VASCULAR CHANGES CAUSED BY THE KÜNTSCHER TYPE OF NAILING

An Experimental Study in the Rabbit

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In the Nuffield Orthopaedic Centre investigations of the blood supply of bone have been pursued for some time, and methods for the visualisation of the vessels have been published (Trueta 1953a, 1953b, Trueta and Harrison 1953, Harrison, Schajowicz and Trueta 1953). Part of this research entailed a study of the vascular pattern of fracture callus, and the results of this work are now being prepared for publication. Among the methods used in this investigation was suppression of one or other of the three main vascular sources of supply to the long bones (periosteal, metaphysial-epiphysial, and medullary) because it was known that the interruption of one or two of these sources stimulates those that remain to take over after a varying interval, an effect that is being used in this Centre to stimulate bone growth (Trueta 1950, 1952, 1953c, 1953d).

During the course of the general investigation into the blood supply of callus the hypothesis was advanced that overproduction of periosteal callus, which has been reported occasionally in man after Küntscher nailing (Küntscher 1940, 1941), could be explained by periosteal vascular proliferation after damage to the nutrient artery by the nail. During the whole of the research on the blood supply of callus special attention was paid to that possibility, and the results of this investigation have been separated from the main body of data collected on the healing of fractures and constitute the present publication.

In the experimental animal, if the circulation of the bone marrow and that of the periosteum are interrupted, an increase in blood flow through the metaphysial vessels is usually observed. On the other hand, if the circulation through the nutrient artery and metaphysial vessels is interrupted, it is the periosteal blood flow which increases. During the course of the present work it was also observed that the proliferation of the periosteal vessels was always followed by new bone formation. When the blood flow through the nutrient artery was interrupted it was noticed that approximately the inner two-thirds of the cortex became ischaemic and subsequently necrotic, but that the outer third always remained alive, indicating that the main blood supply of the outer third of the cortex came across the periosteum. Contrariwise, when the periosteum was stripped and kept detached from the cortex by the interposition of an isolating polythene membrane, the circulation through the nutrient artery having been preserved, only the outer third of the cortex became the site of irregular ischaemia and a large periosteal bone (involucrum) formed round the whole shaft (Figs. 1 to 3).

The correlation between vascular proliferation of the periosteum and bone formation seemed to indicate that the Küntscher method of bone nailing operates through the production of persistent ischaemia of the nutrient artery, in which case vascular proliferation of the periosteum would be responsible for the deposit of new layers of periosteal bone. In the original papers by Küntscher (1940, 1941) and in successive observations by Lauritzen (1949), Erlich (1943), Böhler (1948) and others there is a diversity of opinion about the merits of the
Kuntscher nail and its influence on callus formation. A full investigation of this problem was thus considered worthwhile.

In the course of our previous experiments it was found that when a fracture was produced under circumstances that caused bone marrow ischaemia, union of the fracture took place quicker and the callus was stronger than under ordinary experimental circumstances. As the connections between the terminal branches of the nutrient artery and metaphyseal vessels are very profuse, in order to ensure persistent bone marrow ischaemia blood flow from the metaphyseal vessels towards the nutrient artery was prevented by drilling both ends of the shaft of the bone and plugging the cavities with polythene, a material which constitutes only a mechanical barrier to vascular penetration. After this procedure the circulation through the nutrient artery was not renewed, because at the end of the experiment it was demonstrated by arteriograms that the only remaining blood flow was periosteal (Figs. 4 to 7).

