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Development of Meckel's Cartilage in the Symphyseal Region in Man

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ABSTRACT ***Background:*** **The aim of this work is to clarify the aspects which are at present most controversial about the development of the anterior segments of Meckel's cartilage, such as the role of and determination of the area that is incorporated in the development of the human mandible.**

Methods: **Light microscope studies were done on 25 embryos and human fetuses from the collection of the Institute of Embryology at the University Complutense of Madrid and the Department of Morphological Science from the University of Granada. Specimen length was between 18 and 125 mm crown–rump.**

Results: **During the embryonic period, Meckel's cartilages were placed in the midline of the mandibular arch but fusion was not observed between them. Ossification of Meckel's cartilage begins at the end of the embryonic period and is completed in the fetal period and the portion that participates in mandibular formation is determined. This segment extends from the mental foramen to near the midline of the mandible. In this region, on the dorsal surface of the symphysis, cartilaginous nodules that originate from Meckel's cartilage are isolated.**

Conclusions: **The ventral portions of Meckel's cartilage do not fuse in the midline of the mandibular arch. These present endo- and perichondral ossification and the section from the mental foramen to near the midline (mandibular symphysis) participates in mandibular formation. The ventral ends of Meckel's cartilage, i.e., the ends nearest the midline, do not ossify and remain isolated on the dorsal surface of the fetal mandibular symphysis. Anat. Rec. 249:249–254, 1997.**

Key words: Meckel's cartilage; human embryology; development; mandible

A great many studies have focused on the development of Meckel's cartilage (cartilago mandibularis), a structure belonging to the first branchial arch. Three sections have been described in the cartilage in relation to their position. The proximal or tympanic portion is thought to give rise to the malleus and incus (Richany et al., 1956), with the exception of the anterior process of the malleus bone, which is formed from the os goniale (Rodríguez-Vázquez et al., 1991). The portion that extends from the malleus of the middle ear and the lingula of the mandible is transformed into the sphenomandibular ligament (Richany et al., 1956; Rodríguez Vázquez et al., 1992).

Opinions on the role of Meckel's cartilage in human mandibular development are contradictory. It is classically considered to be a transitory structure that disappears during the fetal period (Magitot and Robin, 1862; Gegenbaur, 1889; Dieulafé and Herpin, 1906, 1907; Maronneaud, 1952); and for other authors its role involves its ossification in mandibular formation (Bertolini et al., 1967; Bolender, 1972; Friant, 1957, 1958; O'Rahilly and Gardner, 1972; Goret-Nicaise and Dhem, 1983). The cartilago mandibularis guides the formation of the mandible but the dental crest is the co-organizer of the corpus mandibulae (Mérida-Velasco et al., 1993). Kjaer (1975) and Goret-Nicaise and Pilet (1983) observed the fusion of the anterior ends of Meckel's cartilage in humans, which was previously described by Bhaskar (1953) in the rat, which he termed the "rostral process."

In our work, we aim to clarify the aspects that are, at present, most controversial regarding the development of Meckel's cartilage in the symphyseal region, such as its contribution in mandibular formation, determination of the specific area involved in this process, as well as the modifications undergone by the ventral ends of the cartilage in this area.

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MATERIALS AND METHODS

Twenty-five human embryos and fetuses from the Collection of the Institute of Embryology at the University Complutense of Madrid, and the Embryo Collections of the Department of Morphological Sciences of the University of Granada, were used. The specimens ranged from 18–125 mm crown–rump (C-R) in length, corresponding to between 48 days and 15 weeks postconception (PC) based on Carnegie's stages (Corliss, 1979). These specimens were previously preserved in 10% neutral formalin. Serial sections ranging from 10–25 µm in thickness, depending on specimen size, were sectioned along the three spatial planes. The slices were stained according to McManus and Mowry's techniques (1968). Table 1 shows the technical data for this group of specimens.

