HISTOLOGICAL CHANGES IN EXPERIMENTALLY DISPLACED UPPER FEMORAL EPIPHYSSES IN RABBITS

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Few observations have been made on the histological changes associated with slipped femoral epiphysis. Those that are available are confusing, if not actually misleading, in that they have been made on material removed at operation some considerable time after the event, and thus show only the late stages of repair (Lacroix and Verbrugge 1951, Sutro 1935). So far as we are aware no observations are available on the early stages of the disease, particularly the prodromal change which allows the displacement to occur.

Since opportunities to secure such material clinically are rare indeed, recourse to experimental methods is desirable. A method has been devised for detaching the upper femoral epiphysis in growing rabbits. While it is admitted that this technique does not parallel the common clinical situation of insidious displacement, it does allow study of the early phases of repair after acute displacement, and is of special value in assessing the various surgical procedures used in treatment of this condition.

MATERIAL AND METHODS

Five to six weeks old male rabbits were used. One hip joint was exposed through a postero-lateral approach and the femur was dislocated from the acetabulum. The periphery of the epiphysial plate could be seen as a rather sinuous blue line. The perichondrium overlying this was incised with a scalpel. This allowed the introduction of a small periosteal elevator, and gentle pressure on this allowed the capital epiphysis to be completely detached. The epiphysis was then reattached to the femoral neck and held by means of a fine Kirschner wire, introduced from the head into the neck. The animals were killed at weekly intervals up to six weeks. Both the femoral head operated upon and the normal femoral head were removed, fixed in 10 per cent formalin and decalcified in buffered citric acid, sectioned in paraffin and stained with haematoxylin and eosin.

The status of the ligamentum teres was ignored in this experiment, as a preliminary investigation indicated that it had no important role in the blood supply of the femoral head. This finding appears to have been established by the work of other investigators, notably Walmsley (1915), Wolcott (1943) and Tucker (1949).

OBSERVATIONS

The histological changes are best considered separately in each of the three components of the head—the epiphysial cartilage, the bony epiphysis and the articular cartilage.

The epiphysial cartilage—The plane of separation through the epiphysial plate was remarkably constant. In most cases it occurred through the layer of hypertrophied cells on the epiphysial side of the zone of provisional calcification (Figs. 1 and 2). Soon after the separation a prolific outgrowth of primitive tissue arose from the metaphysis. This tissue resembled callus, and contained young osteogenic and chondrogenic cells. The callus grew against the epiphysial fragment of the plate, thus uniting the head to the neck. The cartilage in the epiphysial fragment of the plate underwent a prompt change: the cells lost their orderly columnar arrangement and failed to mature into hypertrophied cells (Fig. 3).
The bony epiphysis—Within a few days the epiphysis exhibited all the changes characteristic of dead bone: the lacunae were empty, or contained pyknotic cells, the osteogenic cells covering the trabeculae had disappeared, and the marrow had lost its nuclear basophilism and had become eosinophilic (Figs. 4 and 5).

### TABLE 1

**Observations from First Series of Experiments (Epiphysial Plate Left Intact)**

<table>
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<tr>
<th>Weeks . . . . .</th>
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<td>—</td>
<td>—</td>
<td>5</td>
<td>5</td>
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<tr>
<td>Deformity . . . . .</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>3</td>
<td>4</td>
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Avascular necrosis of head two weeks after epiphysial separation. Figure 4—Control hip. Figure 5—Experimental hip. Note empty lacunae, absence of covering osteogenic cells, and necrotic marrow.

This dead bone was then invaded by the callus arising from the metaphysis and entering the head through gaps in the epiphysial plate. The principal gap was made by the Kirschner wire, but as a rule the trauma of the operation produced other openings, usually at the periphery of the plate, and these also allowed entry of the callus. In the early stages the callus was very vascular, and consisted of primitive cells which resembled young fibroblasts. Later these cells tended to collect on the surfaces of the necrotic trabeculae, where they assumed the appearance of osteoblasts and commenced to lay down new bone matrix on the surface of the old (Figs. 6 and 7). In the final stages the entire head was replaced by new bone and the intertrabecular spaces were filled with seemingly normal bone marrow. This repair process took so long, however, that many of the femoral heads exhibited the collapse and deformity so characteristic of avascular necrosis in man (Fig. 8).

The articular cartilage—In the early stages the articular cartilage showed little change. As avascular necrosis became established, however, the cells tended to clump in nests instead of retaining their regular arrangement, and the intercellular substance became fibrillated. In
those heads which had collapsed, the cartilage was often covered by a pannus arising from the synovium of the hip joint.

Rate of revascularisation—The time required for revascularisation was related to the ease with which new bone penetrated the epiphysial plate. In most cases the main portal of entry for the callus was provided by the perforation produced in the plate by the Kirschner wire. Although quantitative measurement of the re-ossification was difficult to determine accurately it was found to be well established at the end of two weeks, and completed after four weeks. These findings are tabulated in Table I.

