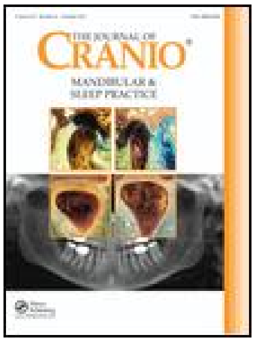

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The Embryology of the Temporomandibular Joint

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The Embryology of the Temporomandibular Joint

Abstract

This study examined 63 human fetuses, ranging in size from 4.5 to 255 mm crown-rump, to follow the embryological development of the temporomandibular joint. Sagittal, coronal, and transverse sections of the joint region were prepared and stained either in Milligan's trichrome, a connective tissue stain, or in hematoxylin and eosin. The results of the study suggest that the lateral pterygoid muscle plays a pivotal role in the histodifferentiation of the temporomandibular joint. The lateral pterygoid muscle, with its fibrous insertions onto the condylar head, malleus, and temporal bone, directly contributes to the formation of the joint's disk. The lateral pterygoid may also contribute indirectly, by mechanical stimulation, to the endochondral differentiation of the condyle and the formation of the inferior and superior joint cavities. The authors suggest that the early connection between the lateral pterygoid, condylar blastema, and Meckel's cartilage which persists throughout the development of the temporomandibular joint may serve a function other than simply reflecting a phylogenic past when the malleus served as part of the mandibular joint.

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Dr. Perry received his D.D.S. degree from Northwestern University in 1952, and his M.S.D. in orthodontics in 1954. He received his Ph.D. in 1961. His dissertation dealt with the physiology of the temporal and masseter muscles and jaw movement.

Dr. Perry has been involved in the treatment of craniomandibular disorders since 1953. He has given numerous lectures on the subject both in the United States and abroad. Dr. Perry is professor and chairman of the Department of Orthodontics at Northwestern University Dental School, a post he has held since 1961.

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Dr. Xu is a member of the Chinese Medical Association and in 1961 she was selected to the Chinese Medical Board of New York. She has written several articles dealing with the growth and development of the temporomandibular joint. She has been a visiting professor at the University of California at Los Angeles Dental School (1982-1983) and at Northwestern University (1983-1984).

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Dr. Forbes is director of the graduate orthodontic program at Northwestern. His research has involved isolating and characterizing factors that regulate osteogenesis.

The Embryology of the Temporomandibular Joint

A Study

By Harold T. Perry, D.D.S., M.S.D., Ph.D., Yinghua Xu, D.D.S., David P. Forbes, D.D.S., Ph.D.

The first evidence of the presumptive temporomandibular joint is the appearance of two distinct blastemas, one representing the anlage of the temporal portion of the joint and the other representing the anlage of the condylar portion. Baume[1,2] observed that these blastemas develop asynchronously, with the condylar blastema developing before the temporal blastema. However, by the fourth fetal month, all of the articular elements of the temporomandibular joint have differentiated.

Several investigators[3,8] have reported a connection from the TMJ disk and the lateral pterygoid muscle to the malleus. Symons[5] observed that this connection persisted to at least the 180 mm crown-rump (C.R.) stage. After birth, humans also have a tiny ligament lateral to the chorda tympani nerve which inserts into the neck of the malleus above the anterior process. Pinto[7] observed that this tiny ligament spread anteriorly, inferiorly, and laterally from the malleus to insert into the medioposterior/superior aspect of the capsule and disk of the TMJ.

In contrast, Yuodelis[9] found no evidence that the lateral pterygoid attached to the malleus or contributed to the articular disk. Van Dongen[8] felt it unlikely that one continuous system extended from the ptergyoid process to the malleus. He considered it a linking system instead.

Material and Methods

The material selected for this study was obtained from the private collection of Harold T. Perry and consisted of 63 human fetuses ranging in size from 4.5 mm to 255 mm crown-rump length. These fetuses were selected because they had excellent preservation of tissue. All the specimens were fixed in 10% phosphate buffered formalin (pH 7.0) and had been prepared for light microscopy. We serially sectioned the specimens at 6 µm thickness in the sagittal, coronal, or transverse planes (**Table 1**). We then stained the sections with Milligan's trichrome, which is a connective tissue stain, or with hematoxylin and eosin.

