THE DEVELOPMENT OF THE PATELLA

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Understanding of the nature and function of the patella has acquired a new significance in view of present-day treatment of patellar fractures. It is usually considered to be a sesamoid bone, sharing the general characters of sesamoid bones, but to be outstanding among them on account of its large size, its specific and relatively constant form, and the important part it plays in the formation of the articular capsule and the mechanism of the joint to which it belongs. Its sesamoid nature and its functional importance, however, are not accepted by all. Bernays (1878) and Kazzander (1894), whose works on the knee joint are classical, and Brooke (1937) have described and illustrated the patella as developing behind the quadriceps tendon and independently of it. De Vriese (1908, 1913), on different premises, also questions its sesamoid nature and suggests that it is an integral element of the skeleton which is undergoing regression in Man. The conflicting views of the development of the patella have found a prominent place in recent clinical literature and, as part of a larger consideration of the subject, I have thought it necessary to examine a series of knee joints in embryos and young foetuses to study again the origin and early history of the patella and the manner of development of the patello-femoral joint.

The material I have used was provided for me by the staffs of several hospitals in Edinburgh and I am indebted to them for it; my special thanks are due to Dr Paterson of the Edinburgh Hospital for Women and Children. It is essential that material to be used for the study of the development of joints should be fixed without delay, for disintegrative changes quickly take place in the primitive joint-plate and false deduction of the presence of a synovial cavity may be made. Most of my specimens were immediately fixed for me in 5–8 % formalin solution.

The specimens I have examined range from the 20 mm. stage to full-term. In the smaller specimens the knee joints were isolated and serial sections made, the left limbs being cut in the longitudinal plane parallel to the flexed tibia and the right limbs in the transverse plane. In the larger specimens sections were taken at chosen intervals, and in some of them dissections were made. The usual stains were haematoxylin and eosin, but Heidenhain's iron haematoxylin and orange G and Mallory's stain were also used.

THE FORMATION OF THE PATELLA AND ITS RELATION TO THE QUADRICEPS FEMORIS

In the 20 mm. embryo, as in later stages of development, the knee joint is in the flexed position; the amount of flexion is usually about a right angle but varies a little in different specimens of the same age and often in the two limbs of the same specimen. The femur and tibia are cartilaginous at this stage; their ends are covered with a thick perichondrio-chondrogenetic layer which consists of closely aggregated rounded cells (Pl. I, fig. 1). The posterior parts of the perichondrial zones of the two cartilages are continuous with one another but the anterior parts are separated by a distinctive layer of loose, less cellular tissue. The quadriceps femoris muscle is well represented and its lower end can be traced to the upper end of the tibia; in structure it consists throughout of a loose network, the superficial and deep surfaces of which can be defined. Where the quadriceps is in relation to the lower end of the femur there is an aggregation of rounded cells in the deeper three-fifths of its substance. This is the early representative of the patella; and, though its margins are indefinite, it is obviously confined to the substance of the quadriceps and there is a gradual transition of its cells into those of the quadriceps network. Between the quadriceps and the femur there is a layer of loose tissue which is continuous below with the loose tissue between the patella and the femur.

At the next stage examined, in the 23·4 mm. embryo (Pl. I, fig. 2), there is a considerable advance in the definition of the patella and the quadriceps muscle. The patellar aggregation is larger and more dense in structure but it still consists of rounded cells. The deeper part of the quadriceps, which contains the patella and is continuous with its substance above and below, is more differentiated than in the 20 mm. stage, but the superficial part is almost unchanged except at its lower end, over the patellar ligament, where its density is increased. On the deep surface of the patella there is a layer of loose tissue which, as in the 20 mm. stage, is continuous with similar tissue beneath the quadriceps above and in the knee joint below; there is as yet no evidence of a synovial cavity in it. The patella is seen to be developed in relation to the lower surface and the lower part of the anterior surface of the femur, and though there is no direct contact of patella and femur the lower part of the patellar surface of the femur has taken form (Pl. I, fig. 3).

