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The development of the mandibular symphyseal region in humans

Rozwój żuchwowego obszaru spojenia żuchwy u ludzi

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ABSTRACT

Introduction. Development of mentum and mandibular symphysis has been rarely investigated. Formation of mentum is considered to be influenced by many factors. However the structure of the anterior part of Meckel's cartilage and its possible role in the formation of the mandibular symphysis has not been specified, similarly to the importance of the rapid connection of both halves of the mandible during the fetal development.
Material and methods. The observations were carried out on serial sections made in three planes (5 µm for embryos, 7 µm for fetuses) stained according to various histological methods. 30 human embryos (37 to 56 days) and 5 fetuses (9 to 35 weeks) were examined under light microscopy.
Results. Since stage 16 Meckel's cartilages were separated in midline by mesenchyme. At stage 18 there is wide space between cartilages filled with mesenchyme and the fibres of suprahyoid muscles inserted in the inferior surface of Meckel's cartilage were observed. At stage 22 both Meckel's cartilages touched each other within the symphysis menti. Between the 9th and 12th week the cartilages were separated with mesenchyme penetrated by connective tissue, the shape of the symphysis was pyramidal. Between the 13th and 18th week marrow cavities and degeneration of the cartilage in the mental region was observed, symphysis was filled with fibrous tissue penetrated by blood vessels. From the 35th week calcified cartilage was still observed within the bone.
Conclusions. The mandibular symphysis' formation is a multistage process started during embryogenesis and almost completely finished before birth.

Keywords: symphyseal fusion, prenatal development, chin, maxillofacial development, orthodontics.

STRESZCZENIE

Wstęp. Rozwój spojenia żuchwy, podlega wielu różnym wpływom, jednak rola chrząstki Meckela nie jest często opisywana, a przede wszystkim uściślona w okresie płodowym.
Materiał i metody. Badaniu poddano wybarwione i cięte (5 µm dla embionów, 7 µm dla płodów) w trzech płaszczyznach seryjne skrawki z okolicy spojenia żuchwy. Badanie w mikroskopie świetlnym przeprowadzono na 30 embrionach ludzkich (37. do 56. dnia) i 5 płodach (9. do 35. tygodnia).
Wyniki. W 16 stadium chrząstka Meckela jest rozdzielona w linii pośrodkowej tkanką mezenchymalną. W 18 stadium chrząska jest nadal rozdzielona, a przestrzeń pomiędzy często wypełniają włókna mięśnia nadgnykowego. Zbliżenie chrząstek w spojeniu bródkowym następuje w stadium 22. Pomiędzy 9. a 12. tygodniem życia płodowego obie chrząstki są rozdzielone tkanką mezenchymalną z elementami tkanki łącznej. Spojenie ma kształt piramidalny. Pomiędzy 13. a 18. tygodniem widoczne są zmiany zanikowe chrząstki, a spojenie wypełnia tkanka łączna i naczynia krwionośne. Do 35. tygodnia pozostałości chrząstki są nadal widoczne w spojeniu.
Wnioski. Rozwój spojenia żuchwy jest procesem wielostopniowym i kończy się dopiero przed urodzeniem płodu.

Słowa kluczowe: połączenie spojenia żuchwy, rozwój prenatalny, bródka, rozwój szczękowo-twarzowy.

Introduction

Studies on the development of the human mandible are focused on the formation of its developmental units: basilar, alveolar, condylar, coronoid, angular and exceptionally, symphyseal [1]. Therefore the development of the mentum and mandibular symphysis requires further studies.

The mentum is phylogenetically a new structure present only in humans. Its formation was probably influenced by the non-masticatory actions of tongue and perioral muscles [2]. Movement of the facial unit under the cerebral one caused extension of the face, formation of the high palate and reduction of mandibular arches. The development of the mentum was also influenced by changes in mastication and the development of infrahyoid muscles [3].

Meckel's cartilage is a transitional structure in the formation of the 1st pharyngeal arch and mandible. Meckel's cartilage appears in the 5th week and contributes to the formation of mandibular units [4,5]. However, the structure of the anterior part of Meckel's cartilage and its possible role in the formation of the mandibular symphysis has not been specified, similarly to the importance of the rapid connection of both halves of the mandible during the foetal development.

Aim

The aim of the study was to identify in details consecutive stages of mandibular symphysis' development.

Material and methods

The study was performed on 30 human embryos and 5 fetuses from the collection of the Department of Anatomy, Poznan University of Medical Sciences. The age of the embryos under investigation (from 37 to 56 days) was determined according to the international criteria of developmental stages and it was expressed in postovulatory days. For these purposes the length of an embryo, its external appearance, and the advances in the development of the internal organs (mainly the eyeball and the nervous system) were included.

The age of the fetuses (from 9 to 35 weeks) was established based on crown–rump length (CR-L), and was expressed in postovulatory days. The embryos were preserved in 10% formalin and embedded in toto in paraffin or paraplast and serial sections of 5 μm were made in the sagittal, frontal and horizontal plane. The fetuses were decalcified prior to these procedures. Some fetuses were embedded in toto, and some were dissected first; their mandibles were taken out for investigations. The 7 μm thick sections were made in three planes. The sections were stained with haematoxylin and eosin, aniline blue according to Mallory's method, and silver protargol according to Bodian's methods. Subsequently, they were observed under light microscopy.