We evaluated chronologically the development of the connective tissues in the region of the presumptive temporomandibular joint to determine the events that occur in the development of the TMJ and to clarify the relationship of the joint with its neighboring structures. We addressed specific attention to the possible presence of structures connecting with the disk of the temporomandibular joint.

Results

As was mentioned earlier, the earliest evidence of the presumptive temporomandibular joint is the appearance of two distinct regions of mesenchymal condensation: the condylar and the temporal blastemas. We could detect these condensations in fetuses measuring 38-45 mm C.R. The condylar blastema, which preceded the temporal blastema in appearance, did not arise independently. Just superior to the condylar blastema was a band of mesenchymal cells extending from the lateral pterygoid muscle to Meckel's cartilage (**Figure 1**). At this stage, we observed no fibers in this mesenchymal band. The formation of both the condylar and the temporal blastemas was usually concurrent with the differentiation of the muscles of mastication. The temporal blastema also demonstrated earlier calcification than the condylar blastema, with calcification first occurring in the region of the zygomatic process of the temporal bone (**Figures 1 and 2**).

Initially, the condylar and temporal blastemas are positioned quite far apart. As the condylar blastema grows dorsally and laterally, this separation is rapidly reduced. This reduction in separation was apparent in the 67 mm C.R. fetus (**Figure 3**).

The formation of the inferior compartment of the joint occurred at about the 45 mm C.R. stage. At this stage, the condylar blastema still consists of mesenchymal cells, but definite orientations of these cells are becoming apparent: the superolateral portion of the condylar blastema has a higher concentration of cells than the inferomedial portion, and a perichondrium has developed. The inferomedial portion of the condylar blastema shows fibrous

Table 1
Size, Number, and Plane of Sectioning of Fetuses Evaluated

	Plane of Sectioning		
	Sagittal	Coronal	Transverse
Number of fetuses evaluated	18*	59	4
Crown-rump length range (in mm)	8-80	45-255	81-227

*In 18 fetuses, both sagittal and coronal sections were made. One lateral half of each head was serially sectioned in the coronal plane, while the other half was serially sectioned in the sagittal plane.

insertions of the lateral pterygoid muscle. The cavitation forming the inferior compartment arises between the condylar blastema and the band of mesenchymal cells that connect Meckel's cartilage with the lateral pterygoid muscle. The temporal region has lost its blastema character at this stage, due to further ossification at the zygomatic region of the temporal bone. Just inferior to this bony trabecula, a band of mesenchymal cells has formed. This is similar to the band overlying the condylar blastema, but not as dense (**Figure 2**).

After the inferior joint cavity has formed, the condylar blastema begins to calcify (**Figure 3**). We found that the calcification occurred exclusively in the marginal regions of the condylar head, and only in the inferomedial half. The superolateral half still consisted of undifferentiated mesenchymal cells. In the center of the condylar head, chondrocytes become differentiated (secondary cartilage formation). The attachment of the lateral pterygoid to the condylar head is quite different at this stage; it consists principally of a fibrous connection between the lateral pterygoid and the now-differentiated malleus (previously part of Meckel's cartilage).

The region beneath the temporal bone also consists of a fibrous band. Located between these two fibrous bands we noted a relatively acellular area, which marked the site of the presumptive superior joint cavity (**Figures 3** and **4**). The formation of the superior joint cavity occurred at about the 70 mm C.R. stage. As we indicated above, this joint cavity formed between the fibrous bands of the temporal and the condylar blastemas (**Figure 5**). Significantly, we could also detect fibrous insertions from the external pterygoid to the temporal periosteum at this stage.