The recognition of the patella at these stages of development is earlier than has been recorded by other workers. Langer (1929) describes the first appearance of the patella at the 26 mm. stage and denies its presence earlier. Bardeen (1905) does not illustrate its presence until the 33 mm. stage; and, regarding its relation to the quadriceps, he says (with reference to his figure of a 20 mm. embryo) "as the musculature becomes differentiated a dense tendon for the quadriceps is formed in front of the knee joint. In it the patella becomes differentiated". Bernays (1878) and others do not describe the presence of the patella until later stages.

The patella begins to become cartilaginous about the 30 mm. stage, but at its periphery there is still a gradual transition of its substance into the quadriceps mass which itself is more differentiated. At the 32 mm. stage (Pl. I, fig. 5) the patella is seen to be well formed and in its original position over the anterior part of the lower end of the femur. The differentiated quadriceps is continuous with its upper and lower ends and superficial to it there is an undifferentiated layer of loose tissue which is now relatively less in thickness; it is obvious that this tissue, superficial to the patella, is in the fascial sheath of the quadriceps muscle and that below it is incorporated in the ligamentum patellae. The deep surface of the patella is separated from the perichondrial layer of the femur by the loose tissue already described in this position; there is no evidence of a synovial cavity in it and none appears in my specimens until the 35 mm. stage. Bardeen (1905) however states that a synovial cavity is present at the 30 mm. stage.

There is now a rapid increase in the growth of the patella especially in its antero-posterior thickness, and a striking change in the tissues on its deep surface. Thus at the 35 mm. stage (Pl. I, fig. 4) the formerly loose tissue between the patella and the femur is condensed to form a perichondrial layer on the posterior surface of the patella; and, further, this layer is fused with the perichondrium of the femur. The fusion of the perichondria begins over the central part of the patella and spreads to the periphery (Pl. II, fig. 7), and when fusion is complete, at or shortly after the 35 mm. stage, the patellar and femoral surfaces are united to one another by a thick perichondrium which separates the cartilages. A secondary fusion such as this must connote an absence of movement between the parts concerned and must be considered, I think, in the discussion of the determination of joint-surfaces; in effect it establishes the conditions which occur primarily in the development of the diarthroses of the axial parts of the limbs, for it leads to the definition of an articular disc or primitive joint-plate. It is not yet known if a similar developmental stage exists at the other sesamoid joints.

The thick articular disc, formed of closely packed cells, thereafter becomes reduced in thickness and the cells become elongated until, about the 40 mm. stage (Pl. II, fig. 9), only a double layer of flattened cells is present between the cartilages; these cells separate the patellar and femoral cartilages from one another so that there is no continuity of the substance either now or, in my specimens, at any later date.

The change in structure of the articular disc, it seems to me, represents the process of definition of the articular cartilages by the loss of their perichondrial coverings; and it appears to follow that the nutrition and further growth of these cartilages become functions of their deep surface and that they are established therefore as particular and distinct parts of the epiphysis to which they belong. The articular cartilages having thus been defined, the synovial cavity of the patello-femoral joint appears between them; each cartilage retains a covering of a single layer of flattened cells which is continuous at the margins of the articular area with the general perichondrium and with the articular capsule derived from it and now established. The synovial cavity appears first at the periphery on the medial side of the patello-femoral joint and then extends completely around the periphery. The extension of the cavity centrally takes place more rapidly on the medial than on the lateral side, and the fusion between the two elements persists for some time on the lateral after their complete separation on the medial side (Pl. II, fig. 9). Langer (1929) has already noted that the formation of the synovial cavity of the knee joint is earlier and progresses more rapidly on the medial than on the lateral side. The patello-femoral cavity is at first separate from the femoro-meniscal cavity, but later communicates with it on both sides of the median septum of the knee joint which subsequently forms the infra-patellar and alar folds.

It is clear therefore that the patella retains in these later stages of development the same relation to the quadriceps mass that its primary rudiment had in the 20 mm. stage, that is, it interrupts the continuity of most of its fibres so that the vasti and rectus femoris proceed to their tibial insertion through it. The superficial uninterrupted fibres now form a perichondrium for its superficial surface and a fibrous layer over it; and these layers are continuous above with the tendon of the rectus and below with the superficial part of the patellar tendon. The patella is thus an intramuscular element which has secondarily acquired a free articular surface in a manner which is constant for the definition of the articular surfaces of movable joints, that is, by the formation of an articular disc or primitive joint-plate and its subsequent developmental change.