Results

Starting from stage 13 in embryos (4–6 mm, 32 days) in the anterior part of the mandibular process the primordium of Meckel's cartilage is visible. During the next two stages 14 (5–7 mm, 33 days) and 15 (7–9 mm, 36 days) there is time of the remodelling of cells within the primordium of Meckel's cartilage, but in the embryos at stage 16 (8–11 mm, 39 days) Meckel's cartilage extends along the mandibular prominence. In the midline of the embryo the places of condensation and thinness of mesenchyme alternate. They correspond to the primordia of suprahyoid muscles and developing muscles of the tongue surrounded by the anterior end of Meckel's cartilage.

At stage 17 (11–14 mm, 41 days) a regular and oval shape of Meckel's cartilage can be observed, which extends from the otic vesicle to the mental symphysis. In the midline symmetrical cartilages are separated by a strip of mesenchyme. At the inferior margin of Meckel's cartilage, near the mental nerve, a single, primary ossification centre appears.

At stage 18 (13–17 mm, 44 days) ossification of the mandible is intensive. From the primary ossification centre, ossification spreads towards the future symphysis menti faster than in the direction of the mandibular angle. Meckel's cartilage in the mental region extends and flexes superiorly. The space between both the right and left Meckel's cartilages is wide and filled with mesenchyme. It is much wider near the inferior margin (**Figure 1**). The geniohyoid, genioglossus and mylohyoid muscles are well visible. Their fibres are inserted in the inferior surface of Meckel's cartilage.

At stages 19, 20 and 21 (16–18 mm, 18–22 mm, 22–24 mm, 46, 49 and 51 days) the anterior segment of Meckel's cartilage becomes extended, especially on its inferior margin. Bone projections invading the cartilage are visible. Meckel's cartilage loses its smooth outline. On the horizontal sections of the symphysis menti a broad strip of mesenchyme dividing both the bone and the cartilage can be observed (**Figure 2**).

Changes in interrelation of both the right and left cartilages occur at stage 22 (23–28 mm, 53 days). The shape of Meckel's cartilage changes and its flexion near the mental foramen increases. Within the symphysis menti both the right and left cartilages touch each other (**Figure 3**). At this stage of the embryonic period their ends are in the closest relation. The perichondrial cells of the right and left cartilage contact each other and only single, fusiform cells between them are visible. A slight flexion of the cartilage in the inferior direction is visible.

At stage 23 (27–31 mm, 56 days) the right and left cartilages contact each other. They are separated by a distinct strip of vertically arranged, stron-

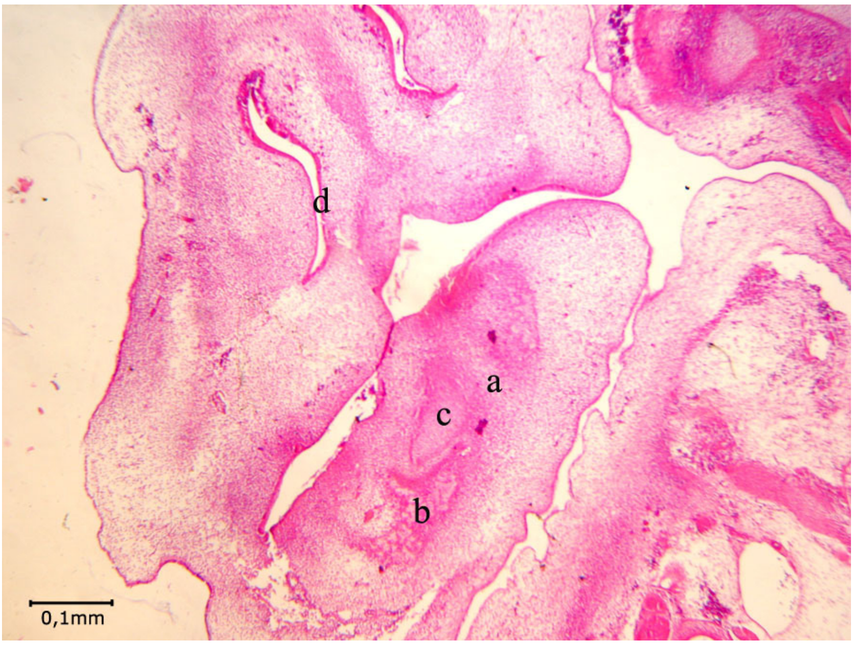

Figure 1. Frontal section through the embryo at stage 18 (44 days). H+E. a — symphysis menti, b — ossifying mandible, c — Meckel's cartilage, d — nasal pit

Rycina 1. *Przekrój czołowy embrionu w stadium 18 (44 dzień). H+E. a — spojenie żuchwy, b — kostniejąca żuchwa, c — chrząstka Meckela, d — szczeliny nosowe*

