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THE PRENATAL DEVELOPMENT OF THE HUMAN MANDIBLE AND
TEMPOROMANDIBULAR JOINT
(Role and Fate of Meckel's Cartilage)

DISSERTATION
Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

* * * * * * *

The Ohio State University
1966

Approved by

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INTRODUCTION

The human mandible has a complex developmental history which is associated with its progressive modification in evolution and with the specialization of its components. Its reduced number of bones, joint structures, and the development of a chin are good examples of this modification and specialization.

The development of the human mandible is described in almost every textbook of embryology and in many specific reports. It might be expected that by this time the accounts of its development in these reports would be uniform, and complete. But the accounts are not uniform and are far from complete; indeed, many are bewilderingly complex in an attempt to reconcile the many controversies that have arisen on the subject. Accordingly, in a study such as this, some attempt should be made to explain the reasons for the controversies and to deal with the fetal development of the mandible in a fairly comprehensive manner. Therefore, this study was undertaken to observe the succession of histological changes that occur in the lower jaw of human fetuses and thus determine (1) the role and fate of Meckel's cartilage, (2) the developmental
pattern of the fetal mandible, and (3) the histogenesis of the condyloid process and its relation to the other structures of the temporomandibular joint.

**Literature Review**

**Role and fate of Meckel's cartilages**

Since the first description of Meckel's cartilages (1) many reports on their role and fate have appeared in the literature. Earlier investigators, who were concerned with the development of the mandible in various mammals, have referred to the cartilages only briefly and were in disagreement on the role the cartilages play in the development and growth of the mandible.

While some investigators (1,2,3,4,5) have claimed that the cartilages disappear early in fetal life without contributing to mandible development, others (6,7,8,9,10,11) have claimed that the cartilages play a role in the incipient stages of mandible development. Reports by the latter group of investigators on the exact role the cartilages play are both brief and vague. They have observed that the anterior portion of the cartilages undergoes degeneration and becomes incorporated into the developing mandible. The degeneration process is described as being an endochondral ossification site similar to that of long bones, except for the fact that no epiphyseal
center forms (11). The mineralization, erosion, and osteogenic replacement of the anterior portion of the cartilages help to form the anterior part of the mandible. An explanation of the directional patterns of the formative processes involved is not found in the literature. Also wanting is the relation of the formative processes to the over-all growth of the mandible. It is interesting to note that the anterior ends of Meckel's cartilages of rats fuse to form a rostral process which serves as a growth center for the anterior part of the mandibular process and mandible halves (12).

The proximal or intratympanic portion of Meckel's cartilages undergoes endochondral ossification, and, as usually stated, is the formative site for both the malleus and incus ossicles of the middle ear. There is total agreement on the origin of the malleus; however, there is still some doubt about the origin of the incus (13).

The portion of Meckel's cartilages between the proximal and distal ossification sites undergoes a peculiar retrogression or transformation to a fibrous connective tissue. The fibrous residue from the distal ossification site to the lingula of the mandible is found to contribute to the lining of the mylohyoid groove (11). The portion between the lingula and anterior process of the malleus becomes ligamentous, forming both the sphenomandibular and anterior malleolar ligaments (11, 14, 15, 16, 17).
The anterior tips of Meckel's cartilages are found to persist throughout fetal life, within the midline (symphyseal) tissue as one or two cartilaginous nodules (11,18). Some investigators (9,10) have reported that the nodules might be formative sites for accessory ossicles of the symphysis.

Developmental pattern of the mandible

The mandible makes its appearance, as generally stated, between the fifth and sixth weeks of intrauterine life. It begins formation as paired membranous bones, lateral to Meckel's cartilage, in the region of the future mental foramen (18).

Various claims have been made in the literature regarding the number of ossification centers of the mandible. From two to six ossification centers have been described. Autenrieth (19) stated that each mandibular half arises from four centers of ossification, one each for the coronoid process, condylar process, body and angle of the mandible. Spix (20) supported Autenrieth and included a fifth center on the medial side of each mandible half—the "piece of Spix". Callender (7) believed that the ossified anterior part of Meckel's cartilage was a separate center of ossification and gave rise to the mentomeckelian bone, homologous to that found in reptiles. Bland-Sutton (21) combined the findings of Spix and
Callender and concluded that there were six centers of ossification for each mandible half. He believed that these six centers gave rise to six separate skeletal elements which correspond to the dentary, splenial, coronoid, condyloid, angular, and endomelkelian elements of the reptile.

Some investigators (22,23,24) have claimed an association between the number of ossification centers and the number of bones. This claim has been strongly criticized (25) on the basis that it is impossible to define what constitutes a bone along embryologic lines in terms of separate ossification centers.

Chondroid tissue sites have been observed in the coronoid and condyloid processes, angle, and alveolar crest of the forming mandible. This tissue has been variously called: accessory cartilage (26), vesicular chondroid bone (25), and preskeletal tissue (11). It is commonly called secondary cartilage because it differs in histological appearance from the typical hyaline cartilage of the primary cartilaginous skeleton. It has larger cells and thinner intercellular partitions than primary hyaline cartilage (27).

Secondary cartilage has been observed in areas of the forming mandibular bone where there is rapid proliferation of osteogenic type cells and a scarcity of blood supply (11). It has been suggested that these areas
are probably subjected to precocious stresses and strains (25,27), and that the cartilage appears as the result of some internal condition factor or induction (28).

The secondary cartilage sites have been described as separate centers of ossification which are destined to give rise to separate skeletal elements (26). This view has been criticised on the basis of the late appearance of the cartilage and the absence of separate ossification centers (29,30,31).

There is evidence that secondary cartilage may transform directly into bone tissue without being resorbed and replaced by osteogenic tissue (11,25,28).

Condyloid process and related temporomandibular joint structures

The formation of the temporomandibular joint is usually described as being different from that of most other synovial joints (32,33). Most synovial joints are formed between cartilage bones. In the case of the mandibular joint the skeletal components are membrane bones which appear at some distance from each other, and by continuous appositional growth toward one another to form a joint.

There is evidence in the literature (34,35) that the joints of the limbs may arise from a continuous blastema which chondrifies and becomes segmented. The
components of the temporomandibular joint have been found to arise from condylar and temporal blastemata (28). The two blastemata differentiate at different times and grow in opposite directions (28,36). The condylar blastema appears in the 24 mm. crown-rump stage and grows backward to contribute to the lower joint structures including the disk. The temporal blastema is seen in the 35 mm. crown-rump stage and grows forward to contribute to the upper joint structures.

As previously mentioned the developing mandible acquires sites of secondary cartilage. The most significant of these sites is the one that appears at the posterior or condylar end of the mandible.

The secondary condylar cartilage has been found to first appear in fetal stages ranging in size from 48 mm. to 120 mm. crown-rump (37,38,39,40,41,42). It has been stated that differentiation of the condylar cartilage is evidently due to adaptation of growth in an area of pressure (43). It is noteworthy that some investigators (44,45) have hypothesized that there is an absence of pressure in regions of joint formation.

The condylar cartilage has been described as a carrot-shaped wedge; its small end is directed below the root of the coronoid process. According to Fawcett (46) the cartilage calcifies as soon as it is formed; the ossification is not independent, but a result of invasion
from the surrounding membrane bone of the mandible. Charles (47) claimed that the wedge of cartilage is in reality a wedge of bone which passes through an intermediate cartilage stage. Macalister (48) found that in a 12 week-fetus the condyle was a carrot-shaped wedge of hyaline cartilage. Richany et al. (11) found that some of the condylar cartilage ("preskeletal tissue") passes directly into bone, and some becomes cartilage which transforms into bone. They noted that while the preskeletal tissue is disappearing, hyaline cartilage appears at the dorsolateral aspect of the growing condyle. Ultimately, the entire condylar head becomes hyaline cartilage. Baume (36) observed the dorsolateral appearance of the hyaline cartilage at the 60 mm. stage and stated that it starts endochondral ossification at the 85 mm. stage to become the growth center of the mandible.

The temporal portion of the temporomandibular joint develops as membrane bone at some distance from the condylar process. According to Moss (49) this portion of the joint first shows signs of ossifications at about the same time condylar cartilage appears. Furstman (50) observed first evidence of the temporal bone in an 8 week fetus. He noted that both the articular eminence and glenoid fossa are well formed by the 22nd fetal week. Baume (28) found that this portion of the joint arises from a blastemal tissue which differentiates in a forward
position toward the condylar blastema. He found the joint fully formed at the 190 mm. crown-rump stage.

Some synovial joints develop intra-articular structures which project into the synovial cavity from the surrounding capsule. These structures take the form of partial or complete disks. They are thought to form from portions of the adjacent capsule and perichondrium (51). The disk of the temporomandibular joint is complete.

The tissues and location of the articular disk have been seen early in fetal life, long before the mandible and temporal bone reach the articular plane (17), and much earlier than cavitation—appearance of the two joint cavities (38). The tissues are mesenchymal and muscular derivatives of the first branchial arch. The mesenchymal tissue which lies between the lateral pterygoid and masseter muscles forms the bulk of the fetal disk. The lateral pterygoid muscle contributes to the formation of a small medial part of the disk. Association of this muscle to the disk was first noted by Kjellberg (52). He described a connection between the forming lateral pterygoid and proximal or malleolar end of Meckel's cartilage. To make this connection the muscle passes between the forming temporal and condylar components of the joint. The position and contributions of this muscle to the disk has been observed by other investigators (17,38,40,41).
Some investigators \((16, 39, 53)\) have stated that the
disk appears after the skeletal components of the joint
reach the articular plane, and arises from the compressed
tissue caught between the articular surfaces.

Cavitation in the temporomandibular joint has been
found to start at the 57 \text{mm.} crown-rump stage \((38)\), and to
be virtually complete between the 65 \text{mm.} and 70 \text{mm.} crown-
rump stages \((33)\). As a result of cavitation the skeletal
components of the joint remain covered by a fibrocellular
tissue. This feature has been described as unique for
this joint \((17, 33, 43)\).
MATERIALS AND METHODS

This study is based on the histologic examination of the heads and lower jaws of 22 human fetuses ranging from 30 mm. to 280 mm. crown-rump length.

All specimens, except the 100 mm. one, were fixed in 10 per cent formalin, decalcified in 5 per cent nitric acid, doubly embedded in paraffin, and cut serially in frontal, sagittal, or horizontal planes. The 100 mm. specimen was cleared for gross observations.

In fetuses larger than 50 mm., the anterior region of the lower jaw was cut along a frontal plane posterior to the mental foramen and embedded as a unit. The remaining right or left posterior portions, through the temporomandibular region, were also removed and separately embedded.

The specimens were embedded in relation to the vertical plane of the face. Thus, the sagittal and horizontal cuts are at right angles and the frontal cuts are parallel to this plane. The direction of the cuts and the sequence of analysis of the sections are found in the observations and photomicrographic descriptions.
The following stains were used: hematoxylin and eosin, Kornhauser's pentachrome, Mallory, Masson, toluidine blue, and napthol green B.

Since the 30 mm. stage was found to be the approximate beginning of the fetal period it was used as the base-line of this study. And, because this specimen served as a beginning it was felt that a more complete set of photomicrographs, serially arranged, was necessary. A graphic reconstruction was made of this specimen to determine the shape of Meckel's cartilage in its full form and its relation to the forming mandible. This reconstruction was based on tracings of sections 30 to 40 micra apart.

Because the 50 mm. stage showed critical changes in the regions of the anterior part of Meckel's cartilage and temporomandibular joint it too was examined and photographed serially as a unit.