THE SUPRA-PATELLAR POUCH AND THE PATELLAR SURFACE OF THE FEMUR

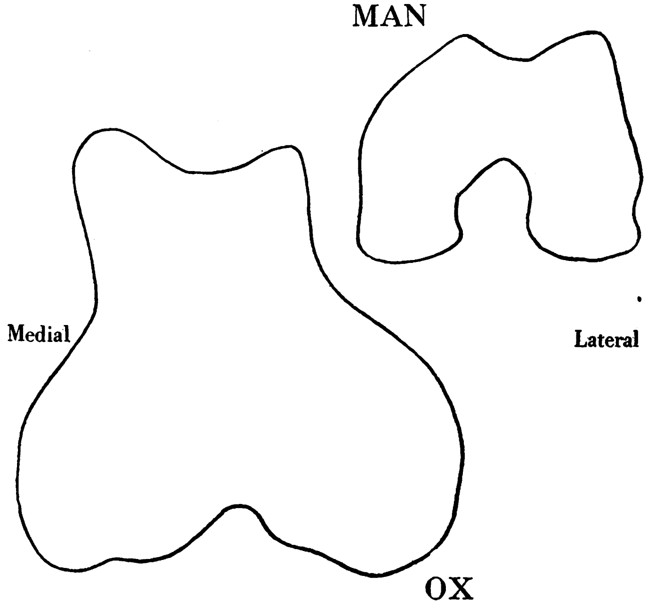
The patella develops, it has been shown, over the antero-inferior surfaces of the femoral condyles; and it is only on these surfaces, in front of which the patello-femoral synovial cavity is formed, that the femoral articular surfaces for the patella are defined (Pl. II, fig. 8). Even before the patella has separated itself from the lateral condyle of the femur, however, the patello-femoral synovial cavity begins to extend upwards in front of the femur beyond the level of the upper border of the patella, and by the 90 mm. stage (Pl. I, fig. 6) a definite supra-patellar pouch is formed. The extension of the synovial cavity is into the tissue which lies superficial to the perichondrium of the femur; at first, before the supra-patellar pouch begins to develop, this tissue is loose mesenchyme, but later what remains of it forms the walls of the pouch and the m. articularis genu. The perichondrium on the front of the femur at the 40 mm. stage, before the supra-patellar pouch is much developed, is a thick cellular layer which extends downwards to the upper border of the articular cartilage then defined; it is shown in transverse section in Pl. II, fig. 10. As the supra-patellar pouch develops, its deep wall becomes lined with synovial membrane and fuses with the perichondrium from below upwards; thereafter the fused layer disappears and is replaced by a single layer of flattened cells (Pl. II, figs. 11, 12). Thus, the supracondylar part of the patellar surface of the femur is defined and acquires an articular cartilage. This process takes place slowly from below upwards, and is not completed until shortly before full-term; and—a striking feature—it is independent of an opposed articular surface since the articular disc, which may be considered to be formed, is constituted by the deep wall of the supra-patellar pouch with the femoral perichondrium and not by the deep surface of the patella.

It has been shown by Langer (1929) that in embryos of the 24 mm. stage the general adult form of the bones of the knee joint already exists. I have noted further in my specimens that the supracondylar part of the patellar surface of the femur has already developed its peculiar human characters by that stage, for even then the lateral part of the surface is greater than the medial part in its transverse width, its proximal extension, and its marginal accentuation (Text-fig. 2); and this, it is to be noted, is in contrast to the delay in the development of the lateral parts of the patello-condylar and condylo-meniscal joints and in spite of the fact that throughout the greater part of foetal life at least part of the surface is covered with perichondrium. The specifically human form of the supracondylar part of the lower end of the femur is therefore primary.