As the condylar head differentiates, secondary cartilage forms mineral endochrondrally along the inferior, medial, and superior surfaces. The lateral surface does not ossify, but consists instead of undifferentiated mesenchymal cells. Inferior to the area where endochondral bone is forming, there is a zone of appositional bone formation, so that two fronts of ossification are present.

After the formation of the superior joint cavity, first the

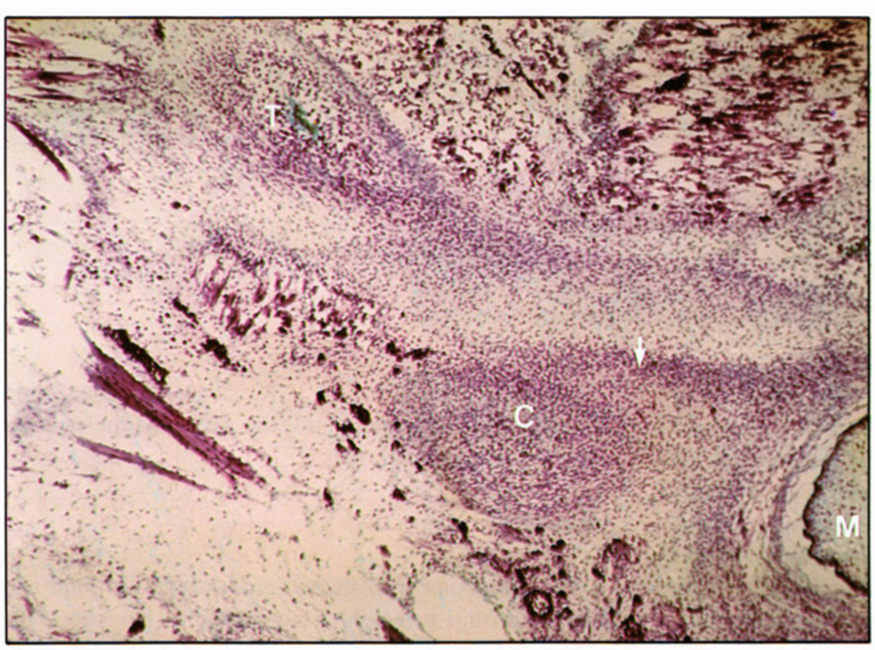

Figure 1
Sagittal section of the temporomandibular joint of a fetus, 45 mm C.R., showing the temporal (T) and condylar (C) blastemas. Note the band of mesenchymal cells (arrow) connecting the condylar blastema to Meckel's cartilage (M). The temporal blastema has started to calcify (green) in the center. Milligan's trichrome X59.5.