TABLE 1. Features of the specimen used

Cat. No.	CR length (mm)	Age	Plane of section	Staining technique
Embryos		days		
CIV	18	48	F	H-E
E-19	19	51	T	A
CAS	20	51	F	H-E
JD-2	20	51	T	H-E
R-1	21	51	T	H-E
GV-7	22	52	S	H-E
PT	23	52	F	B
GI-4	26.5	54	F	H-E
Br-4	28	56	F	A/H-E
BB-2	30	56	T	H-E
Ca-4	30	56	T	H-E
Fetuses		weeks		
Fe	35	8.5	F	H-E
OY	38	9	S	A/H-E
GV-3	41	9	T	H-E
VR-2	45	9	F	H-E
Ca-6	52	10	F	H-E
B-52	57	10	F	H-E
Be-403	62	10	F	H-E
Mu-7	73	11	T	H-E
JR-6	80	12	F	H-E
Bu-23	85	12	T	H-E
B-608	90	12	T	A/H-E
B-30	98	13	T	H-E
B-62	113	14	F	H-E
R-6	125	15	F	H-E

Abbreviations: F, frontal; S, sagital; T, transverse; A, azocarmine; B, bielschowsky; H-E, hematoxylin-eosin.

RESULTS

In order to determine the relationships and the location of Meckel's cartilages in the symphyseal region, we used the deciduous dental germs that form in the mandible as a reference.

Embryonic Period

Our observations show that Meckel's cartilage in a 20 mm C-R length human embryo (51 days PC) approaches the midline of the mandibular arch, the future symphysis, giving rise to wide areas of contact areas through their well-differentiated perichondria (Figs. 1a,b). Caudally to Meckel's cartilage and on each side of the midline, one can observe the beginnings of intramembranous ossification of the mandible (Fig. 1b).

In human embryos of between 23 and 26.5 mm C-R (52–54 days PC), at the level of the deciduous canine tooth, the intramembranous ossification process of the mandible divides into two trabecular laminar formations that form a Y-shaped structure, with the inferior alveolar nerve passing between its branches (Figs. 2a,b). Near the midline of the mandibular arch, the ventral ends of Meckel's cartilage are surrounded caudally, laterally, and ventrally by the ossification of the future mandibular symphysis (Figs. 3a,b). Meckel's cartilages have grown considerably in comparison to the previous stage. This cartilage growth brings about a change in direction, beginning to spread cranially, since intramembranous ossification of the mandible can not progress in a ventro-caudal direction (Fig. 3a). The new arrangement of the ventral ends of Meckel's cartilage results in their perichondria coming into contact in the

