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Vascularization of the condylar cartilage of the human mandible

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INTRODUCTION

There are three main sites of secondary cartilage formation in the human mandible, namely, at the condylar and coronoid processes and at the symphysis. Growth of cartilage at the coronoid process and at the symphysis ceases just before, or shortly after, birth but in the condylar process it continues at least until the beginning of the third decade of life (Blackwood, 1959). In this respect the cartilage of the condyle fulfils a function somewhat similar to that of the epiphysial plate of a long bone and forms a most important centre of growth for the mandible. Its growth contributes to the vertical height of the ascending ramus as well as to the downward and forward growth of the whole mandible and from its position within the temporomandibular articulation the cartilage also provides an articular surface for the mandibular condyle.

The condylar cartilage develops in the cellular blastema covering the dorsal extension of the growing mandibular ramus in the 50–60 mm. crown–rump foetus (Symons, 1952; Baume, 1962) and in the tissues intervening between the cartilage and the developing temporal bone the joint spaces and articular disk of the mandibular joint are formed; the joint is usually clearly defined in the 65–70 mm. crown–rump foetus (Scott & Symons, 1961).

The condylar cartilage is generally described as being avascular and this is true during the greater part of its growth. However, during intra-interine life vascular channels have been described within the cartilage (Vinogradoff, 1910; Symons, 1952; MacAlister, 1955) and several workers have noted the presence of these channels in the condyles of new-born infants (Charles, 1925; Rushton, 1944). The present author (Blackwood, 1957) has shown that the vascular canals are present within the cartilage at least until the second year of life and that they traverse the full thickness of the growing cartilage, reaching to the surface articular layer.

During the period of growth three distinct cell layers or zones within the cartilage can be recognized, namely the articular zone, the intermediate zone and the hypertrophic cartilage zone. A recent investigation of the pattern of cellular proliferation within the growing condylar cartilage of the rat mandible using tritium-labelled thymidine (Blackwood, 1964) has shown that the intermediate cell zone is the main progenitor layer of the cartilage, since it gives rise to the cells which differentiate to become chondrocytes and so provide for growth. The surface articular zone, which is rather fibrous in character, acts only as an articular covering for the cartilage and the cells of this zone are renewed independently, and possibly at a different rate, from those of the underlying intermediate zone. The growing condylar cartilage of the rat is similar in structure to that of man and most other mammals so it is reasonable to assume that, in man, the pattern of cellular proliferation and mechanism of growth is also similar.

The investigation reported here is undertaken with the object of defining the structure of the vascular canals of the condylar cartilage in the human mandible using conventional histological techniques and of establishing the mode of development of the canals in relation to the individual cell zones of the cartilage. It is also hoped by means of arterial perfusion to follow the course of the blood vessels within the canals and so define the nature of the vascular network which is formed within the cartilage. By so doing it may also be possible to gain some knowledge of the function of the canals.

MATERIALS AND METHODS

The intra-uterine growth of the condylar cartilage was studied histologically in 9 human foetuses (75, 100, 120, 130, 135, 170 and 180 mm. crown–rump measurement and 33 and 35 weeks foetal age). The head of each foetus was divided in the mid-line sagittal plane and fixed in 10% formal saline. Demineralization was carried out in 5% formic acid and the tissues were embedded in celloidin. The blocks of tissue were orientated to permit section of the mandibular condyle and joint in a variety of planes, i.e. sagittal, coronal and transverse, and in the 75 mm. crown–rump foetus the plane of section was made in the long axis of the condylar cartilage.

The post-natal growth of the cartilage was studied in sixteen mandibular joints excised from cadavers during routine autopsy examination. The ages ranged from new-born full-term infants to 5 years of age. The tissues were processed in celloidin as described above. Sections of 10 μ thickness were prepared and stained with haematoxylin and eosin.

In order to study the vascular network within the cartilage the arterial systems of six full-term human still-born infants were perfused with a mixture of barium sulphate and Berlin blue according to the method described by Harrison, Schajowicz & Trueta (1953). Perfusion was carried out through the common carotid arteries, following which the tissues were fixed in 10% formal saline, demineralized in 5% formic acid and embedded in celloidin. Serial sections through the mandibular joints were prepared by cutting alternately two sections at 15 μ followed by one section 300 μ in thickness. The thinner sections were stained with haematoxylin and eosin but the thick sections were mounted unstained in Canada balsam. It was found unnecessary to clear these thick sections as recommended in the Spalteholtz technique as the vessels outlined by the injection mass could be easily seen and photographed through the unstained tissues.