This primary definition of the adult form of the supracondylar part of the femur is in strong contrast with the developmental history of the condylar part, for there the medial condyle is originally larger than the lateral condyle and, as has been shown, its articular cartilage and synovial cavity appear earlier; and it is only with the change to the characteristic adult position of the femur and with the establishment of the extension of walking, say at three years of age, that the lateral condyle becomes the dominant weight-bearing condyle and larger than the medial condyle. The femur is then directed downwards, medially, and backwards, and articulates with the tibia at an obtuse angle open laterally; and the supra-patellar part of the quadriceps and the ligamentum patellae form an almost like angle with one another at the patella. The lateral part of the patella thus becomes the chief strain-bearing part and the lateral part of its articular surface is the larger in the adult; the greater size of the lateral part of the supracondylar surface of the femur and the accentuation of its margin are the factors which maintain the patella in its proper relationship with the femur. The definition of the supracondylar surface, early and primary as it is, is thus to meet conditions which arise only well after birth.

I have found it interesting to note that in the ox—whose femur, as in ungulates generally, is directed downwards, forwards, and laterally, with the medial part of the supracondylar surface larger and more accentuated than the lateral part (Text-fig. 1)—there is the same early definition of the adult form; for in an 80 mm. ox foetus the distal end of the femur was similar in form to that of the adult animal. It follows from these observations that the essential form of articular surfaces may be defined before they are in use, that is, before movement occurs at them.

Since the patella develops in relation to the femoral condyles and passes through a stage of fusion with them, the medial and lateral areas of its articular surface are at first approximately equal in size (Pl. II, figs. 7, 9). A change in the relative size, however, begins to appear shortly after the patella has freed itself from the femur; it occurs slowly, but by the 192 mm. stage it has become established and the articular surface of the patella is then divided by a vertical ridge into larger lateral and smaller medial areas which are relatively comparable in size to those of the adult (Text-fig. 2). The change in size of these areas allows the patella to conform to the supracondylar surface of the femur and, of course, movements permitting the apposition of the surfaces have probably occurred; but if movements are stressed as the probable cause of the changes it is necessary also to note that the upper part of the supracondylar surface is still covered with perichondrium and is non-articular (Text-fig. 2, sections C–E). The patella does not acquire the transverse ridges on its articular surface until after birth. These ridges, as was pointed out by Goodsir (1868), subdivide the surface into