The regions of the remaining specimens which showed characteristic changes were analyzed as a group and the photomicrographs were arranged in sets; thus, from the 50 mm. to the 280 mm. stages, those changes which occurred in these stages, in the region of the temporomandibular joint, were recorded in the same place and the photomicrographs were arranged together. This was also done for the anterior regions of Meckel's cartilage and mandible.
For descriptive purposes the terms "anterior" and "posterior" were employed to indicate the relation of parts to the front or back of the head.
30 mm. stage - This fetal head was cut in frontal serial sections and recorded in an anteroposterior sequence.

At this stage the lower lip furrow band or labial vestibular lamina is still a continuous layer of invaginated oral epithelium. It is separated from the underlying mesenchymal tissue by a deeply-stained layer of basal cells which extend onto the external surfaces of the jaw (Fig. 1). In planes just posterior (lingual) to the labial lamina the anterior portion of the dental lamina is seen. Its deep median part is expanded into the deciduous central incisor tooth buds (Fig. 2).

The anterior ends of the mandible halves lie on each side of the midline in planes through the posterior portion of the central tooth buds. This part of each mandible half is arranged in a trabecular network of immature bone tissue (Figs. 3 and 4). Trabeculae above the lower level of the bone are surrounded by clear areas which contain scattered cells (Fig. 4).

The area between the mandible halves is composed of mesenchymal tissue. It is arranged in three ill-defined vertical zones. The lateral zones, adjacent to the bone,
are rich in cells which are surrounded by a dense intercellular substance. The central zone has fewer cells and clearer intercellular areas than the lateral zones (Figs. 3 and 4).

The upper posterior portion of the midline mesenchymal tissue surrounds young hyaline cartilage tissue—the anterior or distal terminal ends of Meckel's cartilages (Figs. 3 and 4). The cartilage tissue outline suggests two circles in juxtaposition; their medial sides are fused (Fig. 4).

Each mandible half lies oblique to the vertical plane in the region of the deciduous lateral incisor tooth germs (Figs. 5 to 12). The superolateral border of the mandible lies inferior to and between the vestibular lamina and the lateral tooth germ; it is wider than the inferomedially directed border. Both borders are osteoid in character and are lined by a brush-like layer of cells. The narrow inferomedial borders of the mandible halves are separated from each other by a narrow zone of mesenchymal tissue, and lie inferior and distant to the lower border of the median portions of Meckel's cartilages. The upper medial surface of the mandible curves around and contacts the surface of the lateral part of the cartilage (Figs. 5 and 6). At this site, in some areas of this region, the cartilage and bone interdigitate (Figs. 7 to 10).
The portions of Meckel's cartilages in the lateral incisor tooth germ region are prominent. They occupy most of the area between the mandible halves. Although the two cartilage masses meet at the midline, their outlines are individually distinct (Figs. 5, 7, 9, 11). The distinction is imparted by the concentration of cells along the periphery of the cartilages. These cells appear to merge indistinctly with the peripheral chondrocytes (Figs. 8, 10, 12). Chondrocytes vary in size and arrangement throughout each mass. They are small and close together at the medial side, and become larger and farther apart toward the lateral side (Fig. 12). At the lateral side, immediately adjacent to the apposed bone, the enlarged chondrocytes occur singly and doubly within the lacunae (Figs. 6, 8, 10, 12). Cell boundaries are ill-defined throughout the cartilage masses.

The mandible halves are Y shaped in the region of the deciduous cuspid tooth germs. Each half consists of lateral and medial plates which continue inferomedially as a single plate (Figs. 13 to 18). The area between the plates, on the interior of the mandible, is less dense in appearance than the area external to the plates. It is composed of scattered cells, nerve and vascular elements (Figs. 15 and 16). The portions of Meckel's cartilages in this region remain prominent. Their long axes change from a horizontal to an oblique plane, posteriorly. The lateral
surface of each cartilage still contacts the medial surface of the corresponding mandible half. Within the anterior region of the cuspid germs the cartilages are still in apposition (Figs. 13 and 14). They become separated toward the posterior region of the cuspid germs. Mesenchymal tissue intervenes between the cartilages. At the posterior extent of the cuspid germ the inferomedial surfaces of the cartilage masses lie below the level of the mandible halves (Fig. 17).

The portion of the mandible which is between the deciduous cuspid and first molar tooth germs has a varied pattern (Figs. 19 to 34). Just posterior to the cuspid germ the medial plate fans out superiorly over the interior area of the mandible and contacts the upper edge of the lateral plate (Figs. 21 and 22).

More posteriorly, the medially directed inferior part of the mandible approaches the horizontal plane. It passes below and contacts the inferior surface of Meckel's cartilage (Figs. 25 and 26). The upper edges of the mandibular plates are connected by a horizontal plate of osteoid tissue (Figs. 25 to 28). The cartilage mass is still clothed in a dense cellular sheath, except where it contacts the bone. And, as in previous regions, the sheath consists of several layers of flattened cells which appear to gradate into the peripheral surface of the cartilage (Figs. 30 and 32). The inferomedial part of the sheath is
joined by fibers of the genioglossus and geniohyoid muscles (Figs. 29 to 31). Within this same region, the forming mental foramen is seen in the lower part of the lateral plate (Figs. 27 and 28). At the site where the mental nerve is first seen passing through the foramen, Meckel's cartilage and mandible no longer contact one another (Figs. 33 and 34). The intervening area is composed of mesenchymal tissue. Chondrocytes are uniform in size and arrangement from this site, posteriorly, to the proximal end of Meckel's cartilage.

The portion of the mandible in the region of the first deciduous molar is extended in the vertical plane (Figs. 35 to 38). The lateral plate extends above the upper level of the medial plate. The inferior part is broad and short and lies in the vertical plane. The portion of Meckel's cartilage in this region is somewhat circular in outline and lies medial to the entire medial surface of the mandible. The inferior surface of the cartilage sheath is adjoined by fibers of the mylohyoid muscle. Cells of the sheath still merge with the peripheral chondrocytes.

The medial plate of the mandible is thinner and shorter than the lateral plate in the region of the second deciduous molar germ. The cartilage, bone, and muscle have the same relationship as in the previous region (Figs. 39 and 40).
Just posterior to the second deciduous molar germ, in the region of the posterior extent of the dental lamina, the upper border of the mandible lies at the level of the dorsum of the tongue (Fig. 41). The finger-like extension of the dental lamina is directed downward toward the upper surface of Meckel's cartilage. The cartilage and lamina form the medial boundary of the interior, clear area, of the mandible. The mylohyoid muscle now meets the lower medial part of the cartilage sheath.

The medial mandibular plate does not extend beyond the area of the dental lamina. From here, posteriorly, the mandible consists of only the lateral plate. The upper portion of the plate is enclosed in a dense mesenchymal condensation. This condensation varies in outline anteroposteriorly. It tapers above and lateral to the upper border of the mandibular plate in the anterior region of the forming coronoid process (Figs. 42 to 46). It is enclosed in muscle tissue. The masseter muscle mass borders the lower lateral side of the condensation; the temporal muscle borders the upper end and medial side of the condensation (Figs. 43 to 46). The forming zygomatic process of the maxillary bone is seen lateral to the upper portion of the masseter muscle. The portion of Meckel's cartilage in this region lies above the lower widened end of the lateral plate. It occupies relatively the same position as the medial plate of the mandible did in the
previous regions (Fig. 45). The cartilage mass, which is oblong in outline, is enclosed in a distinct cellular sheath. Fibers of the mylohyoid muscle are now adjacent to the upper medial part of the sheath.

The mesenchymal condensation around the upper portion of the lateral mandibular plate becomes more distinct in outline posteriorly. In the anterior regions of the lateral and medial pterygoid muscles, the upper outline of the condensation—surface of the bony plate—is a wide curve (Figs. 47 and 48). It is still circumscribed by the masseter and temporal muscles. The masseter muscle extends from the medial side of the forming zygomatic bone downward, along the lateral surface of the lateral plate to the lower third of the medial pterygoid muscle, which is directed downward toward the medial side of Meckel's cartilage.

The mesenchymal condensation is wedge-shaped in the region of the zygomaticotemporal suture (Fig. 53). It tapers downward around the upper half of the lateral mandibular plate. Its upper flat, straight surface is directed superolaterally. The masseter and lateral pterygoid muscle masses still meet the outer surface of the cellular condensation (Figs. 53 and 54). The temporal muscle, seen above the zygomaticotemporal suture area, does not meet the condensation in this region.
More posteriorly, in the anterior region of the zygomatic process of the temporal bone, small openings are present along the upper flat surface of the mesenchymal condensation (Figs. 55 and 56). These openings are similar to those seen in the previous regions (Figs. 51 and 52) between the lateral pterygoid muscle and condensation. The lateral pterygoid mass still meets the upper medial side of the condensation. The posteroinferior portion of the masseter muscle is seen in this region. It lies lateral to the lower portion of the mandibular plate (Fig. 55).

A wide area of scattered cells extends between the zygomatic process of the temporal bone and the superolateral surface of the mesenchymal condensation (Figs. 55 and 56). The medial boundary of the scattered cell area is formed by a dark band of cells in the shape of a V lying on its side; the apex points medially (Figs. 55 to 58). The upper band of cells passes from the lower end of the temporal muscle, above the zygomatic process, medially to the apex, from here the lower band passes laterally and across the superolateral surface of the mesenchymal condensation. A short band of cells from the lateral pterygoid mass joins the lower band above the superomedial side of the mesenchymal condensation (Fig. 58). This area contains the rudiments of the temporomandibular joint.

Posterior to the above region the mandibular plate, Meckel's cartilage, medial pterygoid muscle, and auditory
tube lie oblique to the vertical plane (Figs. 59 to 62). The mandibular nerve and its branches extend downward from the trigeminal ganglion in the vertical plane. The nerve branches lie above the oblong mass of Meckel's cartilage. The upper end of the cartilage mass is directed toward the zygomatic process of the temporal bone. A portion of the auriculotemporal nerve is seen passing around and contacting the upper end of the cartilage sheath (Figs. 61 and 62).

The inferior end of the posterior extent of the lateral mandibular plate is directed toward the inferolateral end of the medial pterygoid muscle (Figs. 63 and 64). This posterior termination of the mandible plate is enclosed in a dense cellular mass (Fig. 64). Meckel's cartilage mass lies above the mandibular plate in this region. Its upper end is directed toward the squamous portion of the temporal bone. In more posterior planes the upper end of the cartilage mass lies just medial to the bone (Figs. 65 and 66).

Frontal serial sections through the posterior or proximal terminal part of Meckel's cartilage show that it broadens and curves back on itself to form a hook-like process (the malleus anlage) (Figs. 68 to 82). This part of the cartilage lies lateral to the cochlear portion of the cartilaginous otic capsule. Its upper posterolateral surface fits in the concave anterior surface of the
cartilaginous incus. The two cartilages are not in direct union. They are separated by a narrow "disk" of cells (Figs. 70 to 80).

An area of immature bone tissue is seen along the inferomedial surface of the proximal part of Meckel's cartilage (Figs. 69 to 74). It represents the anterior process of the malleus.

The cartilaginous incus is first seen lateral to the upper end of the posterior part of Meckel's cartilage--malleus anlage (Fig. 70). The squamotemporal bone, which was seen lateral to the upper end of Meckel's cartilage in the previous regions, lies just lateral to the incus anlage. Frontal serial sections through the incus anlage show that its anterior and posterior surfaces are concave (Figs. 70 to 99). As already described the anterior concave surfaces curve around the posterolateral surface of the malleus anlage. The posterolateral surface of the incus anlage curves around a downward extension of the vestibular portion of the cartilaginous otic capsule (Figs. 85 to 99). The inferomedia l end of this portion of the incus anlage meets the stapedial anlage (Figs. 88 and 90). The two cartilages are separated by a "disk" of flattened cells. The superolateral part of the posterior portion of the incus anlage extends posteriorly along the lateral surface of the otic extension (Figs. 87 to 99).
A direct cartilaginous union exists between this part of the incus anlage and cartilaginous otic capsule (Figs. 88 to 99).

