PROGNOSIS OF EPIPHYSIAL SEPARATION

An Experimental Study

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It has been clearly demonstrated that after experimental separation of an epiphysis the plane of separation is always on the diaphysial side of the epiphysial plate (Haas 1917, Harris 1950). The significance of this observation is that the growing cartilage cells in the plate remain adherent to the epiphysis. Thus, if the nutrition to these cells is not damaged by the separation, growth in the epiphysis should continue with little abnormality. This view is supported by several clinical studies (Aitken 1935a, 1935b, 1936; Aitken and Magill 1952, Aitken and Ingersoll 1956). Yet in a recently reported study of the histological changes after experimental separation of the upper femoral epiphysis, a different result was found (Harris and Hobson 1956). In this case the separation was followed by prompt avascular necrosis of the bony epiphysis and cessation of growth in the epiphysial plate. Repair occurred by new bone which grew across the remnants of the plate. It seems to us that this result might be peculiar to the upper femoral epiphysis, and that it could be related to the fact that, since the upper femoral epiphysis is entirely covered by articular cartilage, its nutrient vessels must enter it by being closely applied to the periphery of the epiphysial plate. In other words the vessels are so situated that they must inevitably be damaged in epiphysial separation. It seemed desirable, therefore, to extend our observations to include a study of the methods by which epiphyses are vascularised and the influence this has upon healing after epiphysial separation.

MATERIAL AND METHODS

The details of the blood supply to epiphyses were studied by means of India ink injections in M. Rhesus monkeys. (These animals were used for the production of Salk poliomyelitis vaccine and were provided through the courtesy of the Connaught Laboratories of the University of Toronto.) A cannula was inserted into the left ventricle, and the animal was perfused with a warm solution of 0-75 per cent sodium chloride, 0-5 per cent sodium oxalate and 0-2 per cent sodium nitrate, a mixture which combines vaso-dilating and anticoagulant properties. This preliminary perfusion was followed by an injection of a heated mixture of 30 cubic centimetres of India ink in 100 cubic centimetres of 5 per cent gelatin. When the circulatory system was completely filled with the latter solution the body of the animal was immersed in ice-water to set the gelatin. The epiphyses and adjacent soft tissues were dissected out, fixed in formalin, decalcified, cut into slabs about one millimetre thick, and finally cleared in oil of wintergreen by the Spalteholz technique (Bensley and Bensley 1938). The cleared specimens were then studied both with the dissecting microscope and by using the cleared slab as a "negative" and placing it in the carrier of a photographic enlarger to provide an enlarged photographic print.

RESULTS

Two basic forms of vascularisation were found; the type depended upon whether or not the epiphysis was entirely or only partly covered by articular cartilage (Fig. 1).
Diagram to demonstrate that when an epiphysis is entirely covered by articular cartilage (A), its blood vessels must enter it by traversing the perichondrium at the periphery of the epiphysial plate. This makes them vulnerable to rupture after epiphysial displacement. By contrast when an epiphysis is only partly covered by articular cartilage (B) its blood vessels enter it in such a way that separation could occur without serious damage to them.

Figure 2—Cleared India ink injection of the femoral head of a monkey (M. Rhesus). The epiphysis is entirely covered by cartilage, and its nutrient vessels enter it by traversing the perichondrium at the periphery of the epiphysial plate. Figure 3—Cleared India ink injection of the upper tibial epiphysis of a monkey. The epiphysis is only partly covered by articular cartilage, and its nutrient vessel enters it by penetrating the cortical bone at the side of the epiphysis.
Type A. Epiphysis entirely covered by articular cartilage—Since vessels cannot traverse the joint space to enter this type of epiphysis, the nutrient vessel must enter the epiphysis by traversing the periosteum at the periphery of the epiphysial plate* (Fig. 2). On entering the bony epiphysis proper, the main vessel breaks up into smaller branches. No direct communication through the epiphysial plate was observed between these vessels and those of the adjacent metaphysis.

Type B. Epiphysis partly covered by articular cartilage—The blood vessels of this type of epiphysis enter the bone by penetrating the cortex at the side of the epiphysis (Fig. 3), just as does the nutrient vessel to the shaft of a long bone. Often more than one vessel enters the epiphysis or a single vessel branches as it enters the epiphysis itself. Again, no direct communication through the epiphysial plate was seen between these vessels and those of the metaphysis.

The upper femoral and upper radial epiphyses are good examples of Type A epiphyses, while most of the rest of the epiphyses in the body may be classified as Type B.

DISCUSSION

The site of the nutrient vessels in relation to the epiphysial plate in each of the two types of epiphysis suggests very strongly that an epiphysis of Type B could be separated with little damage to its blood vessels, while separation of an epiphysis of type A would almost certainly produce serious vascular damage. Experimental proof of the latter hypothesis is provided by the study of the changes after experimental separation of the upper femoral epiphysis (Harris and Hobson 1956). Although there is ample clinical evidence to support our reasoning about the fate of the blood vessels after separation of a type B epiphysis, few experimental studies are available and these lack detail (Kühne 1952, Müller 1924). For this reason the remainder of our investigation was confined to a study of the histological changes found after separation of a type B epiphysis.