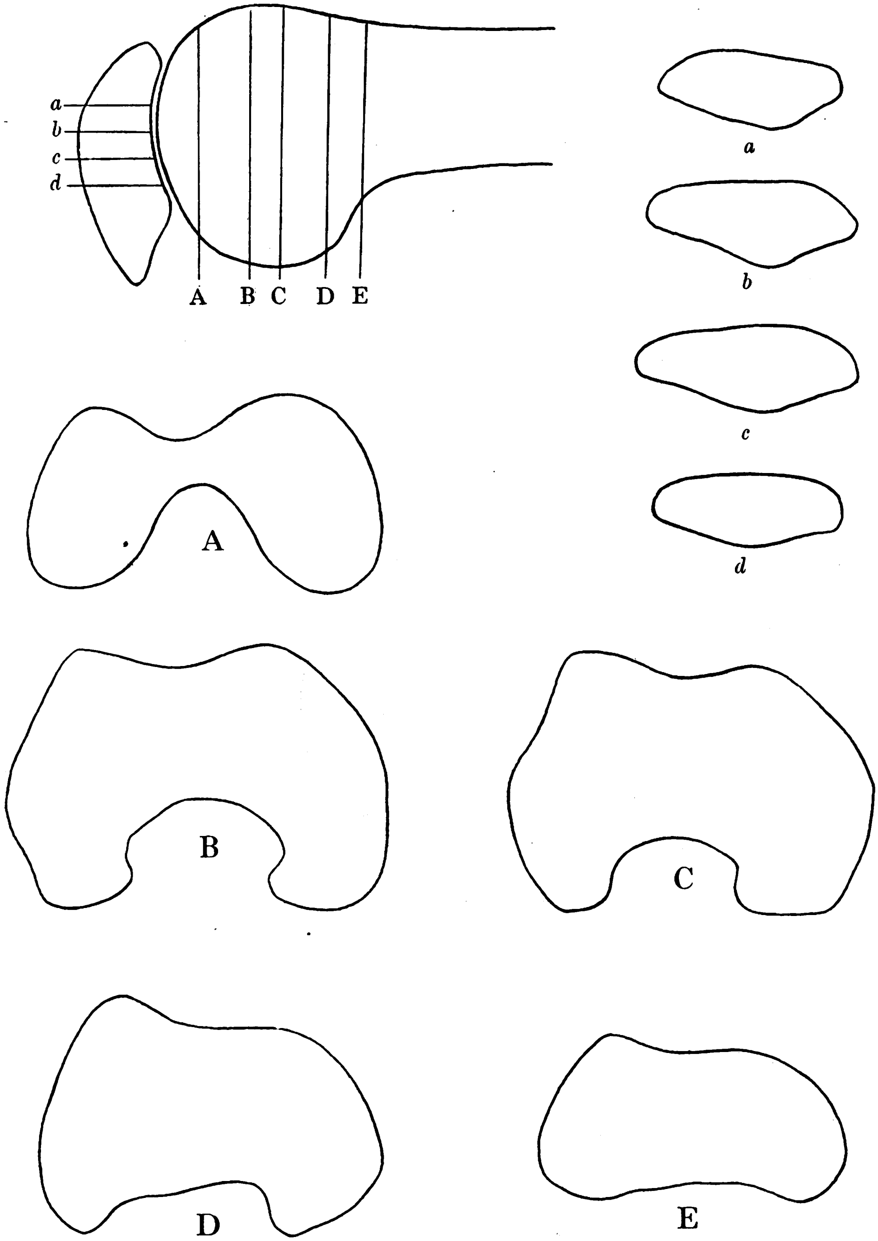


Text-fig. 1. Outline drawings of transverse sections through the supracondylar parts of human and ox femora to show the difference in form of the supracondylar articular surfaces.

functional areas which are in action in different positions of the knee joint; they appear therefore only when the limb is fully in use and full extension of the knee joint has become possible. The general and essential form of the patella is thus defined independently of the femoral surface to which it is to be opposed, but the finer particular details of the functional form are acquired only when its function is established. Such facts are probably true of the diarthroses in general.

THE SIZE AND POSITION OF THE PATELLA

The patella is relatively small compared with the distal end of the femur at its appearance and until the 35 mm. stage. Thereafter growth of the patella is rapid and, as is shown, at the 90 mm. stage (Pl. I, fig. 6) it is much larger relative to the femur. I am thus in agreement with de Vriese (1908, 1913), who has made a full study of the relative size of the patella, that it increases in relative size up to the sixth month of foetal life; she states further that until



Text-fig. 2. Projection drawings of the femur and patella of a 192 mm. foetus. The upper left figure is a projection of the femur and patella made with the tibia and quadriceps in position and the knee joint flexed to about a right angle. The outlines A–E represent transverse sections of the femur and the outlines *a–d* transverse sections of the patella at the levels indicated in the first figure. In the sections the lateral sides of the femur and patella are on the left of the page.

shortly before birth the patella grows at the same rate as the other bones of the lower limb and that thereafter and until puberty it decreases in size relative to them. I am unable to discover in these statements any evidence of retrogression of the patella.

The position of the patella on the femur in the adult varies with flexion and extension of the knee. During the early stages of its development the knee is flexed to about a right angle and the patella lies on the antero-inferior surface of the femoral condyles, a position comparable to that which it occupies in the adult when the knee is flexed to the same extent. I have not found it in my specimens in the position shown in a 33 mm. foetus by Bardeen (1905) articulating with the tibia as well as with the femur, though I have noted that in some marsupials its lower end almost touches the tibia. The patella leaves the distal surface of the femur as the knee is extended and lies more and more in contact with the supracondylar surface; and in full extension in the human subject, when the femur and tibia are in vertical alignment, it is entirely on the anterior surface of the femur. I have noted that in the ox also it lies in this position when the knee is in the position of fullest functional extension, even though there is then a considerable flexion angulation between the femur and the tibia; the patella then lies over the prominent part of the femur and it seems to me clear that in addition to its other functions it will protect the lower end of the femur from the friction of the quadriceps tendon.