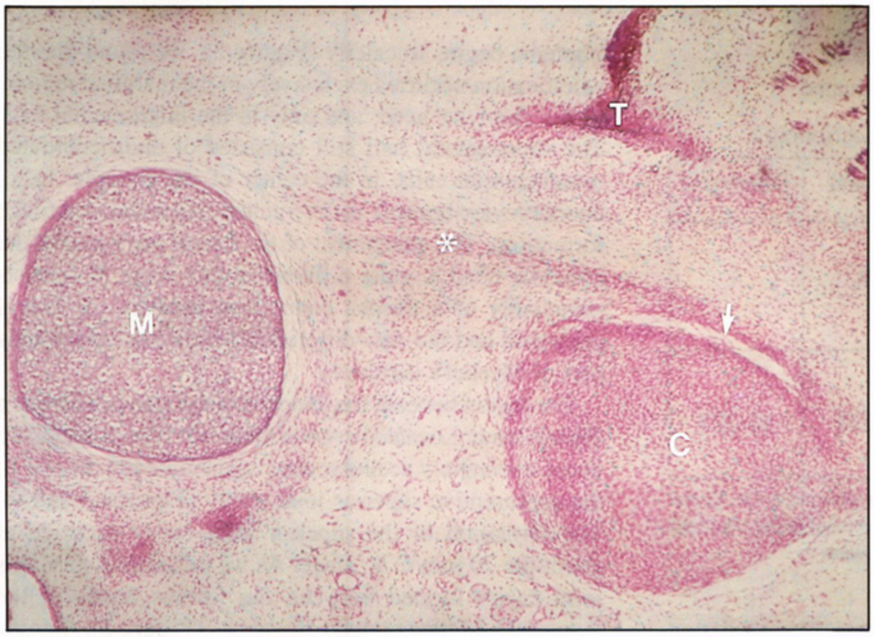

Figure 2
Sagittal section of the temporomandibular joint of a fetus, 67 mm C.R., showing the formation of the inferior joint cavity (arrow). Note that the temporal blastema (T) has differentiated into an osseous trabecula with a condensation of mesenchymal cells on its inferior surface. The condylar blastema (C) has become more organized but still consists mainly of undifferentiated cells. At the superoanterior surface of the blastema, a cavitation has formed just beneath the band of mesenchymal cells (asterisk) connecting to Meckel's cartilage (M). Hematoxylin and eosin X59.5.

Figure 3
Sagittal section of the temporomandibular joint of a fetus, 67 mm C.R., showing the temporal bone (T) with an organized band of mesenchymal cells on its inferior surface. The condylar blastema has started to ossify intramembraneously on its inferior surface (asterisk) but remains undifferentiated in the superior half. Meckel's cartilage has differentiated into the malleus (M) and the incus (I) which, at this stage, are still cartilaginous. The space separating the condylar and temporal portions of the joint has reduced. Beneath the malleus, the Eustachian tube (E) has formed. Milligan's trichrome X37.

medial half and then the lateral half of the condyle differentiate. At the attachment site of the lateral pterygoid and the disk there are areas of vascular penetration into the condyle. These irruption arteries are associated with new sites of calcification. At this stage the disk was appreciably thicker in the medial half than the lateral half (**Figures 6-9**). By the 112 mm C.R. stage, the chondrocytes of the condyle had differentiated, showing the typical banding pattern of a postfetal condyle.

As late as the 130 mm C.R. stage, the connection between the lateral pterygoid, the disk, and the malleus still persisted (**Figure 10**).

Discussion

The development of the temporomandibular joint and its relationship to neighboring structures have been the subject of much controversy. The most disagreement