50 mm. fetus.—At this stage the lateral most part of the anterior portion of Meckel's cartilage is enclosed in the bony splint extension of the mandible (Figs. 1' and 2'). This part of the cartilage shows degenerative changes; the lacunae are enlarged, chondrocytes show pyknotic nuclei, and the matrix is calcified. A portion of the calcified cartilage is eroded by vascular connective tissue. This tissue is seen penetrating the perichondral splint and entering the lower surface of the calcified cartilage (Figs. 3' and 4').

The degeneration (calcified) site and bony splint extend anteromedially to an area just lateral to the midline (symphysis) (Figs. 5' to 10'). From here to the midline the cartilage is unaltered and forms the inner or lingual wall of the anterior portion of the mandible (Figs. 11' and 12'). Thus, at this stage, the anterior portion of the mandible consists of an outer or anterior wall of bone and an inner or lingual wall of cartilage.

The posterosuperior end of the lateral plate of the mandible terminates as the coronoid and condyloid processes. The coronoid process lies lateral to the sagittal plane of the condyloid process. The bone of the
coronoid is arranged in a trabecular network, medially. The trabeculae are continuous externally with a fibrocellular tissue (Figs. 13' to 16').

The condyloid process exists as a medially directed expansion of the posterosuperior end of the lateral mandibular plate. Its upper, posterior surface faces and is parallel to the anteriorly directed surface of the squamous portion of the temporal bone. A dense, continuous mass of mesenchymatous tissue still lies between the two surfaces (Figs. 19' to 34'). The skeletal core of the condyle consists of a rectangular mass of chondroid tissue (secondary cartilage). The cells of this tissue are round, and the intervening matrix is thin and calcified. This matrix is continuous at the periphery with the immature bone tissue of the mandible, except at the growing (articular) end, where it is continuous with the interzonal mesenchymal tissue (Figs. 19' to 34'). From this growing surface anteriorly (internally) the following zones are seen in the condyle: (1) dense cellular; (2) fibrocellular; (3) calcified chondroid tissue (Figs. 26', 28', 31', 33', 35'). All the zones appear to merge into each other. (Appositional growth of the condyle appears to be directed posterosuperiorly at this stage of development). Although there is no discontinuity between the surface of the condyle and the overlying interzonal mesenchyme, the future articular surface is distinct. This
distinction is imparted by the condensation of mesenchymal cells at the surface (Figs. 19' to 34').

The inferomedial portion of the mandible consists of two parallel bony plates (Figs. 19',29'). The plates are connected to each other by short trabeculae. The upper plate, which is actually the original inferior border of the lateral plate of the mandible seen in the 30 mm. specimen, extends posterosuperiorly to the condyle. The posterior end of the lower plate lies at some distance anterior to the surface of the condyloid process. This end of the lower plate will be referred to as the angle of the mandible in subsequent descriptions.

Throughout the regions described above the posterior continuation of Meckel's cartilage is seen above the inferomedial border of the mandible (Figs. 29',30',32',34'). It curves upward, passes below the most medial part of the condyle and continues posterolaterally to the tympanic cavity where it terminates as the hook-shaped malleus anlage (Figs. 34',36',38',40'). A narrow "disk" (histologically cellular in character) still lies between the cartilage models of the malleus and incus. The models both lie a short distance posterior to and below the upper level of the condyloid process. The interzonal mesenchymal tissue lies within the region between the malleus anlage and condyle (Figs. 30',32',34').
The lateral pterygoid muscle is seen extending from the lateral pterygoid plate to and merging with the anteromedial surface of the fibrocellular covering around the medial part of the condyle (Fig. 34'). A "tendon-like" extension of the lateral pterygoid muscle passes posterior to the medial part of the condyle and merges with the fibrocellular sheath over the head of the malleolar portion of Meckel's cartilage (Figs. 36' to 40'). In more medial planes of this region the immature bone tissue of the forming anterior process of the malleus is seen within the fibrocellular cartilage sheath (Fig. 41').

**Changes which occur in the anterior part of Meckel's cartilage in later fetal stages.** -- The erosion of Meckel's cartilages proceeds until the entire diameter at the initial degeneration site is evacuated. As a result of this process the anterior portion of the cartilages becomes separated from the longer posterior portion, which remains relatively unaltered. After separation the extension of the endochondral ossification process toward the medial, midline, surface of the isolated cartilages occurs in an orderly sequence of changes. The changes show a more or less zonal arrangement which can be seen in serial sections of later fetal stages. These zones were observed from the 90 mm. through the 120 mm. stages.

The medial parts of the right and left isolated cartilages protrude into the midline (symphysial) tissue
where they share a common "disk" of cells at their medial surfaces (Figs. 1a, 2a). There is no distinct junction between these cells and the subjacent cartilages.

The appearance of the matrix and the arrangement of the chondrocytes vary throughout the cartilage segments. The cells become progressively larger and the matrix partitions become thinner and calcified toward the lateral end (Figs. 1a, 3a, 5a). Cells in the region of the bony splint extension of the mandible are arranged in indistinct rows which lie parallel to the long axis of the cartilage segments (Figs. 4a, 6a). Lacunae at the lateral surface are opened and contain loose connective tissue. Some of the calcified fragments at this site are encrusted with bone tissue (Fig. 6a). The evacuation site, which becomes progressively elongated throughout the stages mentioned, is occupied by vascular connective tissue, and bone spicules (Figs. 7a to 10a).

The erosive process extends medially, keeping pace with the linear increase of the bony splint extension of the mandible (Figs. 9a, 10a). While the erosive process continues toward the midline, the most medial ends of the cartilage segments remain uncalcified and constantly show maturational changes. As a result of these changes the medial ends of the cartilages vary in shape and position (Figs. 10a, 12a, 13a).
The encased lateral parts of the anterior portions of the cartilages are completely replaced by bone and primary marrow tissues by the 120 mm. stage. All that remains of this part of the cartilages are the midline, medial tips. They lie free in the upper posterior region of the midline connective tissue (Figs. 13a,14a). Through subsequent fetal stages this mass of free cartilage becomes progressively smaller until by the 165 mm. stage all that remains is an indistinct small mass of cartilage (Figs. 15a, 16a). There is no distinct junction between the periphery of the cartilage and the surrounding midline connective tissue.

Changes which occur in the posterior continuation of Meckel's cartilages in later fetal stages. --The posterior portion of Meckel's cartilages, which lies in the vicinity of the developing mandible, remains relatively unaltered through most of the early fetal period.

The anterior part (just posterior to the anterior degeneration site) of this portion of the cartilage lies medial to the inferomedial side of the mandible (Fig. 17a). Its fibrocellular sheath remains continuous with the periosteum of the mandible (Fig. 18a).

Frontal sections through the 115 mm. specimen show that the anterior end of the posterior portion of the cartilage has continued to grow and curved back on its self.
This is indicated by the double masses of cartilage which appear at the inferomedial side of each mandible half (Figs. 19a, 20a). From its inferomedial relationship to the mandible the posterior continuation of the cartilage passes upward to a position below the lingula of the mandible (Figs. 21a to 24a). The part just in front of the lingula comes to lie in a groove formed along the medial surface of this portion of the mandible (Figs. 22a, 23a). The mylohyoid muscle fibers, associated with the sheath of this portion of the cartilage in earlier stages, now pass beyond the cartilage to join the medial periosteum of the mandible (Figs. 21a, 22a). In subsequent stages this part of the cartilage becomes smaller in diameter and its sheath remains continuous with the periosteum of the mandible (Figs. 25a, 26a). Lacunae become enlarged and arranged in groups. Chondrocytes are ill-defined (Fig. 27a). Remnants of this part of the cartilage are still present at the 190 mm. stage (Fig. 28a).

The portion of Meckel's cartilage that extends from the forming lingula of the mandible to the tympanic cavity remains distant to the medial side of the condyloid process throughout its fetal existence. The proximal end of this part of the cartilage remains associated with the forming articular disk and tendon-like extension of the lateral pterygoid muscle. All of these tissues are seen passing
through the opening between the head of the tympanic bone and squamous portion of the temporal bone (Figs. 29a to 38a).

A second degeneration site is seen in the most proximal part of Meckel's cartilage at the 90 mm. stage. It appears just posterior to the anterior malleolar process which elongates posteriorly to contact the surface of the cartilage (Figs. 39a,42a). The degeneration process is similar to that described for the anterior degeneration site of Meckel's cartilage. Chondrocytes enlarge, matrix partitions become thin and calcified. The calcified matrix is eroded and replaced by vascular osteogenic tissue. By the 165 mm. stage most of the proximal end of the cartilage is replaced by bone and marrow tissues, and is recognized as the malleus ossicle (Fig. 43a).

While the endochondral process is occurring in the malleolar end of Meckel's cartilage, the portion that extends through the squamotympanic opening becomes smaller in diameter and is replaced peripherly by a fibrocellular tissue. By the 165 mm. stage all that remains of this part of the cartilage is an ill-defined mass of matrix that blends with the surrounding connective tissue (Fig. 44a).

The portion of the cartilage that extends from the lingula of the mandible to the squamotympanic opening becomes smaller in diameter and is replaced peripherly by fibrous tissue (Fig. 45a). In the region of the forming
lingula of the mandible the fibrous sheath merges with the periosteum (Fig. 46a). In succeeding fetal stages this portion of the cartilage shows more degenerative changes. Its matrix partitions become more defined and nodular swellings occur along its surface (Fig. 47a). By the 190 mm. stage all that remains of this part of the cartilage are isolated remnants surrounded by the fibrous sheath (Figs. 48a, 49a). The part adjacent to the lingula is completely replaced by fibrous tissue which is still continuous with the periosteum of the mandible (Fig. 50a).

Changes which occur in the bone pattern of the mandible in later fetal stages. — During the early fetal stages the anterior part of the mandible consists of a labial plate of immature bone tissue and a lingual plate of cartilage—encased anterior ends of Meckel's cartilages. The lingual plate of cartilage is gradually replaced by bone tissue through the process of endochondral ossification. The replacement occurs in a medial direction and continues through the 120 mm. stage.

At the 90 mm. stage the trabecular pattern of the anterior part of the mandible is more extensive than in preceding stages. Trabeculae surround circular areas of vascular connective tissue. Each of the vascular areas contains one or two prominent blood vessels (Figs. 1b to 4b). At the crest of the bone, anterior to the forming
anterior deciduous teeth, chondroid tissue is seen (Figs. 1b to 4b). Its matrix is continuous with the adjacent bone matrix. Cells of this tissue are large and somewhat rounded in shape. They occur in irregular groups and in some areas two cells exist in a single lacuna. The matrix is thin between individual cells and wide between groups of cells (Fig. 2b). (Serial sections show this chondroid tissue extending from the deciduous cuspid tooth to the medial side of the deciduous central tooth, where it is contiguous with the symphysial connective tissue.)

The dental sacs or follicles of the incisor tooth germs contain sites of large blood vessels and multinucleated giant cells (Figs. 1b to 4b). The giant cells lie along the surfaces of the bone and chondroid tissues that are adjacent to the dental sacs. The surface of the chondroid tissue in the region is concaved and has opened lacunae. There is another site of chondroid tissue at the inferomedial portion of each mandible half. Medially, this tissue is covered by the symphysial tissue; laterally it is continuous with the bone tissue of the mandible (Figs. 5b, 6b). (These chondroid tissue sites were found to persist through the 165 mm. stage.)

The midline (symphysial) connective tissue becomes progressively more fibrous and vascular. It is continuous with the marrow tissue of the mandible halves (Figs. 7b to 10b). Toward the 120 mm. stage the three vertical zones
of the symphysis become more defined (Fig. 10b).