SUMMARY

1. A pre-cartilaginous patella is present in the deeper part of the quadriceps mass at the level of the lower end of the femur in the 20 mm. embryo.
2. A cartilaginous patella is present at the 30 mm. stage. It interrupts the continuity of the quadriceps mass except for a superficial layer which remains undifferentiated.
3. A typical articular disc (primitive joint-plate) is secondarily formed at the 35–40 mm. stage between the patella and the femoral condyles by the fusion of the patellar and femoral perichondria.
4. The patello-femoral synovial cavity develops in the articular disc in a manner typical of the diarthroses, and with it there is a definition of the articular cartilages which are considered to be particular parts of the bones. The processes take place first on the medial side and then on the lateral side, probably reflecting the phylogenetically greater importance of the medial femoral condyle; they are completed by about the 70 mm. stage.
5. A typical supracondylar patellar surface is formed on the femur by the development of the supra-patellar pouch; it is developed independently of the patella and is not completed until shortly after birth.
6. The articular surface of the patella changes from a form adapted to the condyles to a form adaptable to the supracondylar surface soon after it is freed from the condyles. The secondary division of the patellar surface does not occur until after birth.

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REFERENCES

Bardeen, C. R. (1905). *Amer. J. Anat.* **4**, 265.
Bernays, A. (1878). *Morph. Jb.* **4**, 403.
Brooke, R. (1937). *Brit. J. Surg.* **24**, 733.
Goodsir, J. (1868). *Anatomical Memoirs*, **2**, 224. Edinburgh.
Kazzander, J. (1894). *Arch. Anat. EntwGesch.* p. 161.
Langer, M. (1929). *Z. ges. Anat.* 1. *Z. Anat. EntwGesch.* **89**, 83.
Vriese, B. de (1908). *Anat. Anz.* **32** (Ergänzungsheft), 163.
—— (1913). *Bull. Soc. Anthrop. Paris*, ser. **6**, **4**, 306.

EXPLANATION OF PLATES I AND II

Plate I

Fig. 1. Longitudinal section of the knee joint of 20 mm. embryo. The perichondrio-chondrogenetic zones at the ends of the femur and tibia are shown. There is an aggregation of round cells in the quadriceps mass at the level of the lower end of the femur; this is the early rudiment of the patella.

Fig. 2. Longitudinal section of the knee joint of 23·4 mm. embryo. The patellar aggregation is larger and more distinct than at the 20 mm. stage.

Fig. 3. Transverse section of the knee joint of 23·4 mm. embryo through the upper part of the patella; the lateral extension of the patella into the quadriceps mass is shown. There is some artificial separation of the loose tissues.

Fig. 4. Longitudinal section through the lateral part of the knee joint of 35 mm. foetus. The patella is larger and has acquired a perichondrium on its deep surface.

Fig. 5. Longitudinal section of the knee joint of 32 mm. foetus. The larger part of the patellar substance has become cartilage.

Fig. 6. Longitudinal section of the knee joint of 90 mm. foetus. The supra-patellar pouch extends upwards beyond the level of the patella and the m. articularis genu is attached to its apex. The patella is much increased in size.

Plate II

Fig. 7. Oblique transverse section of the knee joint of 38 mm. foetus; the obliquity makes the patella appear thicker than it is. The patella and the femur are united by a thick articular disc (primitive joint-plate).

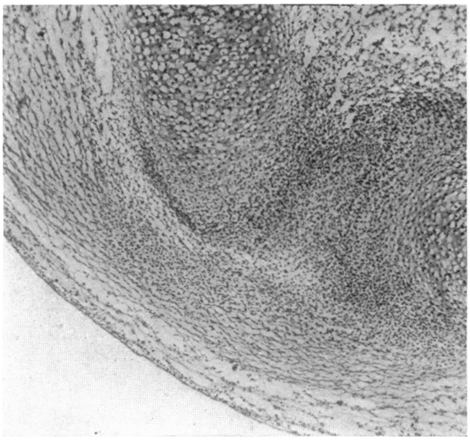
Fig. 8. Longitudinal section of the knee joint of 40 mm. foetus. The section is through the medial part of the patella and shows the synovial cavity over the medial condyle of the femur.