OBSERVATIONS

Histological examination of the younger foetuses shows that the condylar cartilage reaches its maximum development in cartilage in the 75 mm. crown–rump foetus (Fig. 1). At this stage the cartilage is conical in shape. The tapered extremity is surrounded by the growing membrane bone of the mandible and extends anteriorly as far as the crypt of the second deciduous molar tooth. The broader base forms the articular surface of the condyle within the mandibular joint. At this stage of development the joint spaces and articular disk are clearly defined, but on the posterior aspect the peri-articular tissues are still in direct connexion with Meckel's cartilage and the developing structures of the middle ear.

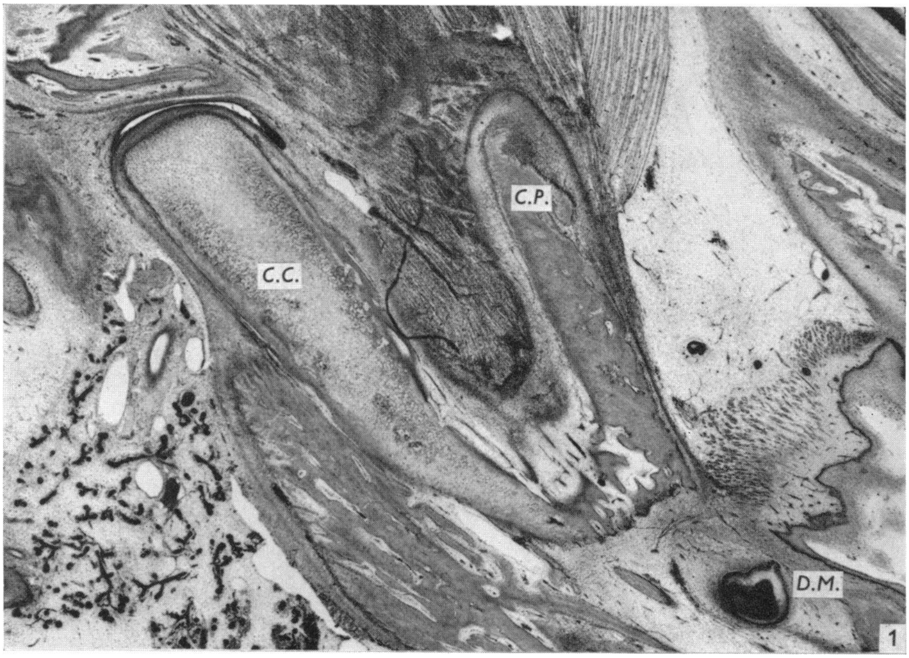


Fig. 1. Section through the long axis of the condylar cartilage in the 75 mm. (C.R.) human foetus showing the relationship of the cartilage (*C.C.*) to the developing mandibular joint and to the crypt of the tooth germ of the second deciduous molar tooth (*D.M.*) and to the coronoid process (*C.P.*). (× 27.)

With further growth of the foetus the anterior portion of the condylar cartilage becomes invaded by the surrounding vascular mesenchyme and this is accompanied by endochondral bone replacement of the cartilage (Fig. 2). The growing base of the cartilage, however, persists but is much reduced in thickness, forming a small cap of cartilage cells surmounting the growing mandibular ramus. The extent of the reduction of the cartilage is shown in the 130 mm. crown–rump foetus (Fig. 3) and in the present investigation this was the youngest specimen in which a vascular canal was observed in the cartilage. Also at this stage the three cell zones of the cartilage are clearly visible (Fig. 4). The articular zone is represented by a layer of rather flattened cells covering the articular surface of the cartilage and continuous with the outer layers of the periosteum of the mandible. Beneath this is the intermediate zone, consisting of a thin layer of densely packed cells and this zone merges into the broader hypertrophic zone in which the characteristic changes of cell hypertrophy progressing to endochondral bone replacement can be observed in the cartilage.

The vascular canals first appear at the periphery of the cartilage in the form of solid cords of cells which extend from the medullary cavity of the condyle through the full thickness of the cartilage. The cells forming the canals are mostly spindle-shaped and are easily distinguished from the surrounding cartilage and haemopoietic marrow. In longitudinal sections the cells are mainly orientated in the long axis of the canals and appear in continuity with the cells of the articular zone of the cartilage. The intermediate cell zone also dips downwards around the canals and for a short distance forms part of the wall of the canal within the hypertrophic