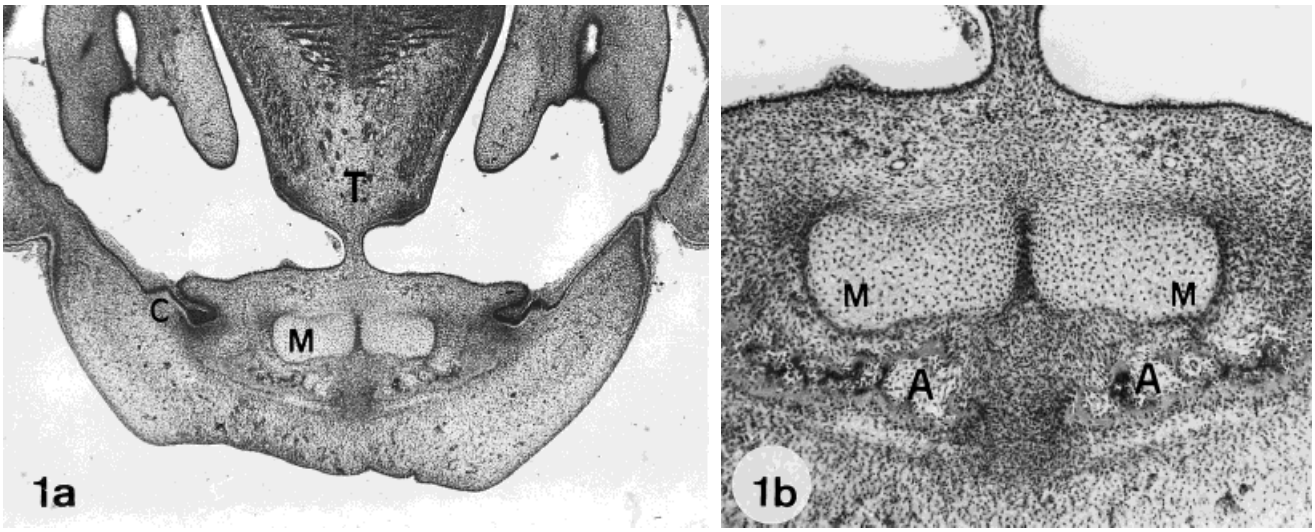
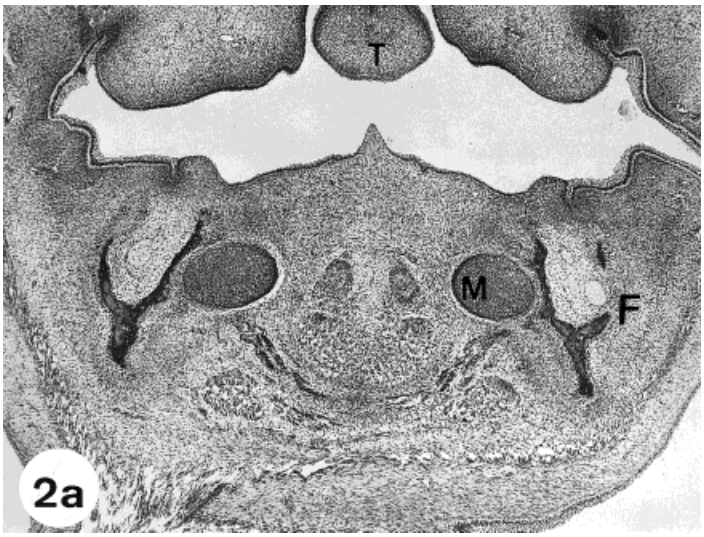


Fig. 1. Human embryo CAS. **1a:** Frontal section of the symphyseal region, Meckel's cartilages (M) from both sides approach the midline. 40X. **1b:** Enlargement to show the zone of contact of Meckel's cartilages (M). Caudally, the beginning of intramembranous ossification of the mandible can be observed (A). 100X.



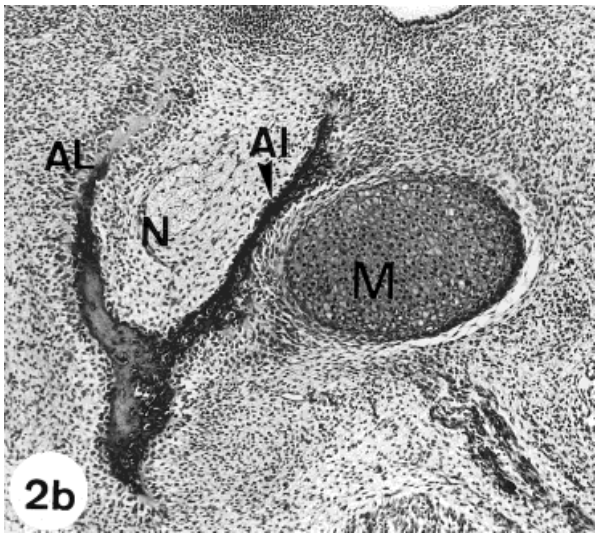
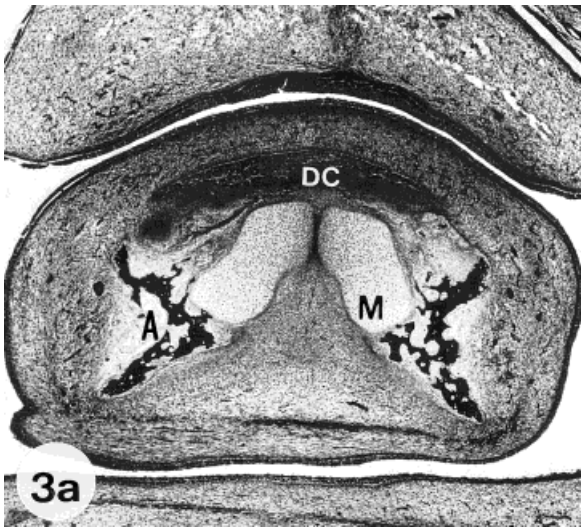