Fig. 9. Transverse section of the knee joint of 40 mm. foetus. The articular disc is still present on the lateral side except peripherally where the synovial cavity has appeared; on the medial side the synovial cavity is complete and the articular cartilages are defined.

Fig. 10. Transverse section of femur of same foetus as in fig. 9 above the level of the patella. It shows the supracondylar patellar surface of the femur covered with perichondrium; the lateral area of the surface is already larger and more prominent.

Fig. 11. Projection drawing of the right knee joint of 127 mm. (fifth month) foetus. The supra-patellar pouch is well formed.

Fig. 12 A and B. Transverse sections of the left knee joint of same foetus as in fig. 11 at the levels shown. A shows the supracondylar surface free of perichondrium and the articular cartilage defined, and B shows the surface covered with perichondrium. The lateral lip of the surface is the larger.



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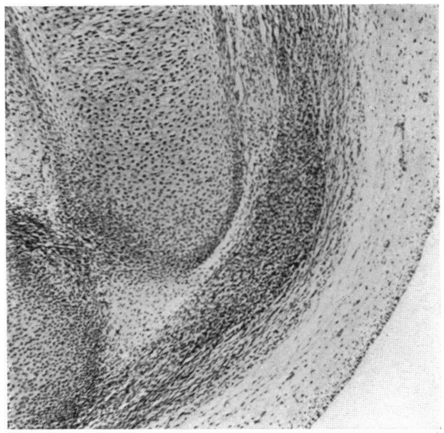

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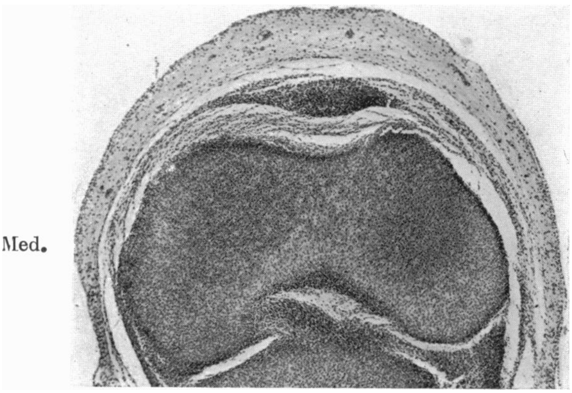

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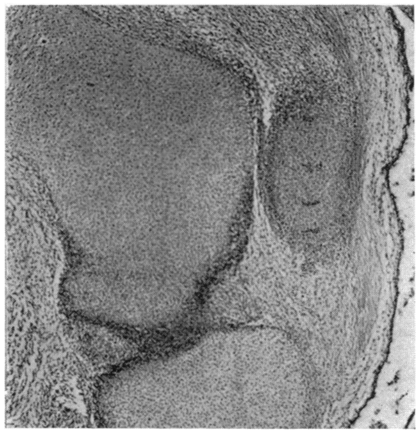

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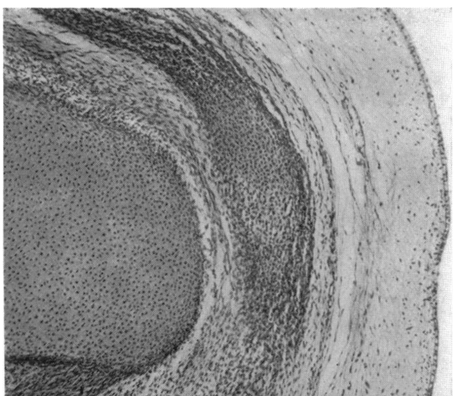

