Observations ON THE NUTRITION OF ARTICULAR CARTILAGE.*

BY

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[With Special Plate.]

THE structure of articular cartilage has been the subject of numerous papers, but the study of its nutrition appears to have been neglected. The generally accepted explanation of the nutrition of this avascular tissue is that the nutritive fluid is derived from the vessels of the adjoining structures, chiefly from the vessels of the marrow and bone, but also to some extent from the *circulus articuli vasculosus* formed by the narrow border of vessels which lie underneath the synovial membrane and surround the circumference of the articular cartilage. The fluid from these vessels is supposed to reach the cartilage cells by imbibition. Some observers have described lymph channels in the hyaline matrix, but the existence of these is very doubtful.

Microscopic examination of a section through the articular cartilage prepared and stained by the ordinary methods reveals a characteristic, well defined structure. The cartilaginous tissue rests upon a thin, practically continuous layer of bone. In the deeper parts of the matrix are seen columns of cartilage cells which run perpendicularly towards the free surface; as these become more superficial the columns contain fewer cells and are distributed in an irregular manner, and the uppermost groups lie parallel to the free surface. The free surface is covered by a layer of cells with thin, elongated nuclei (perichondrium). In the deeper layers of the cartilage, where it lies in contact with the bone, a deposit of calcium salts is seen; this may be called the zone of calcified cartilage. A study of such a section shows that the cells of the superficial layers appear more active than those of the deeper layers, and it is difficult to understand how the nutritive fluid can pass from the vessels of the bone through the bone matrix and through the avascular layer of calcified cartilage towards the surface in sufficient quantity to cause the obviously greater vitality of the superficial layers. It is equally difficult to explain how the fluid from the vessels of the *circulus articuli vasculosus* can reach the cells forming the large area of cartilage on the articular surface.

If, as I believe, the present view of the nutrition of articular cartilage is incorrect, there is yet another source from which it may derive nourishment, namely, the synovial fluid. It is strange that this source of nourishment should not have been more widely discussed. The supply of synovial fluid in a normal joint is sufficient, and granting that it contains material suitable for the nourishment of the cartilage, the cells can obtain by imbibition all the nutriment required by this type of tissue.

In support of this view I offer the following description of the naked eye and microscopic changes seen in certain free bodies which are found occasionally in a joint cavity.

The origin of these free bodies has been discussed by several writers (Klein,¹ Weichselbaum,² Poulet and Vaillard,³ Real,⁴ König,⁵ Rimann,⁶ Ludloff,⁷ and others). The question whether they arise from local changes within the joints, or whether they are of traumatic origin, need not be discussed here, but it seems probable that the majority, if not all, of the type referred to in this paper are due to traumatic detachment of a portion of the articular cartilage. Whichever explanation is the true one, the microscopic changes which take place are of considerable interest.

Four free bodies of this kind have been examined: they were obtained from the joints of three patients. The first was found accidentally in the knee-joint of a youth; the

other three were very kindly presented to me by Major D. W. Hume, and were removed by him at the operation table.

The first specimen is from the knee-joint of a youth, aged 16, whose left lower limb was amputated for sarcoma of the thigh. On opening the joint there fell out a smooth shining lenticular body, 2.3 cm. long and 1.5 cm. broad, with rounded edges. To the naked eye its structure resembles cartilage. On the centre of the outer condyle of the femur there is a slightly depressed area of a shape similar to the free body, but somewhat smaller. The surface of this area is somewhat irregular and is covered with a thin smooth shining tissue, through which the yellowish texture of the underlying bone can be seen. Evidently the free body had been detached some time previously from this area. The articular cartilage of the joint is otherwise quite normal. One surface of the free body is white, smooth, and shining, and exactly resembles cartilage to the naked eye. This smooth surface is present on the rounded edges of the body, and is continued on to the other surface for a distance of 0.3 cm., forming a white ring around it. The other surface is slightly irregular and yellowish, but examination shows that this area is also covered with a thin smooth shining membrane. The smooth white cartilaginous surface evidently represents the free surface of the cartilage and the irregular surface the deeper portion where it was attached to the condyle. Small bony fragments were probably adherent to this side of the free body after its separation from the condyle.