MATERIAL AND METHODS

Because of its accessibility and the ease with which it can be separated the distal radial epiphysis was selected as an example of a type B epiphysis. Four to six weeks old rabbits were used. The epiphysis was exposed subperiosteally through a longitudinal incision. It was easily separated by manual hyperextension of the forepaw. After reduction the periosteum and skin were closed. The shape of the epiphysial plate is such that the reduction was stable, so no fixation was required. The animals were killed at two-day intervals up to ten days, and thereafter at weekly intervals up to four weeks. There were ten animals in each group, making a total of eighty for the whole experiment. Both distal radial epiphyses were recovered, fixed and decalcified in Bouin's fluid and sectioned in paraffin.

RESULTS

Immediately after separation the gap on the diaphysial side of the epiphysial plate filled with fibrin (Fig. 4). Although occasional fragments of necrotic bone and cartilage were seen on the metaphysial side of the separation the metaphysis as a whole remained viable. However, the new bone formation responsible for endochondral ossification ceased. In consequence the calcified cartilage cells on the diaphysial side of the plate persisted unaltered. Simultaneously there was continued growth of the young cartilage cells on the epiphysial side of the plate.

* The ligamentum teres of the femoral head is an apparent exception to this rule. However, in our experience the artery of the ligamentum teres usually terminates at the insertion of that ligament to bone, without supplying a significant amount of the epiphysial bone itself.
These two processes occurring together caused a temporary but pronounced increase in the thickness of the plate (Fig. 5). Finally, callus began to grow from the metaphysis and the peristeam of the shaft across the gap produced by the separation, and united the epiphysis to the shaft (Fig. 6). Once this had occurred, normal endochondral ossification resumed and the thickness of the plate rapidly returned to normal (Fig. 7). At no time during the healing process was there any evidence of avascular necrosis in the bony epiphysis.

The time sequence in each case followed a regular pattern. The increased thickness of the epiphysial plate reached its maximum between seven and ten days, and endochondral ossification was fully re-established by two weeks. After three weeks it was virtually impossible to distinguish between the detached epiphysis and the untreated control epiphysis.

DISCUSSION

The results of this experiment demonstrate that an epiphysis of type B can be separated from its shaft without serious impairment of its capacity for growth. In view of the method by which this type of epiphysis receives its blood supply it seems fair to conclude that its nutrient vessels are not damaged by the separation. The striking contrast between these

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**Figure 4**—Distal radial epiphysial plate of a rabbit, two days after experimental separation of the epiphysis. The narrow line of separation is filled with fibrin and can be seen on the diaphysial side of the plate.

**Figure 5**—Distal radial epiphysial plate of a rabbit ten days after separation. Note the tremendous increase in the thickness of the plate. This is brought about by the temporary cessation of endochondral ossification which allows the dead cartilage cells in the zone of provisional calcification to persist unaltered.
results and those already mentioned after separation of the upper femoral epiphysis leads us to conclude that the prognosis of epiphyseal separation is dependent primarily on the amount of damage to the epiphyseal blood supply rather than the actual mechanical disturbance to the epiphyseal plate. It is recognised that epiphyseal plates may be damaged either by crushing or by being split open at right angles to their diameter so that a regional closure of the plate with subsequent deformation of growth occurs. This particular form of injury was not investigated in this study.

![Image](65x29 to 547x763)

**FIG. 6**
Distal radial epiphysis in the rabbit two weeks after experimental separation. Endochondral ossification is resuming but the former line of separation can still be seen.

A coincidental finding of this experiment is that its results throw some light on the question of how epiphyseal plates are nourished. Three possible pathways exist: from the epiphysis, from the metaphysis or from the perichondrium attached to the periphery of the epiphyseal plate. It is commonly accepted that the principal route is from the metaphysis, and this view is supported by the recent studies of Brodin (1955). The present investigation suggests that the epiphyseal cartilage cells in an epiphysis of type B can survive and indeed proliferate after complete separation from the metaphysis. It does not, however, determine...
whether these cells secure their nourishment from the epiphysis proper or from the soft-tissue attachments at the periphery of the plate.

**SUMMARY AND CONCLUSIONS**

1. The methods by which epiphyses receive their blood supply was studied by means of India ink injections in monkeys. Two types were identified depending upon whether the epiphysis was entirely or partly covered by articular cartilage. In the former, nutrient vessels enter the epiphysis by traversing the perichondrium at the periphery of the plate. In the latter they enter the epiphysis by penetrating the cortex at the side of the epiphysis at a point remote from the epiphysial plate.

2. The histological changes after separation of the second type of epiphysis were also studied. After temporary interference with endochondral ossification marked by increased thickness of the epiphysial plate, healing occurred so rapidly that within three weeks it was difficult to determine that the epiphysis had been separated at all.
3. It is concluded that when nutrient vessels enter an epiphysis at a point remote from the epiphysial plate, that epiphysis can be separated without serious disturbance to its blood supply and accordingly without interference with its capacity for growth. As it has been established that an epiphysis which is entirely covered by articular cartilage cannot be separated without destruction of its blood supply and subsequent avascular necrosis (Harris and Hobson 1956), it is concluded that the prognosis of an epiphysial separation is dependent upon the degree of damage to its blood supply rather than the mechanical disturbance of the epiphysial plate.

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REFERENCES