The portion of the mandible, which lies posterior to the deciduous cuspid tooth, continues to increase in vertical and horizontal directions. More extensive development occurs along the inferior surface. This results in a varied bone tissue pattern. Bone at the inferolateral side is more compact than that at the inferomedial side. The inferomedial side is arranged in an extended trabecular network (Figs. 11b to 14b).

The angle of the mandible, which is represented by a narrow plate of bone in the early fetal stages, increases progressively in width and length throughout subsequent fetal stages. The increased growth results in an extensive trabecular network of bone. This network of bone becomes more compact and continues to form posteriorly below the deep surface of the condyloid process (compare figs. 29', 10c, 16c, 26c, 30c).

The coronoid process continues to expand as a trabecular network of bone until the 90 mm. stage. At this stage chondroid tissue is present along the superoanterior surface of the process (Figs. 15b, 16b). This tissue is similar in appearance to that which is present at the crest of the anterior part of the mandible halves. Its matrix is continuous with the adjacent bone tissue. Osteoclasts are seen along opened lacunae at the inner surface of the chondroid tissue (Figs. 17b, 18b). This
tissue is still present at the 125 mm. stage. In subsequent stages the coronoid process continues to develop as a compact trabecular network of immature bone tissue.

Changes which occur in the condyloid process and surrounding structures in later fetal stages.--The mass of chondroid tissue encased in the posterosuperior end of the outer mandibular plate continues to grow, posterosuperiorly, toward the squamotemporal bone. By the 60 mm. stage the chondroid mass is elongated, forming the distinct inner core of the condyloid process (Figs. 5c, 6c). The peripheral matrix of the chondroid tissue is continuous with the immature bone tissue of the outer mandibular plate, except at the posterolateral and articular surfaces. The posterolateral surface of the condyle consists of young hyaline cartilage which merges, medially, with the chondroid tissue (Figs. 1c to 4c). The articular surface consists of a fibrocellular tissue which merges below with the chondroid tissue (Figs. 5c to 9c). Above, the fibrocellular surface is separated from the interzonal mesenchyme by a small, narrow opening (Figs. 5c to 9c). (This opening represents the forming lower joint cavity.) Small strains of cells cross the opening (Figs. 8c, 9c). A more dense band of mesenchymal cells lies above the opening (Figs. 5c to 13c). The upper surface of this band is straight. From this surface to the squamotemporal bone the
mesenchymal cells are farther apart (Figs. 5c to 9c). The lateral pterygoid muscle fibers still adjoin the mesenchymal tissue at the anteromedial and medial sides of the condyloid process (Figs. 10c to 13c). This relationship remains constant in subsequent fetal stages.

Between the 60 mm. and 75 mm. stages the upper joint cavity appears. At the 75 mm. stage this cavity is relatively straight in outline, conforming to the straight lower surface of the squamous portion of the temporal bone. The lower joint cavity is curved, conforming to the curved articular surface of the condyloid process (Figs. 14c,15c). With the appearance of the joint cavities the intervening mesenchymal tissue is recognized as the articular disk. The upper surface of the disk is straight; its lower surface is concaved. Both surfaces appear to conform to the surfaces of their respective adjacent skeletal components. The middle portion of the disk is narrow; its peripheral portion is wide. The shapes of the articular surfaces, joint cavities, and disk as described above, remain relatively constant in the later fetal stages.

At the 75 mm. stage the chondroid tissue core of the condyloid process is more extensive. It is conical in shape. Its tapered, deep end lies below the coronoid process and above the expanded angle of the mandible. Irregular spaces, filled with loose connective tissue, are present within the tapered end of the chondroid tissue.
Some of the spaces are bordered by immature bone tissue which is continuous with the chondroid matrix (Figs. 16c, 17c). Sections through the mid portion of the condyloid process, at this stage, show a zonal arrangement of the cells and matrix. Proceeding from the lower joint cavity, at the surface of the condyle, downward, the following zones are seen: (1) a narrow layer of concentrated mesenchymal cells, similar in appearance to those of the articular disk; (2) a wide layer of large flattened cells which are far apart and surrounded by a pale staining matrix; (3) the elongated chondroid tissue zone, composed of large round to wedge-shaped cells surrounded by a deeply stained matrix, the groups of cells being separated by a wide calcified matrix, while individual cells are separated by thin matrix partitions (Fig. 18c). All the zones are continuous and appear to gradate into each other. The chondroid tissue core (zone 3) is surrounded at the periphery by osseous tissue, which is actually a continuation of the outer mandibular plate (Figs. 17c, 19c).

The hyaline cartilage, which was first seen at the posterolateral surface of the condyloid process, continues to form at the posterolateral and superior surfaces (Figs. 20c, 21c). By the 90 mm. stage it caps the entire proximal end of the condylar process (Figs. 20c to 27c). The surface of this tissue, facing the lower joint cavity, remains covered by a fibrocellular tissue (Figs. 26c, 27c).
From this surface toward the anterior, deep end the chondrocytes become progressively larger and the matrix partitions become thinner and calcified (Figs. 23c to 25c). Lacunae at the deep end are opened and contain loose connective tissue. Proceeding distally the loose connective tissue surrounds fragments of the mineralized cartilage matrix (Fig. 25c). At this same stage most of the chondroid tissue core disappears (Fig. 26c). Remnants of this tissue are present (Figs. 27c, 28c). The evacuation site contains vascular connective tissue (Fig. 27c). Large blood vessels are seen penetrating the osseous condyloid collar from the outside and entering the evacuation site (Fig. 28c). Although most of the chondroid core of the condyloid process is evacuated its original position and outline remain distinct, as clearly shown by the cleared and stained mandible of the 100 mm. specimen (Fig. 29c).

In subsequent fetal stages the hyaline cartilage continues to form at the proximal end of the condyloid process (Figs. 30c, 31c). Its interior or deep end continues to undergo calcification. The interior area, formerly occupied by the chondroid tissue becomes more vascular (Fig. 32c). By the 120 mm. stage the most distal end of this area, just above the angle of the mandible, contains hematopoietic tissue (Figs. 30c, 33c). At this same stage a wedge of vascular connective tissue is seen penetrating the proximal surface of the hyaline cartilage.
(Figs. 34c, 35c). This tissue is continuous with the fibrocellular covering (articular) surface of the condyle. In succeeding fetal stages the vascular bud becomes larger and more vascular (Figs. 36c to 39c).

By the 190 mm. stage the tissue zones of the condyloid process are more distinct (Fig. 40c). From its lower joint cavity toward the interior of the condyloid process the following zones are seen: (1) a narrow fibrous layer, similar in appearance to the articular disk (Fig. 41c); (2) a concentrated layer of cells (Fig. 42c); (3) a wide layer of hyaline cartilage, the cells of which become progressively larger and farther apart toward the deep end (Figs. 42c, 43c); (4) a layer of calcified hyaline cartilage, the lacunae at the deep surface of which are opened and contain loose connective tissue (Fig. 43c); (5) a layer of calcified cartilage matrix fragments surrounded by loose connective tissue (Fig. 43c); (6) a zone of calcified cartilage matrix fragments enclosed in bone tissue, surrounded by a highly vascular connective tissue (Figs. 44c, 45c).

The squamous portion of the temporal bone, which arises as a narrow plate of immature bone becomes a trabecular network of immature bone tissue. This tissue continues to grow in an anterior direction toward the condyloid process. At the 75 mm. stage masses of chondroid tissue are seen encased in the immature bone tissue.
(Fig. 46c). This chondroid tissue is similar in appearance to that seen in the root of the condyloid process of the 75 mm. stage (compare Fig. 46c to Fig. 19c). By the 90 mm. stage the upper skeletal component of the temporomandibular region has a varied pattern. Its surface, along the upper joint cavity, consists of a dense fibrocellular tissue. This tissue continues above as chondroid tissue (Fig. 47c). The zonal arrangement of the upper joint component persists through the 120 mm. stage (Fig. 48c). By the 190 mm. stage the upper joint component is a trabecular network of immature bone tissue. Its articular surface, along the upper joint cavity, consists of a highly vascular connective tissue (Fig. 49c).
DISCUSSION

Role and fate of Meckel's cartilages

Meckel's cartilages represent the primary skeleton of the lower jaw and serve as a framework around which developing nerve, muscle, and bone tissues can orient themselves. The cartilages, which are among the earliest skeletal elements to appear in man, remain relatively unaltered during the early fetal period and continue to grow for sometime after the rudiments of the mandible appear.

When fully formed the cartilages describe a gothic arch (Fig. 100). Their cranial proximal ends lie lateral to the cochlear portion of the otic capsule. From here they pass downward and forward to the region of the origin of the incisive and mental nerves, where they become flattened, anteroposteriorly, and pass upward and medially. At the midline the cartilages meet one another. Contrary to general opinion their anterosuperior-most ends actually fuse. This early synchondrosis joint at the midline may account for the lag in anterior growth of the lower part of the face to the upper part during the early prenatal period.
Meckel's cartilages undergo peculiar retrogressive changes along their entire length. These changes occur bilaterally and indicate the ultimate role and fate of the cartilages. Endochondral ossification occurs at the distal and proximal ends. The ossification process is similar to that described for cartilage models of bones elsewhere in the body.

The first change to occur is the distal ossification. It begins after the rudiments of the mandible appear in the region of the deciduous cuspid tooth germ. An osseous extension from the mandible at this site forms a bony splint or collar around the degenerating cartilage. As a result of this ossification process the anterior segment of the cartilage becomes separated from the posterior portion, and the lateral part of the segment remains encased in the bony splint extension of the mandible. The right and left anterior segments remain contiguous along their medial surfaces and temporarily serve as the lingual or inner wall of the anterior part of the mandible. Each segment continues to grow, both appositionally and interstitially, at their medial ends while their encased lateral ends continue to undergo degenerative changes and replacement by osteogenic tissue toward the midline. The continuous growth of the cartilage segments toward each other results in the lengthening of the lingual side of the anterior part of the mandible in an
anteromedial direction, and maintains the distance between the mandible halves. Thus, the anterior parts of Meckel's cartilages serve two functions: (1) they form a temporary lingual wall at the anterior part of the mandible; and (2) serve as a secondarily incorporated cartilaginous growth apparatus at the anterior end of each mandible half.

The proximal end of Meckel's cartilages serve as the cartilaginous model of the malleus ossicle. It undergoes endochondral ossification similar to other bones of the body which develop in a cartilaginous environment. The degeneration site at this end of the cartilage occurs after the anterior site appears. It first appears opposite the forming anterior process of the malleus. The anterior process makes its appearance as immature bone tissue, within the perichondrium of Meckel's cartilage, distant to its ultimate position on the malleus. It not only serves as a bony splint to the cartilage degeneration site, but also becomes the anchoring site for the anterior malleolar ligament. This ligament arises from that part of Meckel's cartilage that lies adjacent to the anterior malleolar process.

The intermediate portion of Meckel's cartilages, the part between the two ossification sites, undergoes a peculiar deorganization along its entire length. The part between the anterior degeneration site and lingula of the mandible changes to a loose connective tissue which is
continuous with the periosteum along the medial side of the mandible. The part which is most medial to the mandible and lies between the lingual and proximal degeneration site transforms to a ligamentous tissue. This tissue is in the region which is ultimately occupied by the sphenomandibular and anterior malleolar ligaments.