Microscopic examination of the free body shows that both surfaces as well as the edges are covered by several layers of cells with elongated nuclei. On the side which forms the free surface of the cartilage they exactly resemble the cells of the normal perichondrium, and shade off into hyaline cartilage (Fig. 1). At the edges these cells form a definite layer of cells with elongated nuclei which shade off into young atypical cells (Fig. 2). The under surface is covered by several layers of cells of connective tissue type. This tissue varies in thickness; it is thicker towards the edges and becomes thin where it covers the irregular yellowish tissue seen on the deeper surface of the fragment. There are in this layer of connective tissue cells a few small areas which show signs of proliferation; these appear to be replacing the atypical tissue described below. At the edges of these proliferating cells, where they are in contact with the atypical tissue, a few well-formed giant cells are seen (Fig. 3). These resemble osteoclasts. The greater part of the section is composed of typical hyaline cartilage, which shows no signs of degeneration or of fibrillation. The nuclei stain well and the cells are arranged as in normal cartilage. They represent the free surface of the articular cartilage. There is in the deeper layers of this cartilage a definite deposit of calcium salts, but these are scattered irregularly and are for the most part grouped round cartilage capsules (Fig. 4). They do not show the normal appearance of calcified cartilage, but seem to represent calcium salts which have been set free from the layer of calcified cartilage as well as from bony fragments previously adherent to the cartilage and have then accumulated around the cells and in the matrix of the central part of the specimen where the proliferative processes are least marked. A thin layer of atypical tissue is seen on the under surface between the layer of connective tissue cells and the hyaline cartilage. This layer seems to be derived from and to replace the detached fragment of bone and the zone of calcified cartilage. Two distinct forms of cell are seen; one resembles young hyaline cartilage in the course of regeneration such as is sometimes seen in sections from joints of chronic arthritis. The young cartilage cells are of a hyaline type, but consist of closely set single cells lying in a hyaline matrix. These areas are found lying in and apparently replacing the other form of tissue, which consists of single cells fairly regularly scattered lying in a matrix somewhat hyaline in appearance when seen in sections stained with haematoxylin and picocarmine. Stained by Schmorl's method, the cells present the appearance of typical bone cells with long processes. This tissue passes over in some places into the atypical cartilage tissue just described, and in other places into the layers of cells with elongated nuclei which form a capsule on the under surface of the free body. In no part of the section, however, is the structure of normal bone observed. Some parts of the matrix in which the bone cells lie show in those sections which are

* The expenses in connexion with this study were met by a grant from the Medical Research Committee.

stained with haematoxylin distinct blue granules apparently due to a deposit of lime salts.

From the above histological examination it seems clear that a portion of the articular cartilage was detached from the condyle of the femur, and small fragments of bone remained attached to the articular cartilage at the time of separation. Definite changes have occurred in these structures; the cells have proliferated, and the matrix has undergone changes. Thus the free surface of the hyaline cartilage shows an increase in thickness of the perichondrium, while the fragments of bone adherent to the cartilage show considerable modification. On the under surface the bone cells have proliferated and rearranged themselves so that they form a definite layer of cells of a connective tissue type which blend with the layer of thickened perichondrium, and thus a continuous capsule of connective tissue has been formed around the free body. The bone cells in the deeper parts have also rearranged themselves in an atypical matrix as described. These atypical tissues seem to have been formed partly by proliferation of the bone cells and partly by proliferation of the cells of the hyaline cartilage. In areas where the proliferation is most active new atypical hyaline cartilage has been formed.

The origin of the giant cells mentioned is not clear, but they are found in areas where the connective cells are undergoing proliferation and replacing the atypical bone and cartilage cells. These giant cells have presumably been formed from the proliferating connective tissue cells, and seem to be a form of osteoclast.

Microscopic examination of the depressed area on the condyle, from which the fragment was obviously detached, shows that the free surface is covered with a layer of tissue, which appears to be formed of connective tissue cells somewhat stellate in appearance with branching processes. This layer, which is avascular, is about the same thickness as the hyaline cartilage, which it unites on both sides around the edges of the depression. These connective tissue cells form a fairly sharp zone where they join the normal articular cartilage, the cells of which at the edge of the zone show obvious signs of proliferation. The bone trabeculae upon which the tissue rests show obvious signs of previous fracture and have a very irregular arrangement; they are also somewhat increased in thickness and density. In other respects there is little change in the structure of the articular tissue in this situation.