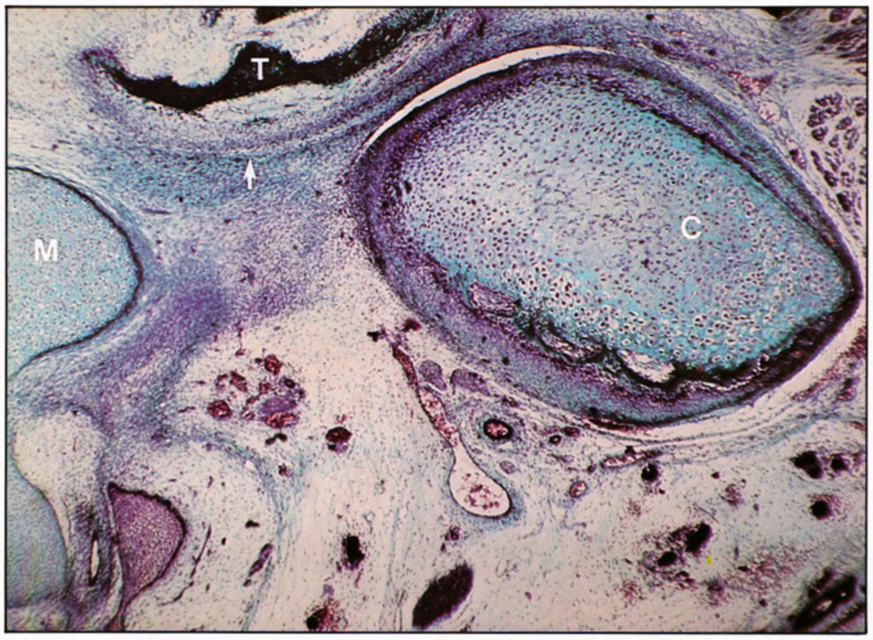

Figure 4
Sagittal section of the temporomandibular joint of a fetus, 80 mm C.R., showing the condylar (C) and temporal (T) portions of the joint in close approximation. The presumptive disk tissue is very cellular and condensed. Note the acellular zone (arrow) between the band of mesenchymal cells of the presumptive disk and the band of mesenchymal cells inferior to the temporal bone. This acellular zone marks the future site of the superior joint compartment. At this stage the condylar head has differentiated further; at the superior surface, the anterior region of the condyle has undergone secondary cartilage formation, while the posterior half is still mesenchymal. The connection of the disk to the malleus (Pinto's ligament) has become more fibrous. Milligan's trichrome X37.

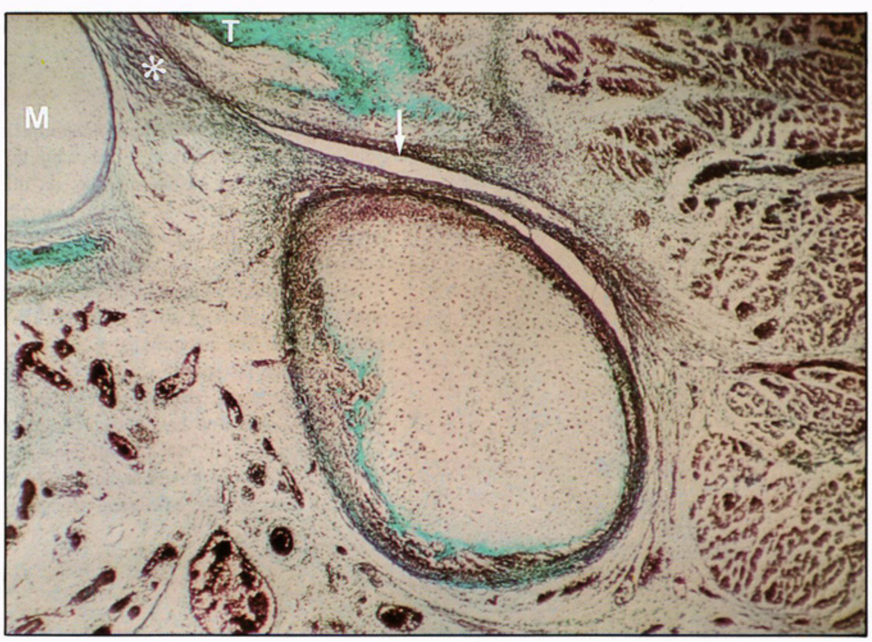

Figure 5
Sagittal section of the temporomandibular joint of a fetus, 70 mm C.R., showing the formation of the superior joint cavity (arrow) between the temporal periosteum and the fibrous connection (asterisk) from the lateral pterygoid to the malleus (M). Note that the lateral pterygoid has attachments to the temporal bone (T). Milligan's trichrome X37.

arises in determining which structures are involved in the formation of the joint and what their degrees of contribution are. Our study corroborates the findings of numerous investigators[1-8] who have reported that the TMJ arises from two distinct blastemas. These blastemas are initially separated, but later approach each other. The blastemas are preceded by the development of the muscles of mastication; the temporal blastema arises between the temporalis and masseter muscles, while the condylar blastema arises lateral to the lateral pterygoid. We do not know whether the muscles of mastication have a role in initiating blastema development. In corroboration with the findings of Baume et al.,[1,2] we found that the condylar blastema appeared before the temporal blastema. However, while we found that the temporal blastema calcified first, Yuodelis[9] reported calcification first in the condylar blastema.

A principal area of dispute in the development of the

Figure 6
Coronal section of the temporomandibular joint of a fetus, 97 mm C.R., showing thickening of the disk (asterisk) at the lateral portion. Note the irruption artery (arrow) with calcification around it. Note also the formation of the zone of hypertrophied cartilage (H). This zone is restricted to the lateral half of the condyle. Milligan's trichrome X37.