Fig. 2. Human embryo GI-4. **2a:** Frontal section of the mandibular arch. The mental foramen (F) can be seen on the left on the lateral lamina of the intramembranous ossification of the mandible. 40X. **2b:** Enlargement to show the Y morphology of the mandible and its relation with Meckel's cartilage (M). The inferior alveolar nerve (N) is present between the two laminas (AL, AI). There is no sign of ossification in Meckel's cartilage. 100X.



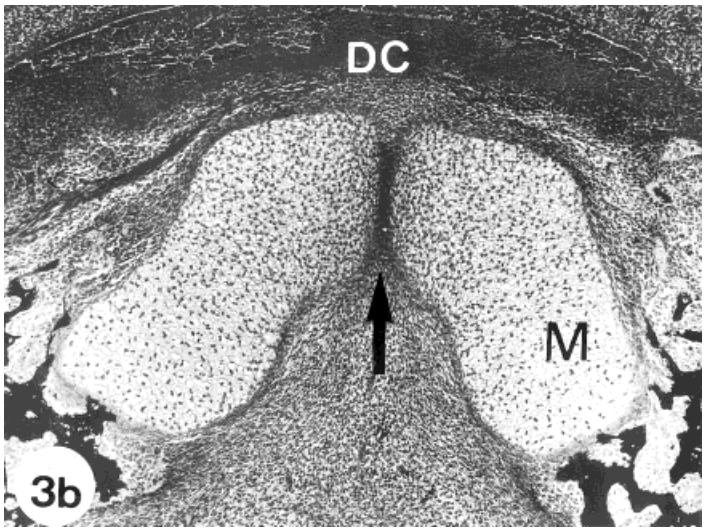


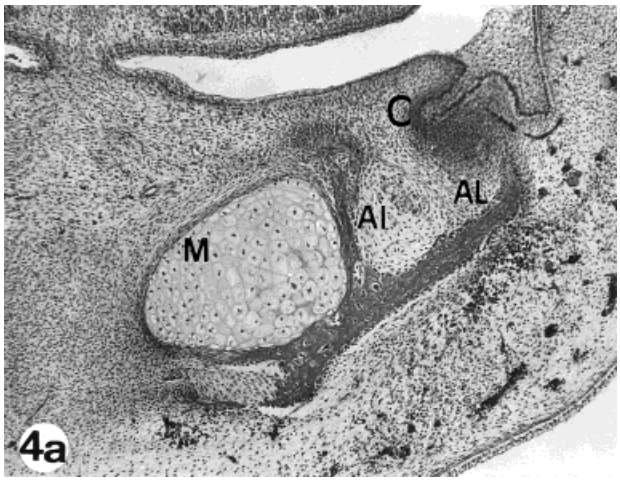
Fig. 3. Human embryo PT. **3a:** Frontal section of the symphyseal region. Meckel's cartilages (M) have grown in a cranial direction. 40X. **3b:** Enlargement to show the contact (arrow), but not fusion, of the ventral ends of Meckel's cartilage. 100X.

midline. This line can be distinguished by a sagittal band that clearly delimits both cartilages (Fig. 3b). At the end of the embryonic period, corresponding to a human embryo length of 28 mm C-R (56 days PC), at the height of the deciduous canine, the medial lamina of mandibular ossification is in contact with the perichondrium of the cartilage and surrounds its lateral and caudal surfaces (Figs. 4a,b). In this region, and for the first time, a cytostructural change appears in Meckel's cartilage. This is identified by light microscopy as a hypertrophy of the chondrocytes and increased density of the cartilaginous matrix together with the appearance of perichondrial ossification at the base of the cartilage (Fig. 4b).

Fetal Period

Meckel's cartilage is surrounded by the ossified medial mandibular lamina and the lamina of its own perichondral sheath during the initial phases of the fetal period (Figs. 5a,b). The cartilaginous cytological structure undergoes deep changes through degeneration processes of a large number of hypertrophied chondrocytes, the areas of which are occupied by vascular structures (Fig. 5b).