The second specimen of free body was removed at operation from the knee-joint by Major Hume. This free body had caused repeated attacks of pain in the joint for several years. The patient made a good recovery, but the attacks of pain continued, and a few months afterwards Major Hume fully exposed the joint, and found lying towards the posterior portion of the joint cavity behind the crucial ligaments a second free body. The larger specimen (which was removed first) is lenticular in shape, 3 cm. long, 1.5 cm. broad, and 0.75 cm. in its thickest part. One surface is smooth and shining and resembles articular cartilage. The other surface is nodular and shows depressions, but is also covered with a smooth, shining tissue.

On naked-eye examination of a section through the specimen two definite types of structure are seen. There is a thin white capsule surrounding the whole specimen. The tissue beneath the surface, which is smooth and cartilaginous in appearance, extends for a depth of 0.3 cm.; it occupies about a third of the area of the section, and resembles hyaline cartilage. The rest of the tissue is yellow and more granular in appearance, but on closer examination it is found to consist of a superficial whitish-yellow portion and a deeper central zone which has a brownish-yellow colour.

The smaller specimen, which was removed at the second operation, is 1.75 cm. long, 2 cm. wide, and 0.75 cm. thick, and shows a similar external structure to the other specimen, one surface being smooth and the other nodular, but on section the larger portion of the cut surface resembles hyaline cartilage. There is a thin layer on the nodular surface which has the same yellow granular appearance as that seen in the larger specimen.

Microscopic examination of the larger specimen shows on the smooth surface, which represents the free surface of the articular cartilage, a somewhat thickened layer of perichondrium; this is continued over the edge on to the

nodular surface, where it is continuous with a tissue formed by several layers of connective tissue cells. These layers form a membrane of some thickness. The hyaline cartilage on the free surface is not much altered, though there is some evidence of proliferation of the cartilage cells, together with an irregular deposit of calcium salts, probably derived from the calcified cartilage and fragments of bone. Near the rounded edge of the specimen there is a formation of a new atypical hyaline cartilage, the cartilage cells being more numerous and the hyaline material less abundant than in normal cartilage. As in the previous specimen, an atypical tissue has replaced the bone which was adherent to the cartilage at the time of separation, and this can again be divided into two forms of tissue—one resembling atypical cartilage and the other atypical young bone. When stained by Schmorl's method well formed bone cells are seen lying in a granular matrix. In places this tissue shades off into a degenerated tissue lying in the centre of the mass, which appears to be made up partly of degenerating, but not necrotic, cartilage, and partly of a degenerate tissue which seems to result from an arrested attempt at the formation of hyaline cartilage. Towards the free surface the bone cells at the rounded edge of the specimen appear to have been transformed into the young hyaline cartilage previously mentioned, and on the under surface they blend with the cells of the connective tissue capsule previously described. Many of the cells in this layer, when stained by Schmorl's method, resemble typical bone cells.

One part of the specimen shows an interesting structure. The connective cells of the capsule, the bone cells in the atypical bone, and those of the young hyaline cartilage meet, and the impression is given that the connective tissue and young cartilage cells arise from the modified bone cells, which in their turn must have originated from the normal bone cells of the bone detached from the condyle.

In one section a small oval area is seen which consists of branching stellate cells with long processes somewhat myxomatous in appearance, resembling the cells seen in the early stages of the formation of fat (Fig. 5). This may be considered a form of avascular atypical marrow tissue.

A few giant cells are also seen in these sections; these appear to be formed from the connective tissue cells forming the capsule, and appear to be taking part in the tissue changes which are taking place at the edges of the atypical bone and cartilaginous tissue. These seem to be acting as osteoclasts.

Microscopic examination of the smaller specimen shows similar changes. The central portion of the section is composed of typical hyaline cartilage, the cells of which form groups owing to proliferative changes. On the free surface of this hyaline cartilage there is a zone of tissue which contains cells resembling atypical hyaline cartilage with single nuclei. Their structure is somewhat like the cartilage found in the ear of a mouse, but it shows more matrix. In some places a definite layer of cells is seen. These cells resemble bone cells when stained by Schmorl's method, and appear to be replacing the perichondrial layer.