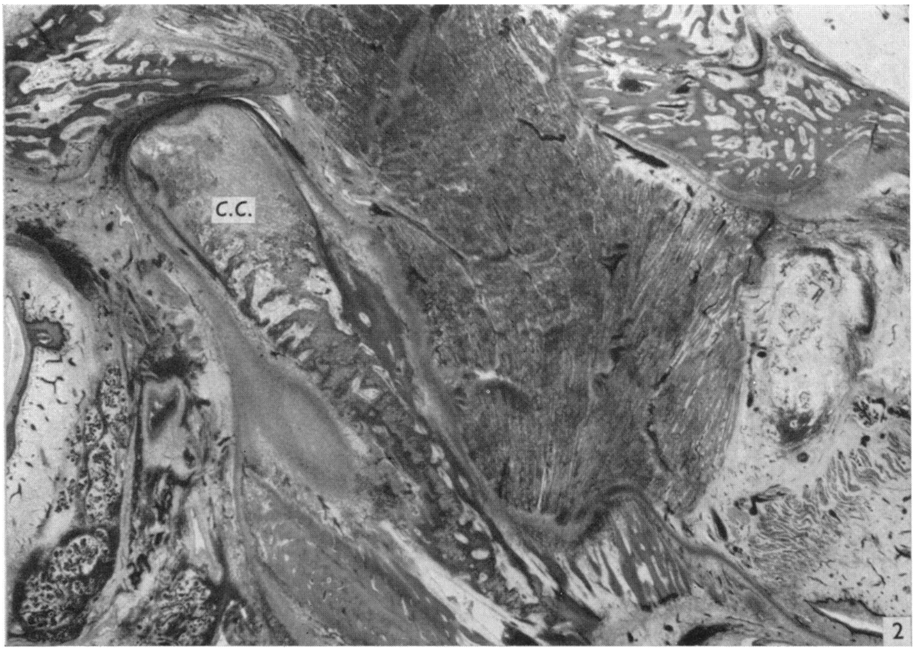


Fig. 2. Replacement of the anterior portion of the condylar cartilage (*C.C.*) by endochondral bone formation in the 100 mm. (C.R.) foetus. (×22.)

zone of cartilage cells. Small blood vessels, mostly of capillary dimension, enter the free extremities of the canals from the medullary cavity and course within the canals for varying distances towards the articular surface of the cartilage (Fig. 5).

Examination of transverse sections of the cartilage shows that initially the vascular canals are confined to the periphery of the cartilage, but as the cartilage enlarges so the canals increase in number and come to lie more deeply within it (Fig. 6). The canals nearest to the surface are only partly surrounded by cartilage cells and appear in continuity with the covering perichondrium (Fig. 7) but those more deeply placed lose their connexion with the perichondrium and become completely surrounded by differentiating cartilage cells (Fig. 8). In the younger specimens the canals tend to be more numerous at the posterior and lateral aspects of the cartilage.

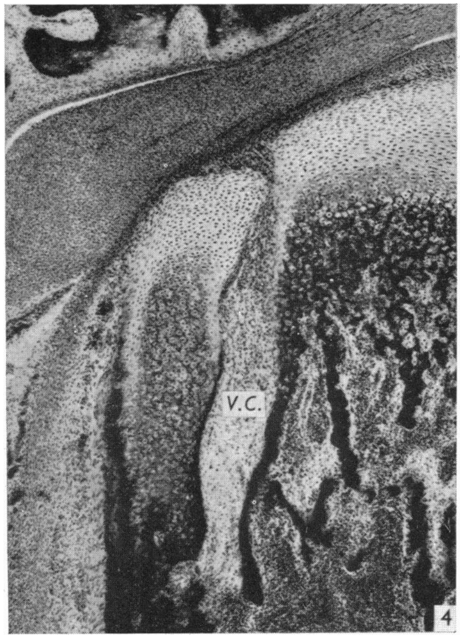


Fig. 3. Section through the body and ascending ramus of the mandible in the 130 mm. (C.R.) foetus showing the development of a small vascular canal (*V.C.*) on the posterior aspect of the condylar cartilage (*C.C.*) (×12.)

Fig. 4. Higher magnification of the developing vascular canal (*V.C.*) shown in figure 3. The three cell zones of the cartilage are also clearly defined. (×32.)