The ossification process that affects Meckel's cartilage is now more advanced, it extends ventrally to the height of the deciduous lateral incisors whereas dorsally it exceeds the height of the canines. Both rostrally and dorsally to these locations, Meckel's cartilage preserves its cytostructure, which undergoes no change at all. Therefore, no cellular modification is observed in the future mandibular symphysis in the region underlying the deciduous central incisors (Fig. 6) where the medial surfaces of the ventral ends of Meckel's cartilage come into contact.



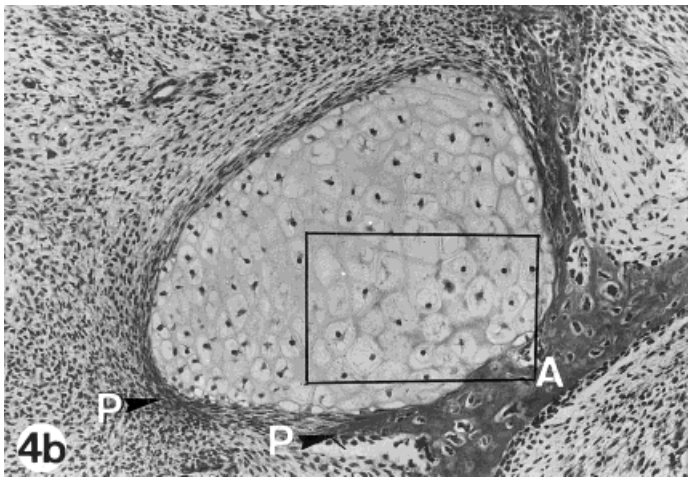
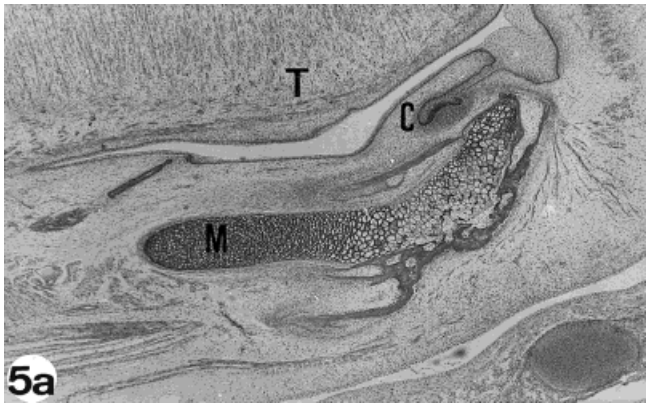


Fig. 4. Human embryo Br-4. **4a:** Frontal section of the mandibular arch at the level of the deciduous canine (C). The medial lamina of mandibular ossification (AI) is in contact with the perichondrium of Meckel's cartilage. 40X. **4b:** Enlargement to show the hypertrophy of the chondrocytes (boxed area) and the beginning of perichondral ossification (P). 200X.



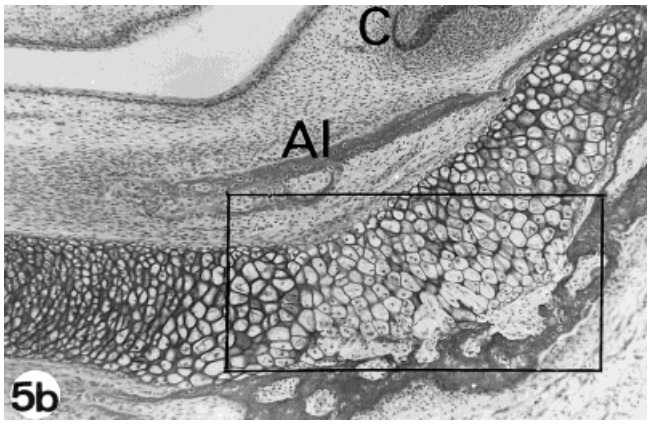


Fig. 5. Human fetus OY. **5a:** Sagittal section of the segment of Meckel's cartilage (M) that participates in mandibular formation. 40X. **5b:** Enlargement to show the cytostructural changes of Meckel's cartilage that occur during endochondral ossification (boxed area). 100X.