The opposite surface of the specimen shows that the deeper layers of the hyaline cartilage are infiltrated with lime salts, and beneath this a layer of cells is seen resembling bone cells, which stain characteristically by Schmorl's method. In this region also there are areas of atypical cartilage tissue composed of single cells surrounded by a hyaline capsule. The free surface is covered with a distinct layer of connective tissue cells. As in the previous specimen areas of myxomatous cells are replacing the atypical cartilage and bone cells from which they seem to originate.

Groups of proliferating connective tissue cells are also seen in these sections. In some of these groups, where the cells are in contact with the atypical bone or cartilage, a few giant cells are found.

The changes seen in the two specimens above described resemble closely those seen in the first examined. In this again there is evidence that the cartilage, when it became detached, carried with it fragments of bone, and that proliferative changes have occurred after its separation both in the bone and cartilage cells. In spite of the long history there is evidence that these changes are still progressing, for otherwise it would be difficult to explain the presence of the well-formed giant cells and the young

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FIG. 1.—Showing connective tissue cells with elongated nuclei on the free surface, A: hyaline cartilage, B. $\times 350$.

FIG. 2.—Showing connective tissue cells, A: cells with elongated nuclei, B. $\times 350$.

FIG. 5.—Showing connective tissue cells derived from proliferating cartilage cells.

FIG. 4.—Showing hyaline cartilage with a granular deposit of lime salts around the cell. $\times 200$.

FIG. 6.—Showing degenerative changes in hyaline cartilage, A: proliferation of the cartilage cells, B: deposit of lime salts, C. $\times 60$.

FIG. 3.—Showing proliferating connective tissue cells, A: giant cells, B. $\times 350$.

fibroblastic cells which are found in certain areas. The presence of stellate cells of pre-adipose tissue type is also of interest.

The fourth specimen of a free body was removed by Major Hume from the knee-joint of a patient who gave a history of recurrent attacks of pain in the joint for many years. The specimen is an irregular round flat body, 4 cm. in its largest diameter, 3.5 in the smallest, and about 0.5 cm. thick. The edges are rounded, and the surfaces are nodular and fissured but covered with a layer of shining, membranous-like tissue. On section the structure resembles modified hyaline cartilage. There can be little doubt that this specimen altered in shape and increased in size after separation.

Microscopic examination of this specimen shows changes which differ somewhat from those described in the previous specimen. No typical articular cartilage is seen. Part of the specimen is composed of a form of young hyaline cartilage mixed with which are areas of atypical fibrocartilage. In some parts of this tissue a deposit of calcium salts is found (Fig. 6). Scattered throughout the section, especially towards the surface, are groups of cells which, on staining by Schmorl's method, are found to be typical bone cells. These do not, however, show the structure of true bone when stained with haematoxylin and eosine, or with picrocarmine. In the centre of the specimen there is an area of degenerating tissue in which lies a small mass of true bone; this appears to be a portion of a fragment of the original bone showing typical bone trabeculae, with Haversian canals surrounded by their system of concentric lamellae. The fat cells of the bone marrow and the blood vessels of the marrow and bone are necrotic. The bone cells do not stain well.

In this specimen again there is evidence of proliferative change both in the cartilage and bone after separation, but this change is more advanced and the resulting structures are more atypical than in the other specimens described.

It seems fair to assume that the changes in structure found in the detached cartilage and bone of the four specimens described occurred after separation from the articular surface; even if this is not admitted, the long history of pain and inconvenience—which ceased in two of the patients after removal of the free body—is evidence that these free bodies had been present in the joint for some years. The staining properties and the appearance of the cells on section show that they were alive at the time of their removal from the joint cavity.

CONCLUSIONS.

It may thus be assumed that nutritive processes were being carried on after separation. That these processes were of an active type is shown by the proliferative changes described.