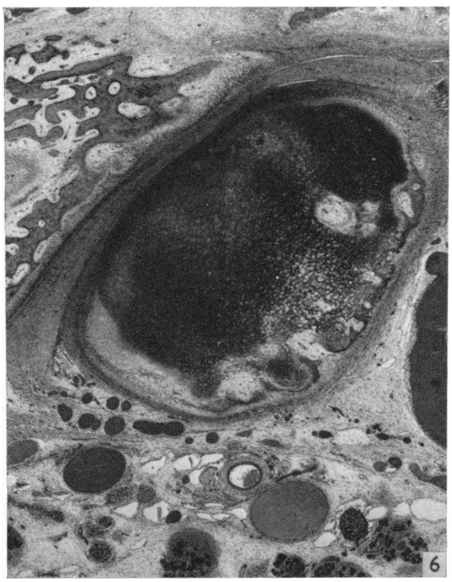
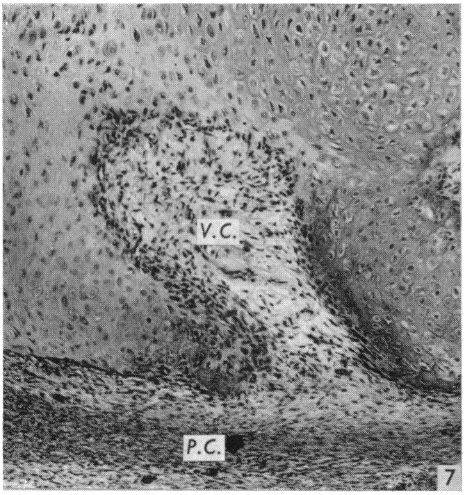


Fig. 5. Longitudinal section of a vascular canal (*V.C.*) showing the relationship of the articular zone (*A.Z.*), intermediate zone (*I.Z.*) and hypertrophic zones (*H.Z.*) of the cartilage to the blood vessels. (×44.)

Fig. 6. Transverse section through the condylar cartilage of the 170 mm. (C.R.) foetus showing the development of vascular canals at the periphery of the cartilage. (×16.)



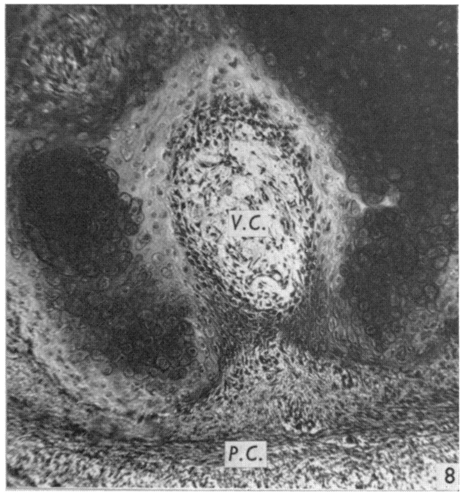
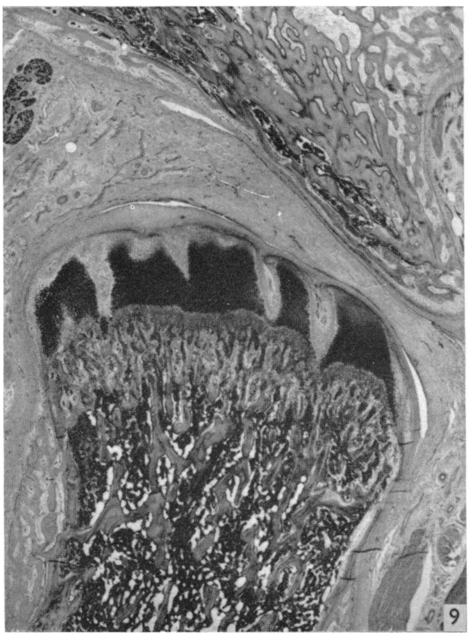


Fig. 7. Higher magnification of figure 6 showing a column of cells forming a vascular canal (*V.C.*) in continuity with the covering perichondrium (*P.C.*) and only partially enclosed by cartilage. (× 44.)

Fig. 8. Higher magnification of figure 6 showing a vascular canal (*V.C.*) which is almost completely encircled by cartilage. The perichondrium (*P.C.*) can be seen along the lower border of the photomicrograph. (× 32.)



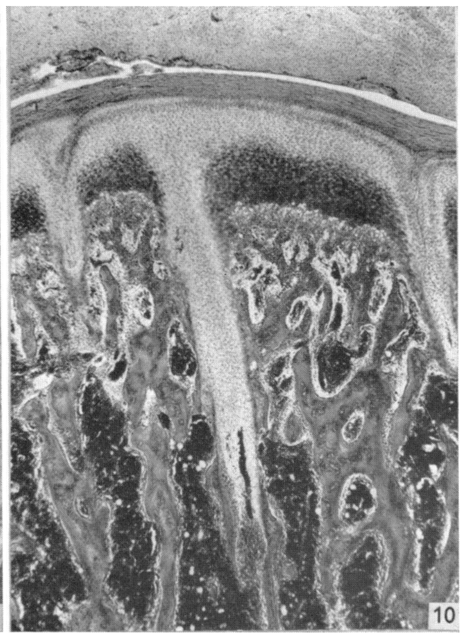
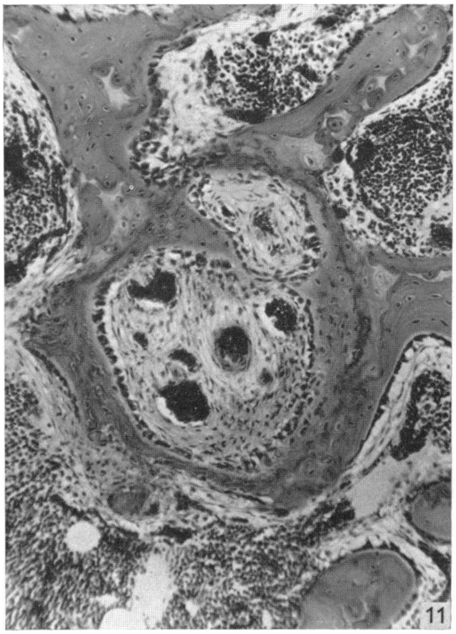