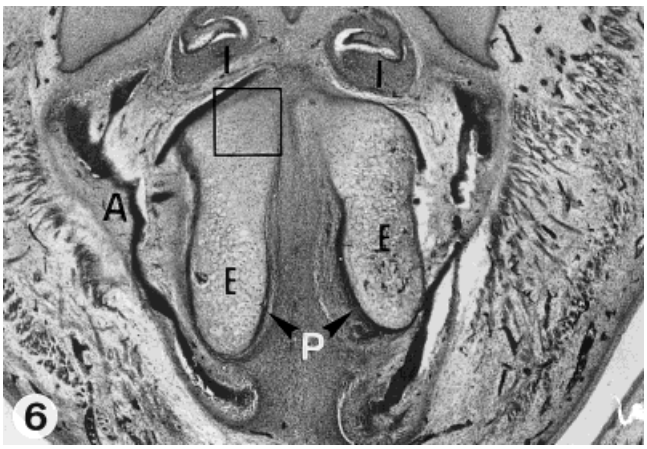


Fig. 6. Human fetus B-52. Frontal section of the symphyseal region at the height of the deciduous central incisors (I). The area of Meckel's cartilage underlying the dental germs of the central incisors shows no signs of any type of ossification (boxed area). The remaining area presents typical endochondral (E) and perichondral (P) ossification. 40X.

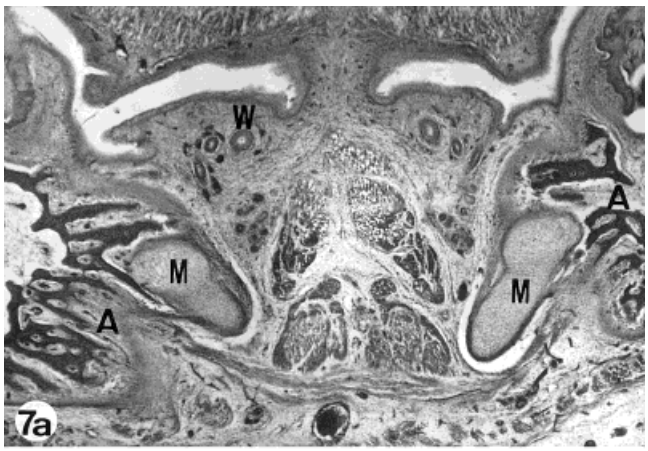
Through this mechanism, the aforementioned sections of Meckel's cartilage become incorporated into the mandible (Figs. 5b, 10) . We observed that the ossified cartilaginous segment that becomes part of the mandible is clearly delimited by a change in the direction of the cartilages both anterior and posterior to its inclusion (Fig. 10). In the posterior region (Figs. 7a,b), Meckel's cartilage is directed cranio-laterally; in the anterior region it points in a cranio-dorso-medial direction (Fig.8).

After 12 weeks PC, only small areas of Meckel's cartilage remain to be ossified and are located in the mandible close to the midline near the symphysis (Fig. 8).

As a result of this ossification process of Meckel's cartilage, the ventral ends become isolated into two nodules (corresponding to Meckel's right and left cartilages) in the fibrous tissue that occupies the dorsal surface of the symphysis (Figs. 8, 9, 10). These cartilaginous nodules, which are at first rounded, begin to acquire an irregular shape, and can even join together to form a cartilage on the dorsal surface of the symphysis.