DISCUSSION

As the upper femoral epiphysis is one of the few in the body entirely covered by articular cartilage the changes seen are not unexpected. Removal of the head automatically disrupts
FIG. 8
Avascular collapse of head six weeks after experimental displacement of epiphysis.

its blood supply, causing avascular necrosis. Repair can only occur by the invasion of new bone from the neck, where the blood supply is intact. The most interesting feature is that the separation of the epiphysial cartilage nearly always occurs in such a manner that the bulk of the cartilage remains attached to the epiphysis. The constancy of this plane of cleavage was first noted by Haas (1917). It seems that this is the weakest point in the plate, for at this level only a few collagen fibrils lying in uncalcified cement substance are present to resist shearing stress (Harris 1950). The persistence of the epiphysial plate thus acts as a barrier which must be penetrated by the callus before successful re-ossification of the femoral head can occur. In the experiment, re-ossification was delayed sufficiently long in some cases to allow typical collapse of the head to occur, and it seems probable that if the plate had not been perforated by the Kirschner wire, re-ossification would have taken even longer. In a few cases, however, re-ossification occurred much earlier than the average. This was apparently due to accidental perforation of the plate by instruments at the time of the experimental separation. These extra openings allowed easier entry of the callus, thus allowing more rapid re-ossification of the head. This observation led to the obvious deduction that deliberate removal of the epiphysial plate might allow more rapid re-ossification of the head. To test this idea a second experiment was performed.

MATERIAL AND METHODS

The second experiment resembled the first in every respect except that the epiphysial cartilage was deliberately curetted from the head before the latter was fixed to the femoral neck.

OBSERVATIONS

Exactly the same sequence of events occurred as in the first experiment, but the time required for these changes was sharply reduced. Vascular osteogenic tissue had invaded half the femoral heads by the end of one week, and between the second and third weeks most of the heads were completely re-ossified. Moreover, removal of the epiphysial plate allowed re-ossification to advance in a uniform manner, instead of in the patchy distribution seen in the first
experiment. It is also significant that the marrow was replaced at an earlier date, and that after six weeks there was only one deformed head in contrast to four seen in the first experiment. These findings are tabulated in Table II, and Figure 9 is a graph comparing the time required for re-ossification in each of the two experiments.

TABLE II

<table>
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<th>Weeks</th>
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</tr>
<tr>
<td>No re-ossification</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>—</td>
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<td>—</td>
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DISCUSSION (concluded)

These observations appear to confirm that the epiphysial plate does act as a barrier to re-ossification of the head, and that its removal appreciably reduces the time required for this process. The findings have an important clinical application in the choice of operative technique in cases of slipped epiphysis requiring open reduction. It has been held that an open reduction through the epiphysial plate would be certain to damage any remaining blood supply to the femoral head and bring about avascular necrosis. For this reason Green (1945) advocated a wedge osteotomy of the neck in order that the deformity could be corrected without damage to the blood supply. But it is common experience that cuneiform osteotomy is followed by avascular necrosis in a high percentage of cases. Paradoxically, Klein and his co-workers (1953), who have done open reduction through the plate in all of their cases,
so far have observed only two examples of avascular necrosis in eighty-two cases of slipped epiphysis (Joplin 1955). It seems to us that either of these procedures could damage the blood supply to the femoral head. The difference in results is related to the site of the vascular damage. The cuneiform osteotomy is so located that it leaves part of the metaphysis as well as the entire epiphysial plate undamaged. Re-ossification in this case must first occupy the metaphysial fragment, and then penetrate the more or less intact epiphysial plate before entering the head (Fig. 10). The time required is ample to allow clinically recognisable avascular necrosis to occur. In contrast, reduction through the epiphysial plate more than likely is accompanied by unintentional perforation of the epiphysial plate. The gaps so made allow ready entry of callus from the metaphysis, so that even if avascular necrosis does occur it is transitory, and it is healed before it becomes clinically recognisable.

For these reasons we are inclined to advocate, in cases of slipped epiphysis that require open reduction, a procedure which effects replacement through the epiphysial plate, and at the same time deliberate curettage of cartilage from the base of the epiphysis, in order to bring about more rapid re-ossification. It is of interest that this principle has previously been advocated both by Kleinberg and Buchman (1936), and by Compere (1950), but their conclusions have evidently not received the attention they deserve.
SUMMARY
An experimental method is described which permits observations on the early stages of repair after acute displacement of the upper femoral epiphysis. Because the epiphysis is intra-articular, displacement brings about avascular necrosis which is slowly repaired by ingrowth of callus and blood vessels from the stump of the neck. As the bulk of the epiphysial plate remains attached to the epiphysis, it acts as a barrier to successful revascularisation. Deliberate removal of the epiphysial cartilage allows earlier revascularisation. It is suggested that in clinical cases reduction be done through the epiphysial plate rather than through the neck, and that it be accompanied by curettage of the remaining part of the epiphysial plate from the under surface of the head.

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REFERENCES