Fig. 9. A section showing many vascular canals in the condylar cartilage of an infant aged 5 weeks. The hypertrophic zone has been heavily stained with haematoxylin. (× 9 (approx.).)

Fig. 10. A vascular canal extending deeply into the medullary cavity of the condyle of an infant aged 7 months. A blood vessel may be seen entering the free extremity of the canal from the medullary cavity. (× 28.)

During late foetal life the number of vascular canals within each condylar cartilage increases (Fig. 9) and this increase continues for the first few months of post-natal life. During this period the cartilage is growing very rapidly and the direction and length of the canals tends to be somewhat variable (Fig. 10). Some canals extend deeply into the medullary cavity of the condyle, whereas others are confined to the width of the cartilage. In the medullary cavity the walls of the canals are formed by an intact ring of bony trabeculae. Within the canals the blood vessels



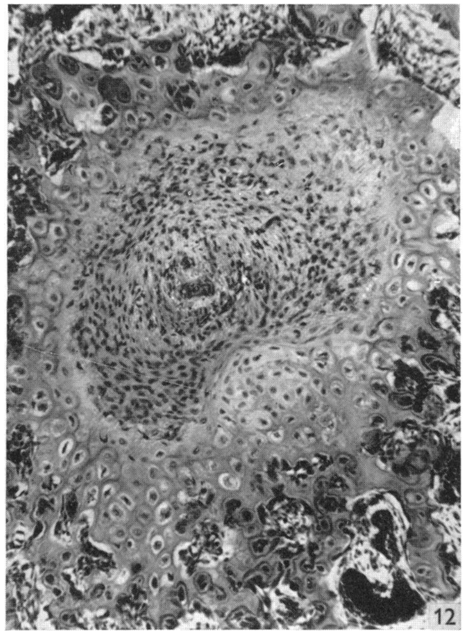


Fig. 11. Transverse section of a vascular canal within the medullary cavity showing the central blood vessels and wall of trabecular bone. (× 60.)

Fig. 12. Transverse section of a vascular canal within the medullary cavity close to the cartilage plate showing the wall formed by proliferating cartilage cells. (× 60.)

run centrally and are supported by a stroma of spindle-shaped cells similar to those observed in the younger specimens (Fig. 11). Close to the cartilage, however, the walls of the canals are formed by hypertrophic cartilage cells which show the characteristic transition to endochondral bone formation peripherally (Fig. 12).

In the perfused specimens it can be seen that the blood vessels enter the free extremities of the canals in the medullary cavity and run upwards towards the articular surface. Owing to their variable direction a section along the long axis of a canal is purely fortuitous but when a stained 15 μ section (Fig. 13) is compared with the consecutive 300 μ unstained section (Fig. 14) the course of the blood vessels can be more easily followed (Figs. 15 and 16). It can be seen that as the blood vessels approach the articular surface of the cartilage they turn sharply at right angles and run for some distance parallel to this surface. Many vessels form short anastomotic loops with vessels from the same canal and also with vessels from adjacent canals (Fig. 16). The blood vessels are mainly confined to the deeper layers of the articular zone of cells covering the cartilage but occasionally some small vessels traverse the full thickness of the fibrous articular layer and come to lie close to the surface of the cartilage. In this position they are separated from the joint space by only one or two cells of the articular layer (Figs. 17 and 18). Clear photographic recording of the blood vessels in the 300 μ sections is made difficult by the thickness of the section.