**METHODS**

Rabbits were used throughout this research, the bone selected being the radius as it was deemed necessary to obtain comparable material throughout the whole series. No immobilisation after the "fracture" was required, the ulna acting as a splint through its connection with the radius by the interosseous membrane. The bone was divided at the same level in all the animals and approximately the same amount of soft-tissue damage and of
periosteal tearing was produced in every case. The bone was divided by a thin Gigli-type saw made from a double twisted stainless steel wire of gauge 40. This was attached to a stouter wire which was threaded on a slightly curved atraumatic needle. A small incision was made on the flexor surface of the rabbit's foreleg, the needle being introduced between the two bones near the lower insertion of the pronator teres to the radius, and pulled through on the extensor surface through a further small skin incision. It was then reintroduced through the same hole round the outer surface of the radius close to the bone. The periosteum was cut transversely on the flexor, medial and lateral surfaces of the radius and the bone was divided with the saw. In this way the nutrient artery was interrupted every time together with the bone. In a number of animals the same method of bone division was used on both sides, with a nail introduced into the medullary canal on one side whilst the other radius was left undisturbed and used as a control. Several materials were tried for the medullary nails, from ordinary stainless steel Kirschner wires to various sorts of round or corrugated rods made from polythene, a substance which has been shown not to cause bone reaction, a fact confirmed by our histological observations. Polythene was used with the idea of obtaining radiographic information in living animals because it is transradiant.
Figs. 8 and 9
Figure 8—Control animal radiographed ten days after the production of the fracture, showing moderate callus formation. Figure 9—Experimental animal whose bone marrow had been obstructed with a Kirschner wire, showing more abundant callus than the control ten days after division of the bone.

Figs. 10 and 11
Control animal (Fig. 10) and experimental animal (Fig. 11) three weeks after the causation of the fracture, showing the more advanced maturation of the callus in the experimental animal. Whereas in Figure 10 the clear endosteal callus is observed, in Figure 11 there is no radiographic trace of it.

Figs. 12 and 13
Figure 12—Radiograph of a control animal after consolidation of the fracture. Figure 13—Widening of the whole diameter of the bone on the experimental side.
When a Kirschner wire was inserted it was introduced through the articular surface of the radius after opening the wrist joint. Three different thicknesses of Kirschner wires were available, and the size selected was that which could be introduced without excessive difficulty after estimating the width of the canal on the radiographs. The rabbits were arranged in two groups according to age, one of young and the other of fully grown animals. The method used was the same in both groups. In young animals the nail was pushed through the epiphysis and epiphyseal plate.

Radiographs of both the limb operated upon and the control limb were obtained at weekly intervals. At the end of the experiment arteriograms were obtained, usually by injecting Micropaque without removing the polythene.

RESULTS

Apart from the series of experiments in which the nutrient artery was ruptured but no foreign body was left filling the medullary canal thirty-one rabbits were used for this investigation, distributed as follows: Nailing with polythene, twenty-one (nine adults, twelve young); nailing with Kirschner wire, ten (seven adults, three young). The results were basically similar whatever the material used for the nail, but there were some differences between young and adult animals which makes a separate description of both groups necessary.

YOUNG ANIMALS

Analysis of the radiographic findings—Between seven to ten days after the introduction of a nail a layer of new bone appeared along the diaphysis, covering it either entirely or to a great extent (Figs. 8 and 9). This new bone is continuous with the periosteal callus and at the outset often does not extend to the very end of the fragments. In the early stages the radiographic appearance of this layer of new bone is cloudy but it soon becomes denser and seems well incorporated in the cortex. This density increases during the first few weeks, but from the second or third week new bone coming from both fragments establishes a continuous bridge across the "fracture" site which unites the two fragments (Figs. 10 and 11). In most of the animals the periosteal callus appears earlier on the nailed than the control side. The size of the periosteal callus which forms the "direct bridge" is never greater and is usually smaller than on the control side, and union is frequently quicker on the nailed than on the control side. As a result of the layer of bone added to the cortex on the experimental side this becomes wider and the whole diameter of the bone increases (Figs. 12 and 13).