**Developmental pattern of the mandible**

The mandible originates from paired membranous ossification centers, and continues to grow and develop as a paired structure throughout the prenatal period. The primary ossification centers appear between the sixth and seventh weeks of embryonic life. They are located lateral to the anterior parts of Meckel's cartilages. Although there were no specimens used in this study which showed the initial site of bone formation, it was possible to determine its location by using observation of other investigators. Reichert (6) noted that the anterior portion of Meckel's cartilages begins degeneration opposite the initial site of bone formation; and, Richany et al. (11) observed that there is a more solid mass of bone at the original ossification site in later stages. In the 30 mm. fetus used in this study, a more solid mass of bone and adjacent degeneration changes in Meckel's cartilage were observed at the level of the mental foramen in the region just posterior to the deciduous cuspid germ. (Fig. 100).
Each primary site of bone formation serves as a nidus from which the mandible halves grow. From this site the extension of the intramembranous bone development progresses forward and backward, so that by the beginning of the fetal period the shell-like rudiments of the mandible halves are present. The forward growth progresses toward the midline as a single plate of bone, the primary anterior, labial plate of the mandible. The primary anterior, lingual plate is formed by the anterior part of Meckel's cartilage. The backward growth progresses toward the masticatory muscle masses as a trough of bone. The outer or lateral plate of the trough reaches the territory of the muscles and continues to grow and develop as the coronoid and condyloid processes. The inner or medial bony plate ends at the future site of the mandibular foramen. These bony plates serve as the template for growth of the mandible halves in length, width and height.

The differences of rate, mechanism, and direction of growth at various sites of the mandible result in a varied tissue pattern. In this study these differences were noted by the: compactness of the membrane bone, position and endochondral ossification of the anterior part of Meckel's cartilages, angle of the mandible, and secondary cartilage sites.

The noticeable difference in compactness between the bone at the lateral and medial sides of the body of
the mandible indicates that growth is constantly more recent and expansive along the medial surface. This growth is probably compensatory to the increase width of the tongue.

The encased anterior portion of Meckel's cartilages forms the temporary lingual wall of the anterior part of the mandible. Since this cartilage segment occupies the ultimate position of the osseous wall of this region and undergoes endochondral ossification, it may be concluded that the developmental mechanism involved in the formation of the osseous lingual wall is endochondral.

The "angle" of the mandible makes its appearance as an extension from the original ossification site. This extension occurs after the start of development of the condyloid process at the posterior end of the lateral plate. Thus, during the early fetal period, the angle is at some distance anteroinferior to the posterior extent of the condyle. The angular extension of bone grows progressively in a backward and vertical direction, along the inferior border of the original trough of bone, toward its ultimate position below the condyloid process. The directional growth of this extension of bone results in an increase in posterior length of the body of the mandible and the formation of the posteroinferior portion of the ramus. While the angular extension is growing posteriorly, below the condyloid process, the condyle is continuing to
grow superiorly and laterally. The histologic features observed in this study, which show that the directions of growth of the mandibular body and condyloid process are relatively independent, support the data obtained from biometric studies.

During the early fetal period the mandible continues to grow, at all its surfaces, as membrane bone. When the fetus attains a length of about 50 mm. a mass of secondary cartilage forms on the posterosuperior border of the outer mandibular plate in the area of the condyloid process. Between this stage and the 90 mm. stage, similar cartilage is also formed at the anterior end of each mandible half and along the superoanterior border of the coronoid process. The ossification observed in these cartilage sites has not been reported as occurring in the usual manner, that is the erosion of the cartilage by osteogenic tissue from the outside. According to other investigators the ossification in these regions is believed to be by invasion of the surrounding bone.

The varied number of ossification centers and separate skeletal elements of the mandible observed by earlier investigators are easily understood when one considers the bone tissue pattern, the appearance of secondary cartilage sites, and the position and fate of the anterior portion of Meckel's cartilages during mandible formation. Consideration must also be given to the
preparation of tissues and the limited number of human specimens used in the earlier studies.

**Histogenesis of the condyloid process and related temporomandibular joint structures**

The condyloid process makes its appearance as an osseous extension of the posterior end of the outer mandibular plate. This end of the bone is clothed in a mass of mesenchymatous tissue which is continuous at its circumference with the masticatory muscles. The mass of mesenchymal tissue serves as the precursor tissue of the growing end of the condyloid process, and as the primordial site of the articular disk and joint cavities.

The osseous condyle continues to grow posterosuperiorly toward the squamous portion of the temporal bone. The squama grows anteriorly toward the condyle. When the fetus reaches a length of about 50 mm, secondary cartilage (chondroid tissue) is formed at the posterosuperior end of the osseous condyloid process. It is significant that this tissue arises in an environment where there is muscle tissue and a paucity of blood supply. These environmental conditions have been implicated as the possible inductors of the secondary cartilage (11,28).

The condylar secondary cartilage continues to form posterosuperiorly and by the 60 mm. stage is elongated as the skeletal core of the condyloid process. At this stage
the condyle has a varied tissue pattern. Peripherally, the secondary cartilage is continuous with osseous tissue everywhere except at the posterolateral and superior ends. The posterolateral surface is composed of hyaline cartilage, and the superior surface is a fibrocellular tissue.

The secondary cartilage and osseous periphery of the condyloid process continue to grow appositionally and independent of each other. There is no evidence of direct transformation of the secondary cartilage to osseous tissue, as claimed by several other workers (11, 25, 28).

By the 90 mm. stage the deep end of the secondary cartilage, the matrix of which appears to be mineralized soon after formation, is eroded and replaced by vascular connective tissue. The erosion and replacement processes occur in the usual manner. Osteogenic, vascular connective tissue penetrates the osseous periphery from the outside and enters the evacuation sites within the secondary cartilage core. It is interesting that hematopoietic tissue first appears in this area of the mandible.

As the secondary cartilage core is being eroded and replaced by vascular connective tissue the hyaline cartilage, which first appears at the posterolateral surface, continues to form and becomes the skeletal component of the upper end of the condyloid process. Its articular or growing surface remains covered by and continuous with a fibrocellular tissue. This hyaline cartilage becomes the
new condylar growth tissue. It grows both interstitially and appositionally. While new cartilage is formed at the fibrocellular articular surface, the older cartilage at the marrow tissue surface is mineralized, eroded, and replaced by osseous tissue. This growth process continues throughout the prenatal period and contributes to the increase in height of the ramus and to the increase in the overall length of the mandible half.

The primordial articular disk is distinct before the skeletal components reach the articular level and long before cavitation takes place. It makes its appearance as a condensation of the interzonal mesenchyme just above the level of the growing condylar surface. It is significant that the shape of the disk at this time is similar to the shape it has after cavitation. From a narrow middle portion it spreads out toward the periphery. The upper and lower surfaces conform to those of the adjacent skeletal component. This conformity of surfaces may be the result of intra-articular compression as postulated by several observers.

The proximal part of Meckel's cartilage and lateral pterygoid muscle are constantly associated with first the interzonal mesenchyme and later the articular disk. This part of Meckel's cartilage serves as an anchoring structure for the posterior portion of the primordial disk and the posterior tendinous extension of the lateral pterygoid
muscle. Both the cartilage and muscle tissues aid in the positioning and shaping of the articular disk. The lateral pterygoid muscle tendon also contributes to the anteromedial part of the disk.

There are several explanations of cavitation within the temporomandibular joint region based on histologic findings. Cavitation, as observed in this study, appears to be a biomechanical process. It is initiated by physiologic stresses and strains caused by the differential and directional growth of the joint structures. The primordial disk mesenchyme is placed under tension created by the directional growth of the proximal part of Meckel's cartilage and tendinous extension of the lateral pterygoid muscle. Posterosuperior and lateral growth of the condyloid process produces a shearing action on the loose mesenchyme immediately below the primordial disk and outside the field of tension. This causes physiologic tearing of the loose mesenchymal tissue, initiating cavitation.

The upper joint cavity is created by the forward growth of the squama and its shearing action on the loose mesenchyme above the articular disk.

The appearance of the lower joint cavity before the upper, as observed in this and other studies, may be explained by the rapid and advanced growth of the lower skeletal component over the upper.
SUMMARY AND CONCLUSIONS

The purpose of this study was threefold: (a) to determine the role and fate of Meckel's cartilages, (b) to observe the growth pattern of the fetal mandible, (c) to determine the histogenesis of the condyloid process and related temporomandibular joint structures.

1. Meckel's cartilages serve as orientation and anchoring structures of the first visceral arch.

2. The anterior portion of Meckel's cartilages serves as a temporary lingual alveolar wall for the anterior part of the fetal mandible. This part of the cartilages also serves as a secondarily incorporated growth apparatus at the medial end of each mandible half.

3. The proximal end of Meckel's cartilages is the cartilaginous model for the malleus ossicle and serves as an anchoring structure for the primordial articular disk and lateral pterygoid muscle.

4. The intermediate portion of Meckel's cartilages retrogresses or reorganizes to become the sphenomandibular and anterior malleolar ligaments.
5. The mandible arises from paired intramembranous ossification centers. Its direction and rate of growth are indicated by its bone tissue compactness.

6. The mandible acquires secondary cartilage masses during its development which alter its tissue pattern and take part in its growth and development.

7. The condyloid process first makes its appearance as an osseous expansion of the posterior end of the outer mandibular plate. In subsequent stages of development the condyloid process continues formation first as secondary cartilage and later as true hyaline cartilage. This hyaline cartilage serves as the secondary growth tissue of the mandible. The evolvement of these tissues appears to be associated with the environmental conditions existing in the temporomandibular joint region at a particular time.

8. The articular disk makes its appearance early as a condensation of the interzonal mesenchyme. Only its anteromedial part is formed by the lateral pterygoid muscle tendon.

9. It is suggested that cavitation in the temporomandibular joint region appears to be a biomechanical process.
BIBLIOGRAPHY


Figures 1 to 99 are successive, anterposterior, frontal planes of the 30 mm. specimen.

Figure 1. Region of labial vestibular lamina.

Figure 2. Region of deciduous central incisor tooth germs.

Figure 3. Region just posterior to central tooth germs. Note zones of mesenchymal tissue between mandible halves.

Figure 4. Higher magnification of midline area of figure 3.

Figure 5. Region of deciduous lateral incisor tooth germs.

Figure 6. Higher magnification of left side of figure 5.

B mandible
ll lower lip
M Meckel's cartilage (anterior tips)
S bony splint extension of mandible
t tooth germs (central incisor)
T tongue
V vestibular lamina (labial)
Figures 7, 9 and 11. Region of the deciduous lateral incisor tooth germs.

Figures 8, 10 and 12. Higher magnifications of left side of figure to the left. Note interdigitation of bone and cartilage, and the arrangement of the chondrocytes.

B  mandible
M  Meckel's cartilage
t  tooth germs (lateral incisor)
T  tongue
V  vestibular lamina
Figures 13, 15 and 17. Region of the deciduous cuspid tooth germs.

Figures 14, 16 and 18. Higher magnifications of left side of figures to the left.

B mandible
i inferior dental nerve
M Meckel's cartilage
t tooth germ (cuspid)
T tongue
V vestibular lamina
Figures 19, 21 and 22. Regions just posterior to the cuspid tooth germs.

Figures 20, 22 and 24. Higher magnifications of left side of figures to the left. Note the expanded medial plate of the mandible and the continuous apposition of bone and cartilage.

B mandible
d dental lamina
M Meckel's cartilage
T tongue
Figures 25, 27 and 29. Regions just anterior to the deciduous first molar tooth germs. Note the mental foramen at the lower part of the lateral plate (figs. 27 and 29), and the relation of the genioglossus (gg) and geniohyoid (gh) to the cartilage (fig. 29).

Figure 26. Higher magnification of left side of figure 25. Note the osteoid bridge (O) across the interior of mandible.

Figure 28. Higher magnification of left side of figure 27. Arrow points to mental foramen.

Figure 30. Higher magnification of cartilage and muscle tissue of left side of figure 29.

B mandible (lateral and medial plates)
cs cartilage sheath
d dental lamina
gg genioglossus muscle
gh geniohyoid muscle
M Meckel's cartilage
O osteoid bridge
T tongue
Figure 31. Mid region of the mental foramen. Arrow passes through mental foramen.