There are two possible sources from which this nutritive material might have been derived:

1. From the death of cells in the fragment. From these dead cells the surviving cells might have obtained their food supply. Nutrition of this type has been described by Burrows and Neymann⁸ as occurring during the growth of cells in isotonic salt solution. This explanation, however, cannot be accepted, as there is evidence that such fragments increase in size after separation while they are lying free in the joint cavity.

2. The other explanation is that the nutritive material is derived from the synovial fluid. If this is so, then the possibility of cartilage cells and of bone cells also being nourished by the synovial fluid must be allowed.

It follows, therefore, that the articular cartilage of the joints may derive some, if not the greater part, of its nourishment from the synovial fluid.

If this hypothesis is true, then the changes which are found in the degenerative types of arthritis can also be explained. The primary cause of these degenerative types will be found not in the cartilage or bone, but in changes in the nutritive value of the synovial fluid. There is evidence, which I hope to produce later, that changes in the nutritive value of the synovial fluid may be due to changes in the vessels of the capsule of the affected joints.

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ON THE USE OF POLARIZED LIGHT IN THE DETECTION AND INVESTIGATION OF SUTURE MATERIALS EMBEDDED IN THE TISSUES.*

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[With Special Plate.]

THE use of the polarizing microscope in pathology has hitherto been mainly confined to the study of the doubly refracting lipoids, "myelin," cholesterol, cholesterol esters, and the like. Such investigations have been made by Adami and Aschoff (1906,¹ 1910²), Powell White (1908,³ 1909⁴), Stewart (1915⁵), and others. Its use as a means of detecting microscopic foreign bodies (fragments and threads of clothing, particles of wood, etc.) in the depths of wounds has been pointed out by Policard and Desplas (1917⁶). Shattock (1917⁷) has shown its value in the elucidation of a unique case of foreign body tumour formed round crystals of silica which had been forcibly intruded into the tissues of the lip eleven years before.

The present communication will show that many of the suture materials in common use by the surgeon are optically active, and that the polarizing microscope affords a ready means for their detection in the tissues as well as for their subsequent investigation. Since the optical activity of these substances is unaffected by treatment with the usual dehydrating and clearing agents, paraffin sections are all that is required for the demonstration of the phenomenon. If such a section be viewed microscopically between crossed Nicol's prisms, the particles of suture material present will, in certain instances, show up brilliantly illuminated on a dark background, and in this way they can often be picked out with great readiness, even when their presence has not previously been suspected.

It is important to notice that certain tissues are normally optically active, even in paraffin sections. Thus, the collagen-fibril bundles of dense fibrous tissue show various degrees of luminosity, at least when they are cut longitudinally or obliquely, and the same is true of the stratum corneum of squamous epithelium and of the hairs in their root follicles. The muscle bundles of striped muscle are also doubly refracting under certain conditions (? of internal strain), and even the stratum lucidum and rete Malpighii may show the phenomenon to a slight extent. In these situations it is sometimes noticeable that luminous and non-luminous segments alternate. Elastic tissue, on the other hand, would appear to be optically inactive.

THE OPTICAL ACTIVITY OF SUTURES.

The suture materials used in surgery fall into two main categories, (1) absorbable (the various kinds of catgut), and (2) unabsorbable (silkworm gut, silk, linen and "celluloid" thread, and horsehair). Kangaroo tendon occupies an intermediate position. These substances have all been examined with the polarizing microscope in the freshly prepared state, before use, and it has been found that silkworm gut, silk, linen and "celluloid" thread show intense optical activity, whereas catgut, horsehair and kangaroo tendon show the phenomenon only to a very slight degree or even not at all. This difference is accentuated by residence in the tissues. Catgut tends to lose very speedily what little optical activity it possesses, whereas that of silk and silkworm gut persists for months and years.

Before discussing the morphological appearances of the more common suture materials as seen in paraffin sections it is necessary to indicate briefly the different purposes for which they are employed.

1. Silkworm gut is now used almost exclusively for skin sutures, whose function is temporary and which are removed by the surgeon after a certain number of days.

2. Catgut is used where absorbable sutures are required, but these must be able to hold the parts in apposition

* Communicated to the Pathological Society of Great Britain and Ireland, January, 1920. The expenses of this research were in part defrayed by a grant from the British Medical Association, for which I beg to express my thanks.