In some animals the widening did not extend the whole length of the diaphysis. In these cases the angiograms obtained at the end of the experiment showed that a stump of the nutrient artery had remained in the marrow cavity and that the bone changes extended exactly up to the end of the arterial stump (Figs. 14 and 15). Whereas without exception on the control side advanced endosteal callus existed from the eighth to the tenth day this did not appear in any of the experimental bones. Radiographically the gap in the fracture line disappeared roughly at the same time in both the experimental and the control bones, but when exceptions to the rule were encountered these showed a slightly earlier filling of the gap in the nailed bone than in the control (Figs. 16 and 17). About four weeks after the fracture some changes in the inner cortex began to take place, usually in the ulnar side of the bone, and gradually spread to its radial side. These changes led to a gradual reabsorption of the inner part of the cortex as if it were moving away from the foreign body. In this way the cortex regained its normal thickness but the total diameter of the bone at the end of the process appeared greater than that of the control (Figs. 18 and 19). In one of the animals

* We considered as adult those rabbits whose radiographs showed the lower radial epiphysis fused.
observed for about three months after nailing, the diameter of the bone remained greater than that of the control, the animal having ceased growing at the end of this observation. In another animal changes were observed up to the seventh month, although they were very mild during the last two months. In exceptionally good radiographs it was possible to see that during the first two or three weeks the inner layer of the cortex appeared denser than its outer part.

Study of the angiograms—Every one of the animals was injected to permit vascular studies at the end of the experiment at varying time intervals according to a prearranged plan. A study of the angiograms showed that in most of the cases the nutrient artery was absent, whereas on the control side it was well injected with radio-opaque substance and quite often the two divided parts had reunited through anastomotic vessels across the fracture line (Fig. 20). Occasionally in the nailed bone there was some injection material in the proximal part of the nutrient artery, but usually the stump of the vessel never reached the fracture level and it was always squeezed against one of the walls of the canal. In no case was the distal part of the nutrient artery found injected.

In order to study the vascular pattern of the cortex after interruption of the blood flow from the nutrient artery it was found convenient to remove the periosteum at the end of the experiment to avoid the superposition of periosteal vessels on those of the cortex. As compared with the control side it was found that the small vessels perforating the cortex in the nailed
Bone were much more numerous (Figs. 21 and 22). The proliferation of vessels at the fracture site, contrariwise, was practically the same on both the experimental and the control sides. The number of small vessels of this area depended on the stage of the healing and on the type of

![Figs. 16 and 17](image)

**Figure 16**—Radiograph and angiogram of the control side. **Figure 17**—Radiograph and angiogram showing the more advanced stage of consolidation on the experimental side.

![Figs. 18 and 19](image)

**Figure 18**—Radiograph of the control side. **Figure 19**—Radiograph of the experimental side showing greater diameter of the bone marrow cavity.

the fracture. If the callus was profuse more vessels were apparent. In angiograms of transverse sections of bone 1 millimetre thick, a number of vessels appeared to be perforating the cortex in a rather straight course, while this direction of the vessels was never seen on the control
vascular changes caused by the Kunstcher type of nailing

side except close to the fracture line (Figs. 23 and 24). These cortical vessels were already present twenty-one days after nailing. The trabeculae were laid down following the straight direction of the vessels (Fig. 25). An increase in the vascularity of the cortex was found in all these nailed bones in spite of the early ischaemic lesions in the inner part of the cortex.

Fig. 20
Angiogram of a control side showing the reunion of the two divided parts of the nutrient artery through anastomotic vessels.

Figs. 21 and 22
Figure 21—Angiogram of control side at the end of the experiment showing the reconstitution of the nutrient artery and the relatively poor periosteal flow. Figure 22—Total absence of nutrient artery and great periosteal vascular proliferation.

caused by the interruption of the blood flow through the nutrient artery. A substantial amount of the radio-opaque material was usually present in the medullary cavity although the nutrient artery had its blood flow permanently interrupted (Figs. 26 and 27). This was further evidence that the blood supply to the cortex after the interruption of the blood flow through the nutrient artery caused by the nail came from the periosteal vessels.