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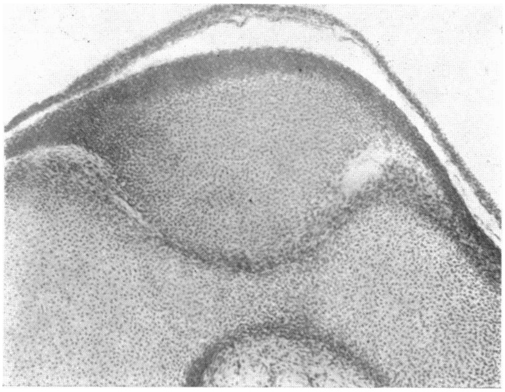

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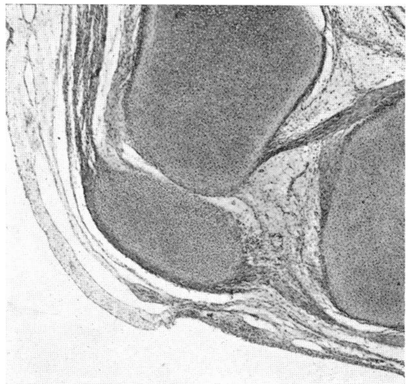

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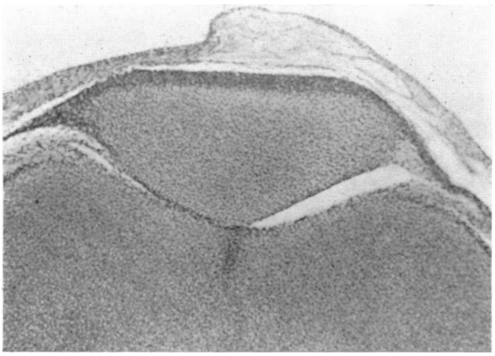

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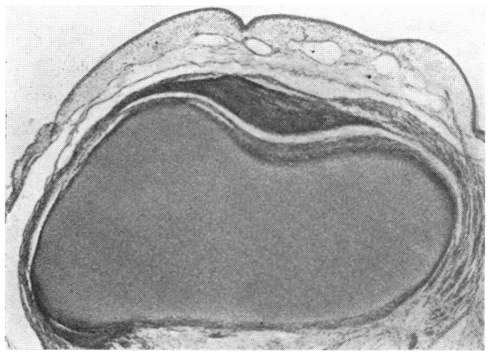

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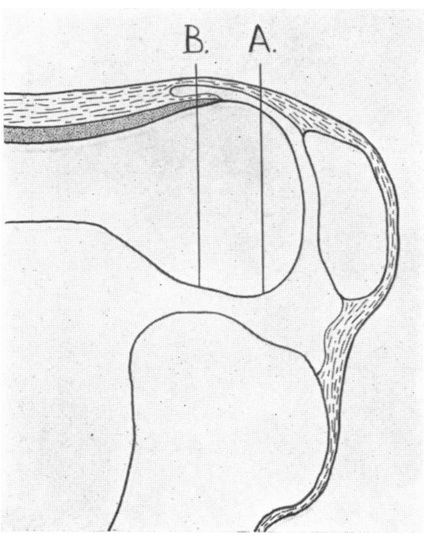

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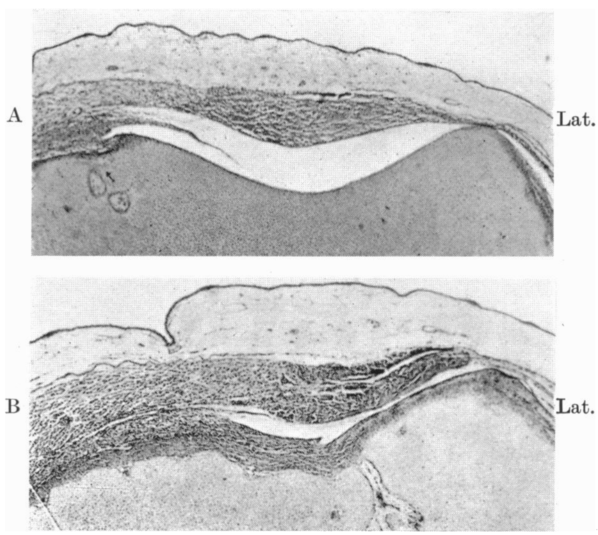

Fig. 12.