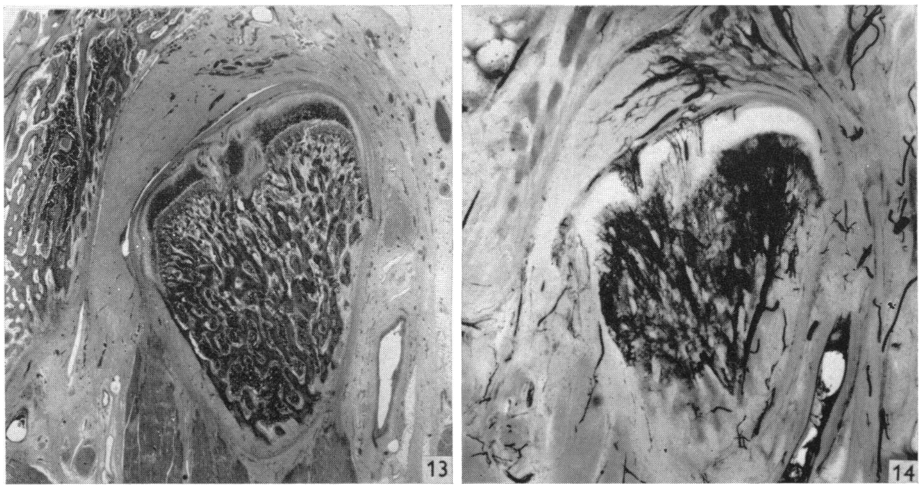


Fig. 13. Perfused specimen showing two vascular canals in the centre of the condyle of a full-term infant. Section cut at 15 μ and stained with haematoxylin and eosin. ($\times$ 8.)

Fig. 14. Serial section to that shown in figure 13 cut at 300 μ and mounted unstained. The vascular network within the cartilage and medullary cavity is outlined by the injection mass. ($\times$ 8.)

Towards the end of the first year of life the vascular canals become fewer in number and this decrease continues into the second year. At this age the canals are usually very short and confined to the width of the cartilage. In the present investigation a single vascular canal was found in a condyle from a child of 2 years and 9 months (Fig. 19) but after this age no canals were found to be present in any of the condyles examined, up to 5 years of age.

DISCUSSION

It would appear from this study that the vascular canals are a constant feature of the developing mandibular condyle, since they were found to be present in all the condylar cartilages examined, from the foetus of 130 mm. crown–rump measurement up to the age of 2 years 9 months. The position of the canals at the periphery of the cartilage as seen in transverse section during early foetal life (Fig. 6) suggests that they develop as the result of an inclusion, or an in-folding of columns of less differentiated cells of the covering perichondrium at certain points on the growing edge of the cartilage. With continued growth of the cartilage the first formed columns

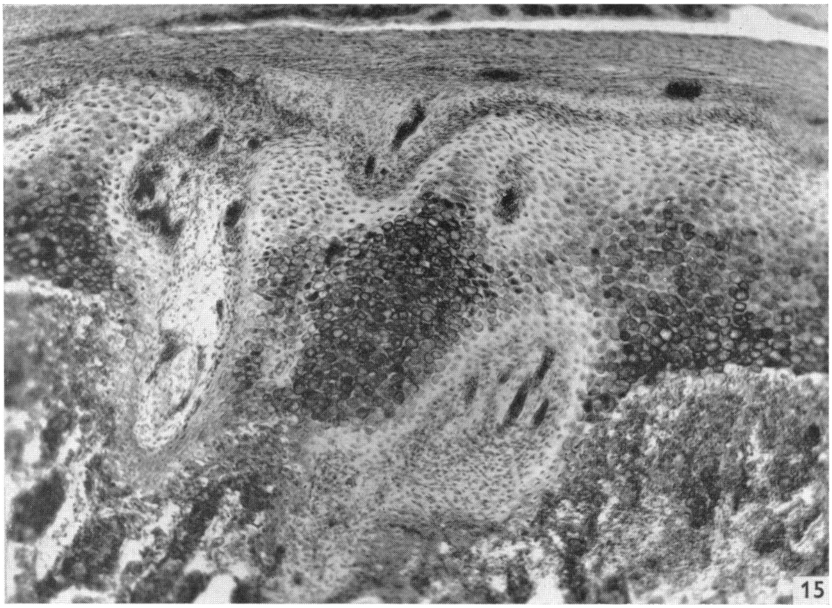


Fig. 15. Higher magnification of figure 13 showing the blood vessels within the two vascular canals and their relation to the layers of the cartilage. (× 35.)