Figure 32. Higher magnification of cartilage and adjacent bone of figure 31.

Figure 33. Posterior region of mental foramen. Note that the cartilage and bone do not contact.

Figure 34. Higher magnification of Meckel's cartilage and medial plate of mandible of figure 33. Note the spicular formation of bone at the crest of the medial bony plate.

B mandible
cs cartilage sheath
d dental lamina
gg genioglossus muscle
gh geniohyoid muscle
i inferior dental nerve
M Meckel's cartilage
m mental nerve
T tongue
Figure 35. Region of the deciduous first molar tooth germs. Note the mylohyoid extending from one cartilage mass to the other.

Figure 36. Higher magnification of left side of figure 35. Note the connection between the mylohyoid fibers and the cartilage sheath.

Figure 37. Posterior region of the deciduous first molar germ.

Figure 38. Higher magnification of Meckel's cartilage and medial plate of mandible of figure 37.

B mandible
dm digastric muscle
gg genioglossus muscle
gh geniohyoid muscle
i inferior dental nerve
M Meckel's cartilage
mh mylohyoid muscle
t tooth germ (first molar)
T tongue
Figure 39. Region of the deciduous second molar tooth germ.

Figure 40. Higher magnification of cartilage region of figure 39. Note the thinness of the bony medial plate.

Figure 41. Region of the posterior extension of the dental lamina.

Figure 42. Region just posterior to the dental lamina.

B mandible
d dental lamina
dm digastric muscle
i inferior dental nerve
m masseter muscle
M Meckel's cartilage
mh mylohyoid muscle
p palatine process
t tooth germ (second molar)
T tongue
z zygomatic process
Figure 43. Anterior region of the forming coronoid process.

Figure 44. Higher magnification of coronoid process region of figure 43.

Figure 45. Just posterior to region in figure 43.

Figure 46. Higher magnification of region around upper part of mandible of figure 45.

B  mandible
C  cellular condensation
i  inferior dental nerve
m  masseter muscle
M  Meckel's cartilage
mh  mylohyoid muscle
os  orbitosphenoid primordial cartilage
p  palatine process
T  tongue
tm  temporal muscle
z  zygomatic process of maxillary bone
Figure 47. Anterior region of the lateral pterygoid muscle.

Figure 48. Higher magnification of upper part of figure 47.

Figure 49. Region just posterior to region of figure 47.

Figure 50. Higher magnification of lower part of figure 49. Note the osteoid tissue bordering the inferior edge of the mandibular plate.

B  mandible
C  cellular condensation
1  inferior dental nerve
l  lingual nerve
lp lateral pterygoid muscle
m  masseter muscle
M  Meckel's cartilage
mh  mylohyoid muscle
mp  medial pterygoid muscle
os  orbitosphenoid
p  palatine process
T  tongue
tm  temporal muscle
z  zygomatic bone
Figure 51. Posterior region of the forming coronoid process.

Figure 52. Higher magnification of upper part of figure 51. Note small opening between lateral pterygoid muscle (lp) and cellular condensation (C).

Figure 53. Anterior region of the zygomatic process of the temporal bone, just posterior to region of figure 51. Note the wedge-shape of the cellular condensation over the upper part of the lateral mandibular plate.

Figure 54. Higher magnification of upper part of figure 53.

B mandible
C cellular condensation
i inferior dental nerve
l lingual nerve
lp lateral pterygoid muscle
m masseter muscle
M Meckel's cartilage
mh mylohyoid muscle
mp medial pterygoid muscle
os orbitosphenoid
tm temporal muscle
z zygomatic process of temporal bone
Figure 55. Anterior region of the forming temporomandibular joint. Note the sparse area of cells over the cellular condensation.

Figure 56. Higher magnification of upper part of figure 55. Note the small openings along the upper surface of the cellular condensation.

Figure 57. Region of temporomandibular joint more posterior to that of figure 55. Note the definite V-shaped dark band of cells forming the medial boundary of the cellular condensation.

Figure 58. Higher magnification of upper part of figure 57. Note the connection between the lateral pterygoid muscle and the lower band of cells over the cellular condensation.

a auditory tube
an inferior alveolar nerve
B mandible (lateral plate)
C cellular condensation
db dense cellular band
l lingual nerve
lp lateral pterygoid muscle
m masseter muscle
mp medial pterygoid muscle
np nasal pharynx
op oral pharynx
z zygomatic process of temporal bone
Figures 59 to 62. Regions of the posterior extent of the forming temporomandibular joint.

a auditory tube
B mandible (lateral plate)
C cellular condensation
lp lateral pterygoid muscle
m masseter muscle
M Meckel's cartilage
Mn mandibular nerve and its divisions
pa auriculotemporal nerve
sl trigeminal ganglion
tm temporal muscle
z zygomatic process of temporal bone
Figures 63 to 66. Successive posterior regions of the posterior extent of the lateral mandibular plate and the anterior regions of the cochlear portion of the otic capsule.

- a auditory tube
- B mandible (later plate)
- co cochlear portion of otic capsule
- M Meckel's cartilage
- mp medial pterygoid muscle
- og otic ganglion
- sl trigeminal ganglion
- tb squamous portion of temporal bone
- tm temporal muscle
Figure 67. The posterior or proximal part of Meckel's cartilage just before it curves back on itself.

Figures 68 and 69. Successive posterior regions of the broadened proximal portion of Meckel's cartilage which represents the malleus anlage (Mm). Note the appearance of the immature bone tissue of the anterior process of the malleus (A) in figure 69.

Figure 70. Region just posterior to that of figure 69 showing the anterior most part of the incus anlage (ia).

Figure 71. Higher magnification of incus anlage area of figure 70. Note the disk of cells between the incus and malleus models.

Figure 72. Higher magnification of anterior process of malleus of figure 70.

Figures 73 and 74. Successive posterior regions to that of figure 70.

Figure 75. Higher magnification of squamotemporal bone (tb), incus anlage (ia) and malleus anlage (Mm) of figure 74.

A anterior process of malleus
a auditory tube
co cochlear portion of otic capsule
e external auditory meatus
M Meckel's cartilage
Mm malleus anlage (proximal end of Meckel's cartilage)
s1 trigeminal ganglion
tb squamous portion of temporal bone
tm temporal muscle
Figures 76 to 82. Successive posterior regions of the posterior extent of the proximal part of Meckel's cartilage or malleus anlage (Mm). The anterior part of the vestibular portion of the otic capsule (vo) appears in figure 79.

Figures 83 to 87. Posterior regions of the incus anlage (ia). Note that in these regions the incus anlage curves around a downward extension (oe-figure 87) of the vestibular otic capsule.

- a auditory tube
- co cochlear portion of otic capsule
- e external auditory meatus
- ia incus anlage
- Mm malleus anlage
- oe extension of vestibular portion of otic capsule
- tb squamous portion of temporal bone
- vo vestibular portion of otic capsule
Figure 88. Region just posterior to that of figure 87. Note the union between the lateral segment of the incus anlage and otic extension.

Figure 89. Higher magnification of lateral segment of incus anlage (ia) and otic extension of figure 88. Note the direct cartilaginous union of the two cartilage masses.

Figure 90. Region just posterior to that of figure 88. Note the apposition of the medial incus anlage segment with the stapedial anlage (st).

Figure 91. Higher magnification of lateral incus anlage segment (ia) and otic extension of figure 90. Note that the two cartilaginous masses remain in direct union.

Figure 92. More posterior to region of figure 90. Note that the lateral segment of the incus anlage (ia) is still present and remains united with the otic extension (oe).

Figure 93. Higher magnification of lateral segment of incus anlage (ia) and otic extension (oe) of figure 92. Note that the direct cartilaginous union of the two masses still persists.

Figures 94 to 99. Regions through the termination of the lateral segment of the incus anlage (ia). Note that the lateral segment of the incus anlage remains in direct union with the otic extension throughout its extent.

a auditory tube
ia incus anlage (two parts)
oe extension of vestibular portion of otic capsule
st stapedial anlage
vo vestibular portion of otic capsule
Figure 100. Graphic reconstruction, seen from above, of Meckel's cartilage and outer and inner plates of the mandible halves of the 30 mm. specimen.
Figures 1' to 12' are successive, lateromedial, sagittal planes through the anterior part of the mandible and Meckel's cartilage of the 50 mm specimen.

Figure 1'. Lateral most side of the anterior part of Meckel's cartilage encased in the bony splint extension of the mandible. Note the mineralized cartilage matrix.

Figure 2'. Section medial to figure 1' showing the medial extent of the degenerating process within the anterior part of Meckel's cartilage.

Figure 3'. A more medial section showing the degenerating part of Meckel's cartilage and its posterior unmineralized continuation. Note the evacuated area within the degenerated cartilage part.

Figure 4'. Higher magnification of the mineralized cartilage and evacuation site of figure 3'. Arrow points to the osteogenic, vascular tissue which penetrates the bony splint and enters the evacuation site.

Figure 5'. Section medial to the evacuation site and still in the same plane as the posterior, unmineralized continuation of Meckel's cartilage.

Figure 6'. Medial continuation of the mineralized anteromedial part of Meckel's cartilage.

B anterior part of mandible
M anterior part of Meckel's cartilage
S bony splint extension of mandible
t the deciduous cuspid tooth germ
Figure 7'. Region of deciduous lateral tooth germ showing the extent of mineralization in the anteromedial part of Meckel's cartilage and its position as the temporary lingual plate of the anterior part of the mandible.

Figure 8'. Higher magnification of the lower part of Meckel's cartilage of figure 7'. Note the association of the bony splint extension (S) of the mandible to the mineralized matrix of Meckel's cartilage.

Figure 9'. Over all mid-sagittal section of the lower jaw. Note the relationship of the labial plate of the mandible and the anteromedial part of Meckel's cartilage to the genioglossus (gg), geniohyoid (gh), and mylohyoid muscles (mh).

Figure 10'. Higher magnification of the bony splint and most medial extent of degeneration in Meckel's cartilage at this stage of development.

Figure 11'. Over all section of the lower jaw just lateral to the midline. Region of deciduous central tooth germ.

Figure 12'. Higher magnification of the lower part of Meckel's cartilage of figure 11'. Note the unmineralized matrix and cellular arrangement.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>B</td>
<td>Labial plate of the anterior part of mandible</td>
</tr>
<tr>
<td>gg</td>
<td>Genioglossus muscle</td>
</tr>
<tr>
<td>gh</td>
<td>Geniohyoid muscle</td>
</tr>
<tr>
<td>h</td>
<td>Cartilaginous hyoid</td>
</tr>
<tr>
<td>M</td>
<td>Anteromedial part of Meckel's cartilage</td>
</tr>
<tr>
<td>mh</td>
<td>Mylohyoid muscle</td>
</tr>
<tr>
<td>S</td>
<td>Bony splint extension of mandible</td>
</tr>
<tr>
<td>T</td>
<td>Tongue</td>
</tr>
<tr>
<td>t</td>
<td>Germ of deciduous lateral and central teeth</td>
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Figures 13' to 41' are successive, lateromedial, sagittal sections through the temporomandibular joint region of 50 mm. specimen.

Figures 13' to 15'. Lateromedial planes of the coronoid process.

Figure 16'. Higher magnification of upper end of coronoid process shown in figure 15'.

Figures 17' and 18'. Most medial region of the coronoid process. Arrows point to coronoid notch.

B mandible
m masseter muscle
tb squamous portion of temporal bone
tm temporal muscle
z zygomatic process of temporal bone
Figures 19', 21' and 23'. Lateromedial planes through the lateral temporomandibular joint region. Note dense mesenchymal tissue between the condyloid process (cp) and squamotemporal bone (tb). Also note relation of incus anlage (ia) to condyloid process.