DISCUSSION

According to our observations, several aspects of the development of Meckel's cartilage in the symphyseal region must be clarified. Fusion of the cartilages has



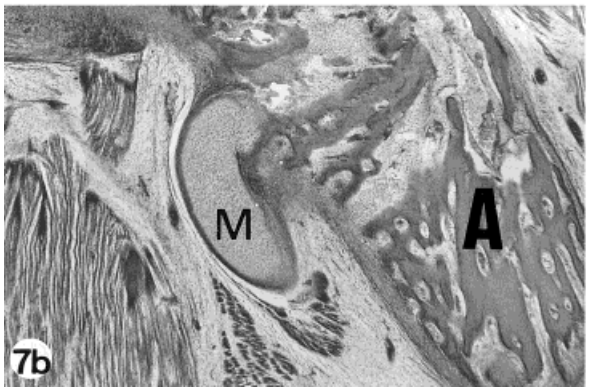
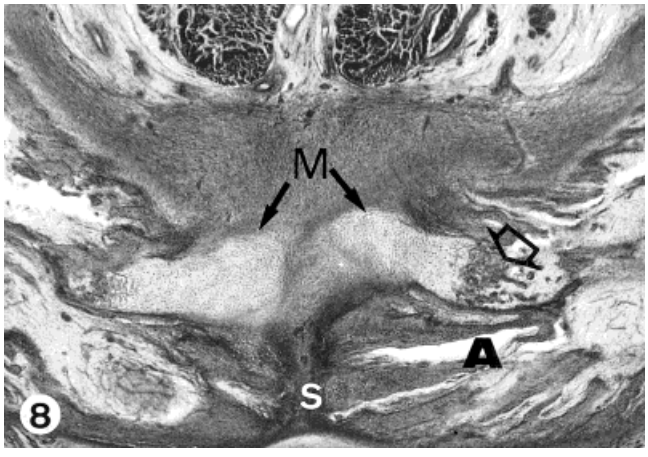


Fig. 7. Posterior edge of the area of Meckel's cartilage (M) that participates in mandibular formation, showing its morphological arrangement. **7a:** Human fetus B-52. The change in direction of Meckel's cartilage in a frontal section. 40X. **7b:** Human fetus B-608. The change in direction of cartilage in a transverse section. 40X.



Figs. 8. Human fetus Bu-23. Anterior edge of the area of Meckel's cartilage (M) that participates in mandibular formation. Ventral ends of the cartilages point dorso-medially, as can be observed in the transverse section. These parts do not ossify. Small areas of Meckel's cartilage that are in the process of ossification can still be observed in the mandible (arrow). 40X.

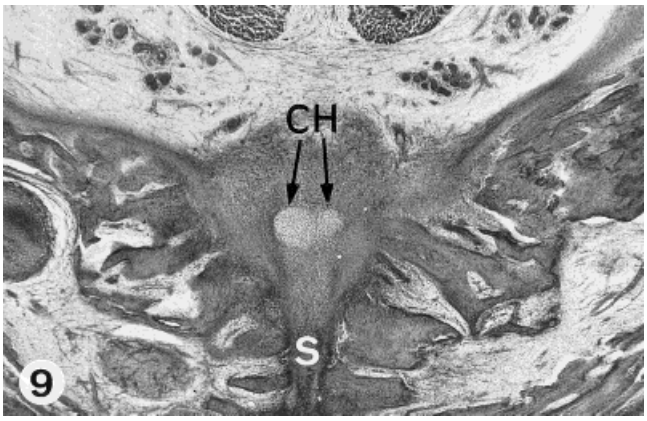


Fig. 9. Human fetus B-608. Cartilaginous nodules corresponding to the ventral ends of Meckel's cartilages that have not ossified and remain isolated in the mandibular symphysis forming the "chondriola symphysea" (CH). 40X.

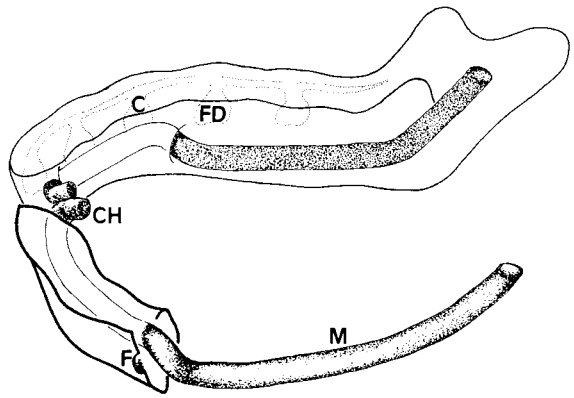


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Fig. 10. Diagram of the morphological layout of Meckel's cartilage. The area of cartilage that participates in mandibular formation is determined; the posterior edge lies between the deciduous canine (C) and the first deciduous molar (FD). The anterior edge is in the mid-ventral region of the mandible, where remains of non-ossified Meckel's cartilage (CH) are present on the dorsal surface of the mandibular symphysis ("chondriola symphysea").