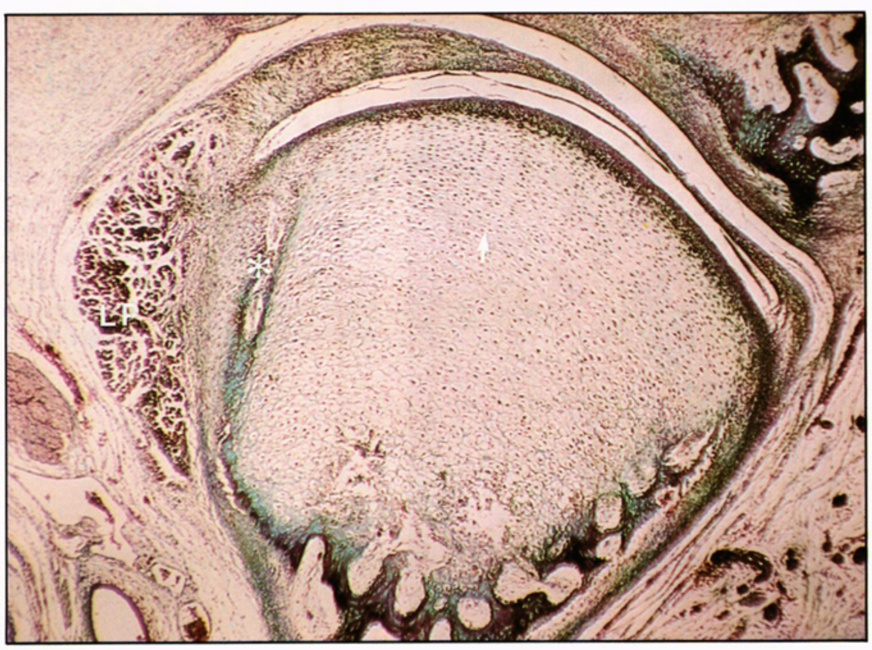

Figure 7
Coronal section of the temporomandibular joint of a fetus, 112 mm C.R., showing further differentiation of the condyle. At this time, the chondrocytes have become organized, with the superior portion of the condyle consisting of less differentiated cells arranged in thin rows (arrow), and the inferior portion consisting of hypertrophied chondrocytes. The metaphyseal region of the condylar head (asterisk) is located inferiorly and adjacent to the lateral ptergyoid muscle (LP). The lateral wall has more pronounced calcification than the medial wall. Note that the disk is markedly thinner at the lateral half than the medial half. Milligan's trichrome X37.

TMJ is whether there is a connecting system extending from the lateral pterygoid across the condylar blastema to Meckel's cartilage. Kjellberg,[3] Symons,[5] and Moffett[6] all reported on the presence of a tendinous attachment from the lateral pterygoid to the articulare (the end region of Meckel's cartilage). Yuodelis,[9] however, found no evidence to support this. Throughout the formation of the temporomandibular joint, we always noted a connection between Meckel's cartilage (the anlage for the malleus) and the lateral pterygoid. At first, this connection consisted merely of condensed mesenchymal cells that had differentiated superior to the condylar blastema. These cells looked similar to the cells of the condylar blastema. Later, as the temporomandibular joint region differentiated, we detected fibers in this connection between the lateral pterygoid and the malleus. We do not know whether the connection between these two structures merely reflects phylogenically a relocation in the mammalian joint

Figure 8
Transverse section of the temporomandibular joint of a fetus, 130 mm C.R., showing the posterior band of the disk. Note the fibrous connection of the disk to the vaginal plate of the temporal bone (V) and the passage of a ligament through the petrotympanic fissure (GF). Also note the high vascularity of this region (arrows). (M) is the medial attachment of the disk. Milligan's trichrome X37.