Figures 20', 22' and 24'. Higher magnifications of posterior most end of condyloid process of figure to the left. Note character of cells and matrix.

AM angle of mandible

cp condyloid process

e external auditory meatus

i inferior dental nerve

ia incus anlage

tb squamous portion of temporal bone

tm temporal muscle
Figures 25' and 27'. Mid-lateral side of the temporomandibular joint region. Note dense arrangement of cells along proximal surface of condyloid process (cp).

Figures 26' and 28'. Higher magnification of interzonal mesenchyme and proximal end of the condyloid process of figures to the left. Note cellular and matrix arrangement of condyloid process.

Figure 29'. Region of the angle of the mandible (AM). This and figure 27' are in the same sagittal plane.

AM  angle of mandible
B  inferior side of the outer mandibular plate
cp  condyloid process
ia  incus anlage
M  Meckel's cartilage
tb  squamous portion of temporal bone
tm  temporal muscle
Figures 30' and 32'. Middle sections of the temporomandibular joint region. Note relation of incus (ia) and malleus (Mm) cartilage models to condyloid process (cp).

Figures 31' and 33'. Higher magnifications of interzonal tissue and proximal part of condyloid process of figures to left.

Figure 34'. Mid-medial plane of the temporomandibular joint region. Note position of most proximal end of Meckel's cartilage (Mm). Also note position of the lateral pterygoid muscle (lp) and its relation to the condyloid process (cp).

Figure 35'. Higher magnification of condyloid process in figure 34'.

AM angle of mandible
B mandible
cp condyloid process
ia incus anlage
lp lateral pterygoid muscle
lpp lateral pterygoid plate
M Meckel's cartilage
Mm malleus anlage (proximal of Meckel's cartilage)
tb squamous portion of temporal bone
tm temporal muscle
Figures 36' and 38'. Region of the most medial side of the condyloid process (cp). Note hook-like process (Mm) of the proximal end of Meckel's cartilage. Also note position of lateral pterygoid muscle (lp) and its relation to medial side of the condyloid process and to Meckel's cartilage.

Figures 37' and 39'. Higher magnification of the condyloid process region of figures to left. Note connection of lateral pterygoid tendon (lpt) to sheath of Meckel's cartilage.

Figure 40'. Region just medial to plane of figure 38'.

Figure 41'. Region just medial to that of figure 40', showing position of the anterior process of malleus (A) and its relation to Meckel's cartilage.

A anterior process of malleus
B mandible
cp condyloid process
ia incus anlage
lp lateral pterygoid muscle
lpp lateral pterygoid plate
lpt lateral pterygoid tendon
M Meckel's cartilage
Mm malleus anlage
mp medial pterygoid muscle
ty head of tympanic bone
vo vestibular portion of otic capsule
Figure 1a. Frontal section through midline portion of mandibles (B) and Meckel's cartilages (M) of 110 mm. specimen. Note relation of cartilages to each other and to symphysial tissue (Sy).

Figure 2a. Higher magnification of distal ends of Meckel's cartilages seen in figure 1a. Note "disk" of cells between cartilages and arrangement of chondrocytes.

Figure 3a. Frontal section just posterior to that shown in figure 1a.

Figure 4a. Higher magnification of encased portion of Meckel's cartilage of figure 3a. Note calcified matrix, opened lacunae, and vascular connective tissue in former site of cartilage. Also note the bony splint extension of the mandible (s) and its relation to the cartilage.

Figure 5a. Frontal section just posterior to that of figure 3a.

Figure 6a. Higher magnifications of incorporated part of Meckel's cartilage shown in figure 5a. Arrow points to calcified cartilage matrix remnant. Note size and arrangement of lacunae at this site.

B  anterior part of mandible halves
s  bony splint or collar extension of mandible
Sy  symphysial connective tissue
Figure 7a. Frontal section of encased lateral side of the anterior part of Meckel's cartilage of 113 mm. specimen. Note medial extent of bony splint (s).

Figure 8a. Frontal section of the anterior portion of the distal part of Meckel's cartilage of 115 mm. specimen. Arrow points to calcified cartilage matrix remnant.

Figure 9a. Frontal section through posterior portion of distal part of Meckel's cartilage of 115 mm. specimen. Arrow points to bony spicule in evacuation site. Note that bony collar splint outlines area that was formerly occupied by cartilage.

Figure 10a. Frontal section through plane of deciduous lateral incisor tooth germs of 120 mm. specimen. Arrows point to medial ends of Meckel's cartilages.

Figure 11a. Higher magnification of evacuation site seen at left side of figure 10a. Arrows point to calcified cartilage remnants encrusted with bone tissue. Note extent of evacuation site (endochondral process) to lateral side of symphysial tissue (Sy).

Figure 12a. Frontal section through medial (anterior ends of Meckel's cartilages of 125 mm. specimen. Note shape of cartilage and size of chondrocytes.

B anterior part of mandible halves
M anterior part of Meckel's cartilage
s bony splint of mandible
Sy symphysial tissue
T tongue
t deciduous lateral incisor tooth germ
Figure 13a. Frontal section through midline ends of Meckel's cartilages of 130 mm. specimen. Note shape of cartilages.

Figure 14a. Frontal section through midline ends of Meckel's cartilages of 135 mm. specimen.

Figure 15a. Frontal section through anterior part of medial end of Meckel's cartilage of 165 mm. specimen.

Figure 16a. Frontal section through posterior part of medial end of Meckel's cartilage of 165 mm. specimen. Note how the indistinct cartilage mass appears to "blend" with the surrounding symphysial tissue (Sy).

B anterior end of mandible halves

M medial (anterior) ends of Meckel's cartilages

Sy symphysial tissue
Figure 17a. Frontal section through anterior part of the posterior continuation of Meckel's cartilage (right side) of 115 mm. specimen.

Figure 18a. Higher magnification of area of Meckel's cartilage seen in figure 17a. Note the relation of the cartilage sheath (cs) to the periosteum of the mandible (B).

Figure 19a and 20a. Frontal sections through region just posterior to that of figure 17a. Note double masses of cartilage which demonstrate the hook-like bend of this part of the cartilage. Ma is the anterior part of bend. Mp is the posterior continuation to the tympanic cavity.

B mandible
cs cartilage sheath
dm digastric muscle
M Meckel's cartilage
mh mylohyoid muscle
Figure 21a to 24a. Frontal sections, from deciduous first molar region to lingula of mandible of 115 mm. specimen.

Figure 21a. Region of deciduous first molar. Note relation of mylohyoid muscle (mh) to periosteum of mandible and to Meckel's cartilage.

Figure 22a. Region just posterior to figure 21a. Note position of Meckel's cartilages in groove along medial side of mandible.

Figure 23a. Region just anterior to lingula of mandible.

Figure 24a. Region of lingula of mandible (LM).

B mandible half (right)
i inferior dental nerve
l lingual nerve
LM lingula of mandible
M Meckel's cartilage
mh mylohyoid muscle
Figure 25a. Sagittal section showing posterior portion of Meckel's cartilage in region of mandible.

Figure 26a. Sagittal section showing posterior portion of Meckel's cartilage in region of mandible of 165 mm. specimen. Note nodular swellings in cartilage and enlarged lacunae.

Figure 27a. Sagittal section showing posterior portion of Meckel's cartilage in region of mandible of 180 mm. specimen. Note the grouping of the enlarged chondrocytes and the continuation of the cartilage sheath with the periosteum.

Figure 28a. Sagittal section showing posterior portion of Meckel's cartilage in region of mandible of 190 mm. specimen. Note changes in cartilage mass and compare to previous figures.

B mandible half
M Meckel's cartilage
Figures 29a to 34a. Successive, lateromedial, sections through the proximal part of Meckel's cartilage, in region of temporomandibular joint, of 75 mm. specimen.

Figure 29a. Region of medial side of condyloid process (cp). Note relation of posterior part of articular disk (d) to sheath of proximal (malleolar) and of Meckel's cartilage (Mm).

Figure 30a. Higher magnification of posterior portion of disk and malleolar end of Meckel's cartilage of figure 29a.

Figure 31a. Region of lateral pterygoid muscle (lp) and tendon (lpt), showing their relation to proximal part of Meckel's cartilage.

Figure 32a. Higher magnification of lateral pterygoid tendon (lpt) area of figure 31a, showing relation of tendon fibers to sheath of malleolar end of Meckel's cartilage (Mm).

Figure 33a and 34a. Sections just medial to those of figure 31a, showing portion of Meckel's cartilage that lies just outside of tympanic cavity.

A anterior process of malleus

cp medial part of condyloid process

d articular disk

uc upper joint cavity

lp lateral pterygoid muscle

lpt lateral pterygoid tendon

M Meckel's cartilage

Mm malleolar end of Meckel's cartilage

th squamous portion of temporal bone

ty head of tympanic bone
Figure 35a. Sagittal section, of 90 mm. specimen, through medial part of condyloid process (cp) showing posterior extent of articular disk passing through opening (fissure) between squamotemporal bone (tb) and tympanic bone (ty) into tympanic cavity.

Figure 36a. Sagittal section, medial to that of figure 35a, through region of lateral pterygoid muscle (lp) and tendon (lpt). Note tendon passes, posteriorly, through opening between the squamotemporal bone (tb) and tympanic bone (ty).

Figure 37a. Sagittal section, of 120 mm. specimen, through medial part of condyloid process (cp) showing relation of disk (d) to opening between the squamotemporal bone (tb) and tympanic bone (ty).

Figure 38a. Sagittal section, medial to that of figure 37a, through region of lateral pterygoid muscle (lp) and tendon (lpt). Note position and character of tendon.

- cp: medial part of condyloid process
- d: articular disk
- uc: upper joint cavity
- lc: lower joint cavity
- lp: lateral pterygoid muscle
- lpt: lateral pterygoid tendon
- M: Meckel's cartilage
- tb: squamotemporal bone
- ty: tympanic bone
Figure 39a. Overall sagittal section, of 60 mm. specimen, through posterior continuation of Meckel's cartilage.

Figure 40a. Sagittal section, just medial to that of figure 39a, through malleolar end of Meckel's cartilage.

Figure 41a. Sagittal section, of 115 mm. specimen, through malleolar end of Meckel's cartilage. Arrow points to degeneration site.

Figure 42a. Sagittal section, of 120 mm. specimen, through malleolar end of Meckel's cartilage. Arrow points to degeneration site. Note position of anterior malleolar process (A).

Figure 43a. Horizontal section, of 165 mm. specimen, at plane of lateral pterygoid muscle (lp) through temporomandibular joint and tympanic cavity regions. Note relation of lateral pterygoid muscle (lp) and articular disk (d) to proximal (malleolar) end of Meckel's cartilage.

Figure 44a. Higher magnification of proximal portion of Meckel's cartilage. From same general region as in box seen in figure 43a. Note indistinct cartilage matrix and how it "blends" with surrounding connective tissue.

A  anterior malleolar process  M  Meckel's cartilage
B  mandible  Mm  malleus anlage
cp  condyloid process  mo  malleus ossicle
d  articular disk  mp  medial pterygoid muscle
ia  incus anlage  oc  oral cavity
io  incus ossicle  T  tongue
lp  lateral pterygoid muscle  tb  squamotemporal bone
m  masseter muscle  ty  tympanic bone
Figure 45a. Sagittal section, of 75 mm. specimen, showing Meckel's cartilage extending from region of the lingula of the mandible (LM).

Figure 46a. Higher magnification of lingula region of figure 45a. Note relation of cartilage sheath to periosteum of lingula portion of the mandible (LM).

Figure 47a. Sagittal section, of 180 mm. specimen, through Meckel's cartilage in region of the lingula of the mandible. Note character of the cartilage and its relation to the periosteum.