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**Histology** - As early as two weeks after the "fracture" a continuous layer of new bone was seen covering practically the whole of the diaphysis of the nailed side (Fig. 28). This new bone was formed by trabeculae directed obliquely towards the surface of the cortex and continuous with the periosteal callus. Because of this new layer of bone the total thickness of the cortex was greatly increased in comparison with that of the control side. Opposite to this layer of new bone the old cortex showed extensive necrosis of its inner part, some laminae appearing completely empty of cells and others showing hyperchromatic nuclei. No clear-cut line of demarcation of the necrotic cortex was apparent, but the ischaemic changes affected mainly the inner third of the cortex. Some transformation was going on within the necrotic cortex, such as widening of the Haversian canals and their invasion by new vessels, osteoclasts and osteoblasts. Vessels were seen breaking through the necrotic cortex towards the medullary canal. This revascularisation was taking place much more from the ulnar than from the radial side of the bone (Fig. 29). In fact it has been found throughout this research that removal of the dead bone and its replacement proceeds much more quickly on the ulnar than...
on the radial side of the bone. At seven weeks most of the necrotic bone had been reabsorbed, although some dead bone still remained on the outer side of the nailed radius. It was found

![Fig. 28](image)

*Fig. 28*
Section of the cortex and periosteum showing the continuous layer of new bone covering the diaphysis of the control (nailed) side, two months after the introduction of the nail.

![Fig. 29](image)

*Fig. 29*
Vessels from the periosteum breaking through the necrotic cortex towards the medullary canal.

that the fracture had united well through the peripheral callus and by new bone formed between the two fragments after partial absorption of the necrotic ends. No cartilage was
seen in this process of callus formation. The bone marrow became progressively nearer to normal and some new bone formed inside the marrow canal around the nail. In transverse sections through the diaphysis the layer of new bone on the outer surface of the old cortex was seen to be greatly decreasing in thickness but still contained many empty trabeculae on its inner surface. At six and a half months the bone seemed apparently normal and there

was no trace of the previous fracture, but on closer observation there were still several areas of bone necrosis (Fig. 30). A layer of new bone had formed either all around the nail or on one side of it. The marrow showed great cellularity, with many macrophages or giant cells containing lipoid. It appeared well injected and in some places could not be distinguished from the normal.

**ADULT ANIMALS**

In contrast to the young animals, in the adults it was not possible to find any large mass of new bone covering the outer surface of the cortex. On close observation, however, a slight thickening of the whole of the cortical shaft was seen about two months after the nailing, much later than in the young animals. This thickening was followed by some absorption of the inner cortex which was still continuing after eight months when the experiment was ended. In this way the total diameter of the bone increased here also, although the increase was not comparable with that seen in young animals. It was found that the periosteal callus, as in the young animal, appeared earlier than on the control side in all cases; but in four of the adult animals a much more voluminous callus than had been seen in younger animals was observed (Figs. 31 and 32). It was impossible to determine the reason for the formation of the profuse callus. It was thought that perhaps bone marrow expressed by the nail through the fracture site could have contributed to the formation of this exuberant callus, but why this did not happen in the young animal remains unexplained. The profuse callus was soon absorbed. Finally, endosteal callus did not appear here either. The time of union was similar to that of the control bone and in no case was union delayed.
The disappearance of the fracture line took place at the same time on both the experimental and the control sides. But in the few exceptions encountered it was observed that the nailed bone consolidated slightly earlier than the control.

**Figs. 31 and 32**

Figure 31—Control adult animal in which drilling of the metaphysial ends of the diaphysis was effected without destruction of the nutrient artery or plugging with polythene. Figure 32—Experimental adult animal in which the nutrient artery has been divided and its regeneration prevented by plugging the metaphysial ends of the shaft. Note the abundant callus and more advanced consolidation of the experimental side.

**Fig. 33**

Necrotic cortex seen in an adult animal eight months after nailing. The inner two-thirds of the shaft are affected.

**Angiograms**—In no case was the nutrient artery intact and usually it was completely absent. In two animals there remained a proximal stump consisting of part of a proximal branch of nutrient artery. This corresponded to the end of the nail at the metaphysial enlargement.
of the shaft. In one animal there was also a stump of the distal branch ending about a centimetre above the fracture site. The cortex did not show in the adult the same amount of increased vascularity found in the young animal. The proliferation of vessels in the nailed bone was similar to that on the control side. Angiograms of transverse sections of the bone did not show the same striking appearance of vessels perforating the cortex as in the young animals, although a few of them were seen here also.