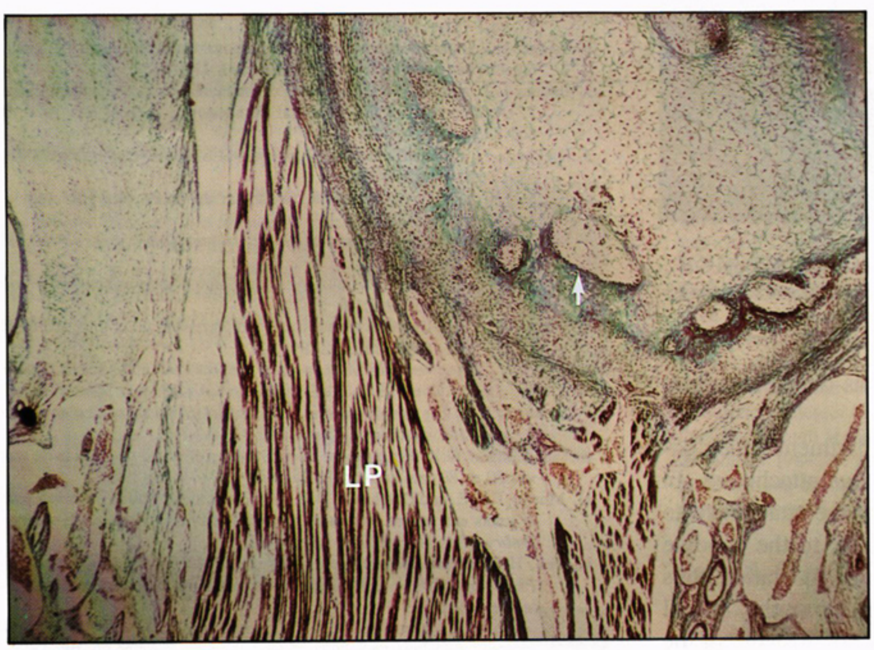

Figure 9
Transverse section of the temporomandibular joint of a fetus, 130 mm C.R., showing the attachment of the inferior band of the lateral pterygoid to the condyle (LP). Note the numerous irruption arteries (arrow) with concomitant calcification in this region. Milligan's trichrome X37.

from the articular bone to the condyle or whether this connection functions in initiating histodifferentiation of the TMJ. We will make a case to suggest that the latter possibility may be correct.

Murray and Drachman[11] have reported that movement in the region of the joint is necessary for cavitation to occur. In the absence of muscular activity, Fell[12] observed that the TMJ failed to cavitate. When the inferior compartment is evolving, the lateral pterygoid is functional and has fibrous extensions running over the condylar head to the malleus. It is significant that at the time of cavitation, the condylar head histodifferentiates into secondary cartilage. Stutzman and Petrovic[13] reported that histodifferentiation of the condylar secondary cartilage also requires the mechanical stimulation of the lateral pterygoid. Consequently, the lateral pterygoid appears to be functional during the cavitation process. The lateral pterygoid may facilitate the cavitation process through

Figure 10
Coronal section of the temporomdnaibular joint of a fetus, 255 mm C.R., showing a fully differentiated condyle and disk. Milligan's trichrome X37.

differential pulling at its two insertions (at the condylar head and the malleus).

The formation of the superior compartment which occurs later also requires this ligamentous attachment. In this case, differential pulling occurs at the attachment to the temporal bone's periosteum superior to the condyle and at the attachment to the malleus. Cavitation thus occurs above the fibrous extension from the lateral pterygoid to the malleus and below the periosteum of the temporal bone. Cavitation in the superior compartment occurs later than in the inferior compartment because the mesenchymal head inferior to the temporal bone histodifferentiates into periosteum at a later stage. This ligamentous attachment of the lateral pterygoid to the malleus is thus responsible for the direct formation of the disk, and, through mechanical interaction, may indirectly initiate the cavitation of both the inferior and the superior compartments of the joint.

The formation of the temporomandibular joint is complex, so it is difficult to separate associations from cause and effect. The findings of our study suggest that the lateral pterygoid, with its connections to Meckel's cartilage, may play a pivotal role in the formation of the disk and in subsequent compartment development.

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