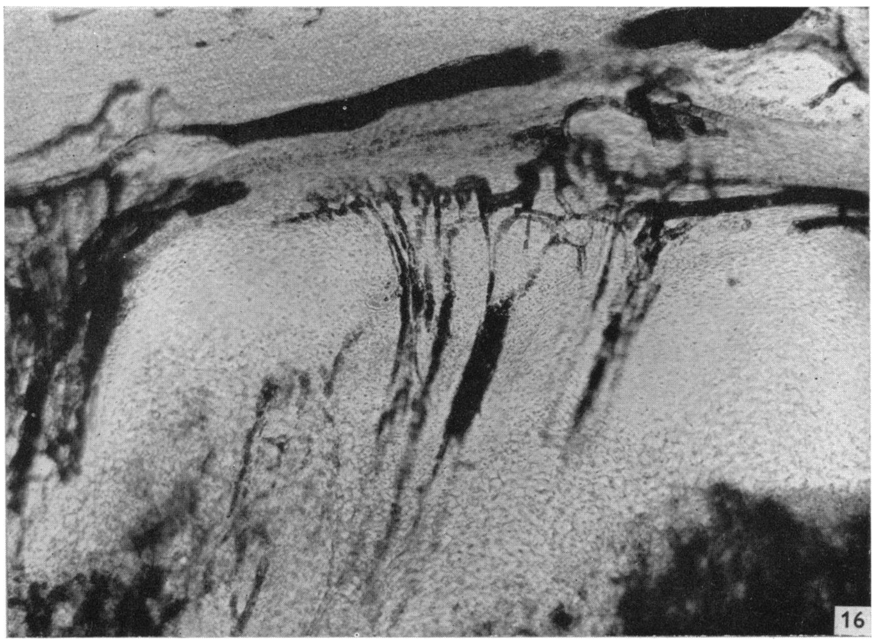


Fig. 16. Higher magnification of figure 14 showing the short anastomotic loops of the blood vessels within the cartilage. (× 40.)

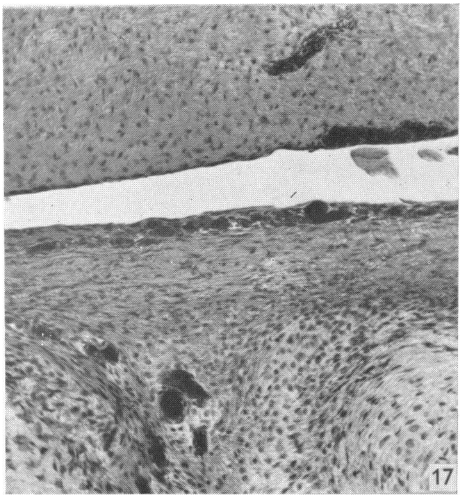


Fig. 17. Small blood vessels beneath the articular surface of the cartilage seen in a section cut at 15 μ and stained with haematoxylin and eosin. Part of the articular disk is shown above the joint space. ($\times$ 60.)

Fig. 18. Serial section to that shown in figure 17 cut at 300 μ and viewed unstained. The vessels close to the joint space in the cartilage are filled with the perfusion mass. ($\times$ 60.)

Fig. 19. A single vascular canal in the condyle of a child aged 2 years and 9 months. ($\times$ 8 (approx.).)

of perichondrial cells come to lie more deeply within the substance of the cartilage as was observed in the older foetal specimens. The fact that the cells of this outer layer of the perichondrium have a much lower rate of proliferative activity than the cells of the intermediate zone (Blackwood, 1964) would account for them becoming surrounded and enclosed by the more actively proliferating cells of the intermediate layer. This mode of development is illustrated diagrammatically in Fig. 20, which serves to summarize some of the histological observations made in this study.

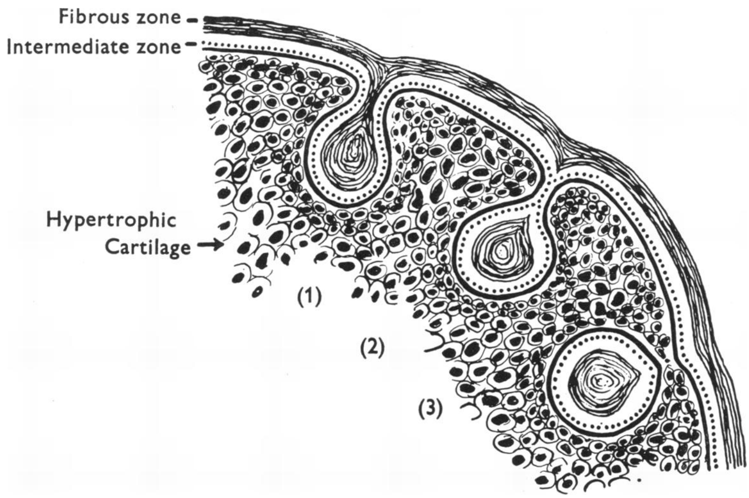


Fig. 20. The development of vascular canals in the condylar cartilage. Three stages are represented showing the inclusion of the perichondrium (1) by the peripheral growth of the cartilage (2) and (3).