**Histology**—The extent of necrosis was roughly the same as in the young animals and involved from one-third to two-thirds of the inner cortex in cases in which no stump of the nutrient artery had remained perfusible—that is, in nearly every case. The changes were here much more limited and slower in appearing. At five weeks after the nailing the following was the main picture. Necrosis was spreading over the inner part of the cortex with the same characteristics as in the young animal. There was a thin layer of lamellated new bone formed all round the diaphysis. This was thin in comparison with that seen in young animals and even thinner on the proximal fragment than on the distal. In most of the diaphysis the marrow was necrotic and did not contain any vessels. Near the metaphysis giant cells containing lipoid were seen adjacent to living marrow. The fracture was uniting through a bridge established from the outer side which contained a little cartilage, but there was no callus as yet between the fragment ends. No endosteal callus was apparent. Two weeks later—that is, seven weeks after nailing—the picture had changed slightly. There was now some transformation mainly on the ulnar side of the cortex, where a few vessels had broken through the cortex into the canal. In some places a thin layer of new bone was found on the inner surface of the necrotic cortex. Very little bone marrow was present in the canal, but in some places its remnants looked like being transformed into new bone lamellae. A small amount of new bone was formed around the nail. The fracture had now united mainly through bone, but there was some cartilage on the outer surface of the callus. Even eight months after the nailing the picture had not substantially changed and there were still a few portions of necrotic cortex to be seen scattered about affecting the whole of the two inner thirds of the shaft (Fig. 33). On the proximal fragment the layer of new bone was still seen, as little transformation had taken place, particularly on the outer side. On the distal fragment, where the layer of new bone on the outer surface of the cortex was thicker, the greater part of the necrotic bone had been removed and partly replaced. It looked as if in these adult animals there were two types of behaviour in relation with the dead bone: 1) either the new bone was laid down slowly on both the inner and the outer surfaces of the dead bone, or 2) the dead bone was covered on its outer surface by new lamellae and was then removed from its inner surface.

**DISCUSSION**

Many investigators, among them Küntscher (1940, 1941), Greissmann and Reich (1944), Maatz (1951) and Silani and Amante (1949), have noticed the new bone formation at the diaphysis of nailed fractures, the experimental production of which has been described here. The explanations for this finding are varied. It has been considered the result of chemical or physical irritation from the material of the nail. It has also been ascribed to pressure of the nail against the bone, and to hormone diffusion from the marrow. Küntscher did not believe that these changes were the result of injury to the bone vessels, but some other authors, among them Silani and Amante (1949) and Marneffe (1951) suggested that the injury to the vessels might be responsible for the proliferation of the subperiosteal bone. One of the reasons why this problem has not been solved seems to be the insufficient knowledge of the role of the nutrient artery in the nutrition of the cortex. Even Marneffe (1951) has repeatedly stated that the nutrient artery contributes very little to the nutrition of the cortical bone of the rabbit. In a series of experiments we have found that, contrary to the current opinion, the nutrient artery is responsible for the nutrition of the greater part of the cortex. This is in agreement with the findings of a few early investigators such as Johnson (1927)
and others. It is quite reasonable, then, to expect that the changes we have mentioned will be produced when a large foreign body is forcibly introduced with considerable violence along the length of the marrow canal. Even if part of the nutrient artery could escape damage numerous branches would be destroyed and consequently a great part of the diaphysis would be deprived of its nourishment. It is to be noted that in rabbits, in which the progress of bone healing is rapid, large parts of the necrotic cortex persist eight months after medullary nailing.

Although this paper does not deal with nailing in man the results of the investigation might be of some help in the interpretation of the behaviour of human bone after Kuntscher nailing.

REFERENCES