been described in rodents by Bhaskar (1953) and Frommer and Margolies (1971), and in humans by Dieulafé and Herpin (1906), Kjaer (1975), and Goret-Nicaise and Pilet (1983). We demonstrated that no loss or dehiscence of the perichondria, which would allow fusion and, thus, continuity of Meckel's cartilage from both sides in the midline, occurred in any of the developmental stages studied. This is in accordance with studies by Bolender (1972), Ten Cate (1985), Orliaguet et al. (1993a), and Bareggi et al. (1994). Very close contact was only observed during the same period in which Kjaer (1975), Goret-Nicaise and Pilet (1983), and Fuentes and González (1987) observed a fusion.

Concerning the ossification process, in the light of our observations we consider that Meckel's cartilage presents an endo- and perichondral ossification process. This contributes to mandibular formation in a well defined section between the site of the deciduous canine and the first deciduous molar (approximately at the level of the mental foramen), to the mid-ventral region of the mandible, caudally and dorsally to the deciduous central incisors. In this region, the cartilages are isolated on the dorsal surface of the future symphysis. In accordance with Orliaguet et al. (1993b), we

observed the start of endochondral ossification near the mental foramen, but not restricted to this area as Oliarguet et al. (1994) found. Kjaer (1975) considers fusion of the cartilages to coincide with cartilaginous endochondral mineralization, a process which the present authors believe stabilizes disintegration of the cartilaginous system. In our opinion, if this theory is true fusion would continue throughout the entire ossification process. However, Kjaer (1975) demonstrates that this phenomenon does not occur. According to Goret-Nicaise and Pilet (1983), endochondral ossification and fusion are chronologically independent.

Another important and highly controversial aspect is the type of ossification that Meckel's cartilage presents. Richany et al. (1956), Kjaer (1975), Goret-Nicaise and Dhem (1983), and Oliarguet et al. (1994) regard it as endochondral. According to Friant (1957, 1958, 1968), however, ossification of Meckel's cartilage occurs differently throughout ontogeny, since in mammals it is endochondral whereas in archaic animals such as the "Talpa" and the "Tarsius" it is the more primitive conjunctive ossification. In our opinion, endochondral ossification is accompanied by perichondral ossification of the cartilage, forming a periosteal sheath, as shown by Durts-Zivkovic and Davila (1974). According to our study, the lateral surface of the periosteal sheath that surrounds the Meckel's cartilage is comprised of the internal bone lamina of the mandible and the rest is ossified cartilage perichondrium that has ossified by the process of perichondral ossification described previously.

As a result of the ossification of Meckel's cartilage and, more specifically, formation of the perichondral bone sheath, together with the growth and increased width of the mandible, the cartilages undergo a change in direction in the anterior and posterior regions, which form the boundaries of the cartilaginous section that, when ossified, becomes part of the mandible. This same phenomenon was observed by Bolender (1972), who described the form acquired by the cartilage as that of a bayonet.

In studies on our specimens, we demonstrated that the ventral ends of Meckel's cartilage did not become ossified at all and remained in the form of nodules on the dorsal surface of the symphysis. These cartilaginous parts correspond to the "chondriola symphysea" described by Bertolini et al. (1967) or the "meckelian isolates" observed by Bolender (1972) and also referred to by Goret-Nicaise (1982) and Goret-Nicaise and Dhem (1982, 1983). These cartilaginous nodules, therefore, originate from Meckel's cartilage and should not be mistakenly defined as secondary or accessory cartilages, as Dumont (1993) suggests, since secondary cartilages arise independently and, as demonstrated by Hall (1970) and Goret-Nicaise and Dhem (1993), are not in any way related to Meckel's cartilage.

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