It has not been possible in this study to determine with accuracy whether the blood vessels observed in the canals were enclosed with the perichondrial cells during the formation of the canals or whether they developed later, by invasion from the medullary cavity. The latter alternative is the more likely as blood vessels have not been observed in the perichondrium before the development of the canals. Moreover, the fact that blood vessels have been shown to be in direct continuity with those of the medullary cavity adds further support to this view.

Assuming the canals to be developed from the outer layer of the perichondrium it is not surprising, therefore, to find that the larger blood vessels as they approach the surface of the cartilage ramify and form their anastomoses within the deeper layers of the articular zone. In this position they are protected from any mechanical injury due to movements of the joint but the small blood vessels which were shown occasionally to reach to the articular surface (Figs. 17 and 18) are not so protected and could be subjected to mechanical injury. It is unlikely that injury to these vessels would arise in the normal course of jaw movements but trauma inflicted to the jaws at birth by obstetrical manipulations, or by the misappliance of obstetrical forceps, might be sufficient to rupture these superficial vessels and so result in a haemorrhage directly into the joint space. Resolution of such a haemorrhage could lead to partial, or even complete, ankylosis of the joint. This sequence of events could account for some forms of mandibular joint ankylosis and retarded mandibular growth observed in very young children. A similar outcome could also result from infections of the joint, where no doubt the infection and its sequelae could be profoundly influenced by the vascular nature of the cartilage during this early period.

Concerning the possible function of the vascular canals Vinogradoff (1910) described them as 'Crampons' responsible for fixing the perichondrium to the underlying cartilage but there is little doubt that their true function is to increase nutrition of the cartilage during a period when there is a demand for rapid growth. Growth of the skeleton is extremely rapid during the latter part of intra-uterine life and early post-natal life and in relation to the jaws this is also the period of development and eruption of the deciduous dentition. It is significant, therefore, that the existence of the canals within the cartilage coincides very closely with the development of the deciduous dentition, which should normally have completed eruption into the oral cavity by the beginning of the third year of life, that is about the same time at which the canals finally disappear from the cartilage.

If the canals are concerned with nutrition and growth it would be reasonable to assume that they should be present where growth of the cartilage is greatest. It was observed that the canals were more numerous on the posterior and lateral aspects of the cartilage and this position corresponds with the direction of growth which the cartilage must assume in order to keep pace with the increasing lateral dimensions of the skull and the downward and forward growth of the mandible.

A well-defined system of vascular channels is present in all the larger cartilage primordia of the human foetal skeleton. These channels are contained in a network of fine canals which penetrate the substance of the cartilage and it has been shown that they develop by an inflexion of the deeper layers of the perichondrium into the growing cartilage (Haines, 1933; Hurrell, 1934). Vascular canals are present only in the larger cartilage primordia of the foetus and there is general agreement that their function is primarily for the nutrition of these cartilages, which otherwise would be too large to be supplied by 'diffusion' of nutriment through their substance. In the condylar cartilage it must be presumed that after three years of age, when the vascular canals are no longer present, all the metabolic needs of the cartilage must be met by 'diffusion' from the medullary cavity of the condyle or from the synovial fluids in the joint space.

During the period of growth up to 21 years of age the condylar cartilage of the mandible fulfils a function similar to the epiphysial plate in a long bone. Blood vessels have been described in the epiphysial plates of long bones both in man and in animals. It is thought, however, that these vessels are connecting branches between the large vessels of the epiphysis and diaphysis which simply penetrate the cartilage plate but do not contribute to it (Tilling, 1958; Spira, Farin & Karplus, 1963). Such vessels cannot, therefore, be considered as analogous to those described in the cartilage of the mandibular condyle.

SUMMARY

1. The histological structure and development of the condylar cartilage of the human mandible is described.

2. Vascular canals develop within the growing condylar cartilage in the 130 mm. crown–rump foetus and are present until the end of the third year of life.

3. The canals form as a result of uneven peripheral growth of the cartilage enclosing columns of cells of the outer layer of the covering perichondrium.

4. Perfusion of the arterial system shows that blood vessels enter the canals from the medullary cavity of the condyle and form anastomotic loops in the deeper layers of the articular zone of the cartilage.

5. Some small blood vessels may penetrate the articular zone and come to lie immediately beneath the articular surface of the cartilage. The possible sequelae of mechanical injury to these vessels in the new-born infant is discussed.

6. It is thought that the function of the canals is to enable more rapid growth of the cartilage during the period when the growing mandible has to accommodate the developing and erupting deciduous dentition.

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