminished values.

## Discussion

Injection of a bolus of microspheres in the ascending aorta gives exact flow estimates in all the other organs and tissues, excluding coronary circulation (Neutze et al. 1968). Due to capillary trapping, recirculation does not cause a problem as happens when using soluble isotopes.

The proportion in tibial blood flow of cardiac output appeared to be 0.11 per cent, which is close to that observed by Tothill & McCormick (1976), who measured 0.089 per cent of cardiac output distribution in the tibiofibula in the rat.

A significant increase in tibial blood flow was seen 6 days after diaphyseal osteotomy, reaching a maximum at 18 days. This is in agreement with the experiments by Pizzetti et al. (1967), in which they demonstrated angiographically cortical vessels traversing the os-

*Table 2. The percentage of skeletal distribution of cardiac output in ten rabbits after right tibial osteotomy and external fixation*

| Days after osteotomy and external fixation | Skeleton total | Right tibiofibula with osteotomy | Left tibiofibula | Ratio operated/unoperated |
|---|---|---|---|---|
| 6 | 4.94 | 0.13 | 0.12 | 0.87 |
| 6 | 6.10 | 0.21 | 0.33 | |
| 12 | 4.38 | 0.21 | 0.13 | 1.95 |
| 12 | 4.40 | 0.22 | 0.09 | |
| 18 | 6.54 | 0.43 | 0.12 | 3.22 |
| 18 | 6.48 | 0.15 | 0.05 | |
| 24 | 6.35 | 0.11 | 0.06 | 1.75 |
| 24 | 6.64 | 0.28 | 0.17 | |
| 30 | 5.60 | 0.20 | 0.10 | 1.76 |
| 30 | 5.37 | 0.11 | 0.07 | |
| Mean | 5.68±0.88 | 0.21±0.10 | 0.12±0.07 | |

teotomy line in the rabbit tibia 10 days after diaphyseal osteotomy and external fixation. Increased bone blood flow and mineral deposition in fractured bone are closely related, as shown by Paradis & Kelly (1975). This indicates that the bone blood supply has mainly been restored within 18 days after division of the intramedullary vessels in the rabbit tibia accomplished by osteotomy.

Wray & Lynch (1959) showed that a fracture is associated with vasodilatory response also in the injured limb as a whole. They demonstrated maximal vascularity in the rat limb 9 days after closed fracture of the tibia. Their observation of vasoconstriction in the opposite limb is not, however, supported by our study. A slight decrease in total skeletal blood flow was seen to follow tibial osteotomy.

The mean skeletal uptake of cardiac output in unoperated rabbits was 6.70 per cent, which confirms the results of Shim et al. (1968) of a 7.1 per cent share of cardiac output. They used soluble isotopes and based their result on an estimation of rabbit skeleton as 10 per cent of total body weight. Brookes (1970) reported a skeletal uptake of 28 per cent of cardiac output in the rat using microsphere injection. Tothill & McCormick (1976) could not confirm this; using a similar technique, they found a mean skeletal blood flow of 3.1 per cent of cardiac output. The difference between these two observations can only partly be explained by variations in particle injection and sampling technique. In the dog, Tothill & McCormick (1976) reported preliminary results with radioactive microspheres, giving a mean value of 7.6 per cent of skeletal uptake.

Our study showed that an increase in tibial blood supply after osteotomy is accompanied by an insignificant skeletal vasoconstrictory effect.

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