Figure 48a. Sagittal section, of 190 mm. specimen, through proximal end of mandible and tympanic cavity. Note relation of Meckel's cartilage to lingula. Also note extent of endochondral ossification of malleus (mo).

Figure 49a. Higher magnification of remnant of cartilage shown in left box of figure 48a; region of lingula.

Figure 50a. Higher magnification of same general area outlined in right box of figure 48a, region of lingula.

cp condyloid process
cm coronoid process
cs cartilage sheath
d articular disk
io incus ossicle
LM lingula of mandible
M Meckel's cartilage
mo malleus ossicle
mp medial pterygoid muscle
tb squamous portion of temporal bone
ty tympanic bone
Figure 1b. Frontal section, of 90 mm. specimen, through region of the deciduous cuspid tooth germ (t). Note secondary cartilage (sc) at crest of mandible.

Figure 2b. Higher magnification of region just posterior to crestal area of figure 1b. Note size and arrangement of secondary cartilage cells and relation of cartilage matrix to bone tissue matrix.

Figure 3b. Higher magnification of crestal region of opposite mandible half of figure 1b. Arrows point to osteoclasts along dental sac (ds) surface of secondary cartilage.

Figure 4b. Frontal section just posterior to that of figure 3b. Arrow points to osteoclast.

Figures 5b and 6b. Frontal sections, of 90 mm. specimen, through the inferomedial parts of the mandible halves at the symphysis (Sy). Note character of secondary cartilage and its relation to the bone tissue matrix.

ds dental sac
Sc secondary cartilage
Sy symphsial connective tissue
t deciduous cuspid tooth germ
Figure 7b. Frontal section, of 90 mm. specimen, through symphysial (middle) region. Note relation of symphysial tissue to marrow tissue of mandible halves.

Figure 8b and 9b. Successive frontal sections, of 115 mm. specimen, through symphysial region. Note increased vascularity of the region.

Figure 10b. Frontal section, of 120 mm. specimen, through symphysial region. Note the three vertical zones of the region.

B medial ends of mandible halves

Sy symphysial tissue
Figure 11b. Frontal section, of 115 mm. specimen, through second deciduous molar region of right mandible half. Note difference in bone tissue compactness of the inferior part of the mandible.

Figure 12b. Higher magnification of inferomedial part of mandible that is just posterior to plane of figure 11b. Note trabecular pattern at medial side and its relation to Meckel's cartilage.

Figure 13b. Frontal section, of 125 mm. specimen, through deciduous cuspid region of right mandible half. Note the bone pattern. Also note diminished size of Meckel's cartilage and its position.

Figure 14b. Frontal section, of 125 mm. specimen, through mental foramen region. Arrow points to mental nerve and foramen.

B  mandible
i  inferior dental nerve
M  Meckel's cartilage
mh  mylohyoid muscle
t  tooth germs
Figure 15b. Sagittal section, of 90 mm. specimen, through coronoid process showing secondary cartilage (Sc).

Figure 16b. Higher magnification of upper part of coronoid process of figure 15b. Note character of secondary cartilage and compare to that of the condyloid process in figure 23c.

Figure 17b. Sagittal section, of 125 mm. specimen, through coronoid process showing secondary cartilage (Sc).

Figure 18b. Higher magnification of lower, interior end of coronoid process of figure 17b. Arrow points to osteoclasts along inner surface of the secondary cartilage.

Sc  secondary cartilage

tm  temporal muscle
Figures 1c to 13c are successive, lateromedial, sagittal sections through the temporomandibular joint region of 60 mm. specimen.

Figure 1c. Sagittal section through lateral side of condyloid process.

Figure 2c. Higher magnification of young condylar hyaline cartilage seen in figure 1c.

Figure 3c. Section medial to that of figure 1c showing the hyaline cartilage merging medially with the secondary cartilage core.

Figure 4c. Higher magnification of secondary cartilage (Sc) and hyaline cartilage (hc) seen in figure 3c.

Figure 5c. Section through temporomandibular joint region at plane of coronoid process (cm).

Figure 6c. Sagittal just medial to that of figure 5c.

cp condyloid process
-cr coronoid process
d articcular disk
hc condylar hyaline cartilage
lc lower joint cavity
m masseter muscle
tb squamous portion of temporal bone
tm temporal muscle
Figure 7c. Sagittal section through temporomandibular joint region, just medial to plane of figure 6c. Note shape and position of the primordial articular disk (d).

Figure 8c. Higher magnification of area around the lower joint cavity (lc) of figure 7c. Note cellular arrangement in condyloid process and in interzonal area.

Figure 9c. Higher magnification of area around lower joint cavity of region just medial to that of figure 8c. Note strands of cells that cross lower joint cavity (lc).

Figure 10c. Overall, sagittal section of the right mandible half; plane medial to that of figure 7c. Note relation of the anterior and posterior portions of Meckel's cartilage to the mandible, and the position of the angle of the mandible (AM).

Figure 11c. Higher magnification of condyloid process region of figure 10c. Note relation of lateral pterygoid muscle (lp) to upper, anterior end of the condyle.

Figure 12c. Medial to figure 11c showing relation of lateral pterygoid muscle (lp) to medial portion of condyloid process.

Figure 13c. Medial to figure 12c showing relation of lateral pterygoid muscle to lateral side of condyle and to articular disk.

AM angle of mandible
B mandible
cp condyloid process
d articular disk
lc lower joint cavity
lp lateral pterygoid muscle
M Meckel's cartilage
oc oral cavity
tb squamous portion of temporal bone
tm temporal muscle
Figure 14c. Sagittal section, of 75 mm. specimen, through temporomandibular joint region. Note shape of articular disk, and upper and lower joint cavities.

Figure 15c. Higher magnification of disk area of figure 14c. Note the similar histologic features of the disk and covering (articular) surface of the condyloid process.

Figure 16c. Sagittal section, of 75 mm. specimen, through the angle of the mandible (AM) and temporomandibular joint region. Note the position of the malleolar end of Meckel's cartilage and its relation to the articular disk (d).

Figure 17c. Higher magnification of the secondary cartilage core of the condyloid process seen in figure 16c.

Figure 18c. Higher magnification of the proximal end of the condyloid process of figure 17c. Note the zonal (1,2,3) arrangement of the condyloid cells and matrix.

Figure 19c. Higher magnification of the deep end of the condyloid secondary cartilage (Sc) of figure 17c. Note histologic features of the secondary cartilage and its relation to the osseous condylar collar (o).

AM angle of mandible
cp condyloid process
d articular disk
ia incus anlage
lc lower joint cavity
Mm malleus anlage
o osseous condylar collar
Sc secondary cartilage
tb squamotemporal bone
tm temporal muscle
uc upper joint cavity
Figures 20c to 25c are successive, sagittal sections through the lateral portion of the condyloid process of the 90 mm. specimen.

Figures 20c and 21c. Note the size and arrangement of the young cartilage cells. Also note evidence of proliferation.

Figures 22c and 23c. Mid-lateral region of the condyloid process showing the size gradation of the chondrocytes, and the matrix passing from uncalcified to calcified tissue.

Figures 24c and 25c. Sagittal sections, medial to figure 22c. Figure 24c shows the young chondrocytes at the proximal end of the process. Figure 25c, same plane as figure 24c, shows the deep end of the process; note opened lacunae and calcified cartilage fragments surrounded by loose connective tissue.

\begin{itemize}
\item \textit{cp} condyloid process
\item \textit{d} articular disk
\item \textit{uc} upper joint cavity
\end{itemize}
Figure 26c. Sagittal section, of 90 mm. specimen, through the angle of the mandible (AM) and temporomandibular joint region. Note position of the angle in relation to the condyloid process.

Figure 27c. Sagittal section, medial to that of figure 26c, of the temporomandibular region. Note the young hyaline cartilage forming upper end of condyle and the evacuated area below. Arrow points to secondary cartilage remnants.

Figure 28c. Sagittal section through the deep end of the condyloid process, just medial to figure 27c. Arrow points to the blood vessels entering the evacuation site. Note the secondary cartilage remnants (Sc).

Figure 29c. Lateral view of the proximal end of the mandible half of the cleared 100 mm. specimen. Note the gross outline of the condyloid process and its relation to the angle (AM).

AM  angle of mandible

cp  condyloid process

cr  coronoid process

d  articular disk

o  osseous collar of condyloid process

Sc  secondary cartilage

tb  squamous portion of temporal bone
Figure 30c. Sagittal section, of 120 mm. specimen, through regions of the angle and temporomandibular joint. Note position of the angle of mandible.

Figure 31c. Higher magnification of the proximal end of the condyle, of figure 30c, showing size gradation and arrangement of the chondrocytes.

Figure 32c. Sagittal section, medial to that of figure 30c, of the deep region of the condylar hyaline cartilage (hc). Note calcified cartilage remnants and vascular tissue (vc).

Figure 33c. Sagittal section, medial to that of figure 32c, of the region above the angle (AM) showing the hematopoietic tissue (hc). Note osseous condylar collar (o).

AM  angle of mandible
cp  condyloid process
cr  coronoid process
d   articular disk
h   hematopoietic tissue
hc  condylar hyaline cartilage
o   osseous condylar collar
vc  vascular connective tissue
Figure 34c. Sagittal section, of 120 mm. specimen, through proximal portion of the condyloid process. Arrow points to wedge of vascular tissue that penetrates proximal surface of the condylar hyaline cartilage.

Figure 35c. Higher magnification, medial to figure 34c, through vascular bud.

Figure 36c. Frontal section, of 165 mm. specimen, showing the medial position of the vascular bud.

Figure 37c. Higher magnification of vascular bud seen in figure 36c. Note its continuation with the articular covering and increased vascularity.

Figure 38c. Sagittal section, of 190 mm. specimen, through temporomandibular joint region. Arrow points to vascular bud.

Figure 39c. Higher magnification, medial to figure 38c, of the proximal vascular bud.

d articular disk
lc lower joint cavity
tb squamous portion of temporal bone
uc upper joint cavity
Figure 40c. Sagittal section, of 190 mm. specimen, through articular disk and proximal end of condyle.

Figure 41c. Higher magnification of middle portion of the articular disk and fibrous (articular) condylar covering of figure 40c. Note the histologic similarities of the disk and articular covering.

Figure 42c. Sagittal section, of 190 mm. specimen, showing zonal arrangement of the proximal end of the condyle.

Figure 43c. Sagittal section, of 190 mm. specimen, through deep end of the condylar hyaline cartilage. Note opened lacunae of the calcified cartilage, and calcified cartilage remnants surrounded by loose connective tissue.

Figure 44c. Sagittal section, deep to that of figure 43c, showing calcified cartilage matrix encrusted with bone tissue, at arrows.

Figure 45c. Higher magnification of the calcified cartilage matrix encrusted with bone tissue, medial to that of figure 44c. Note the degree of vascularity.

d articular disk
hc condylar hyaline cartilage
lc lower joint cavity
uc upper joint cavity
Figure 46c. Sagittal section, of 75 mm. specimen, through the squamotemporal bone (upper joint component). Note secondary cartilage tissue (Sc) encased in immature bone tissue.

Figure 47c. Sagittal section, of 90 mm. specimen, through squamotemporal bone. Note histologic features of the skeletal tissues.

Figure 48c. Sagittal section, of 120 mm. specimen, through squamotemporal bone. Note histologic features of skeletal tissues. Arrow points to vascular bud penetrating skeletal tissue from articular covering.

Figure 49c. Sagittal section, of 190 mm. specimen, through squamotemporal bone. Note histologic features of skeletal tissue and increased vascularity in region of upper articular covering.

cp condyloid process
d articular disk
lc lower joint cavity
Sc secondary cartilage
uc upper joint cavity