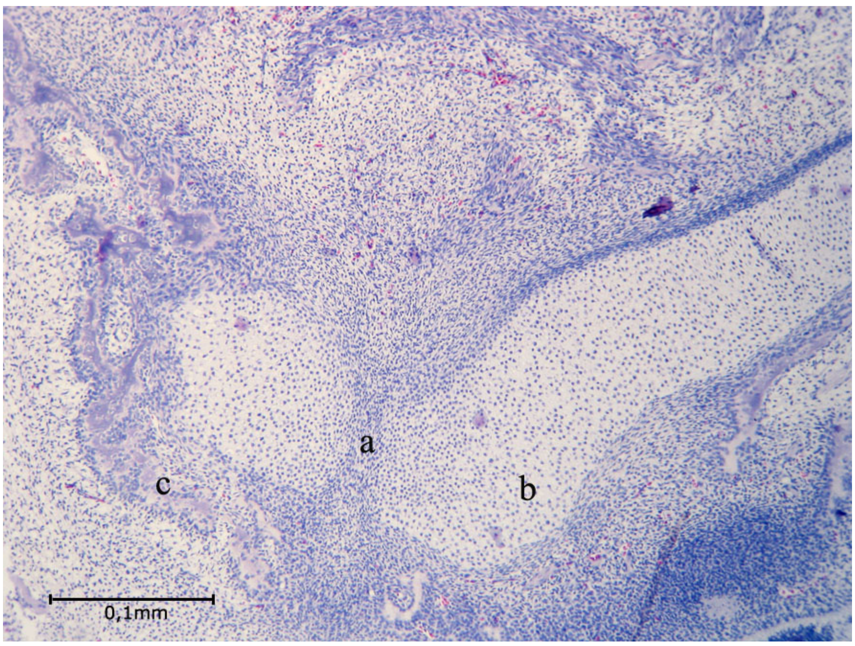

Figure 2. Transversal section through the embryo at stage 21 (51 days). H+E. a — symphysis menti, b — Meckel's cartilage, c — mandibular bone with visible bone outgrowth

Rycina 2. *Przekrój poprzeczny embrionu w stadium 21 (51 dni). H+E. a — spojenie żuchwy, b — chrząstka Meckela, c — dojrzewająca kość żuchwy*

gly flattened mesenchymal cells. The narrowing at the inferior pole of the anterior end of Meckel's cartilage is evident. Meckel's cartilage near the primary ossification centre and in its inferior and anterior segments is completely surrounded by the developing bone.

During the period between the 9th and 12th week of fetal life the mandibular bone surrounds the external surface of Meckel's cartilage within the branch and the external and inferior surface of the cartilage within the body. The inferior alveolar nerve runs between the cartilage and mandible.

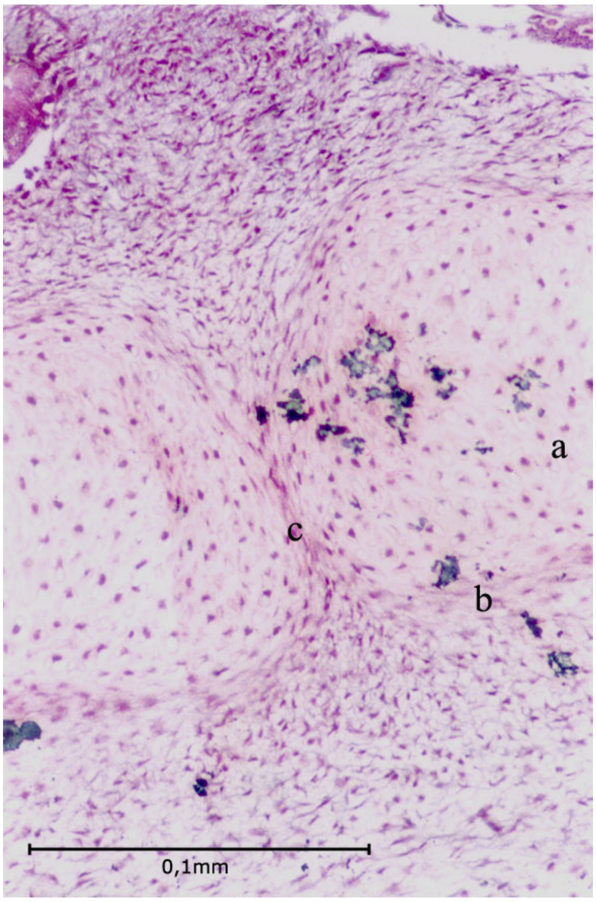

Figure 3. Transversal section through the embryo at stage 22 (53 days). Ogawa stain. a — Meckel's cartilage, b — perichondrium, c — single fusiformal cells between similar Meckel's cartilages in symphysis menti

Rycina 3. *Przekrój poprzeczny embrionu w stadium 22 (53 dni). Barwienie Ogawa. a — chrząstka Meckela, b — ochrzęstna, c — pojedyncze komórki odpowiadające komórkom chrząstki w spojeniu bródkowym*

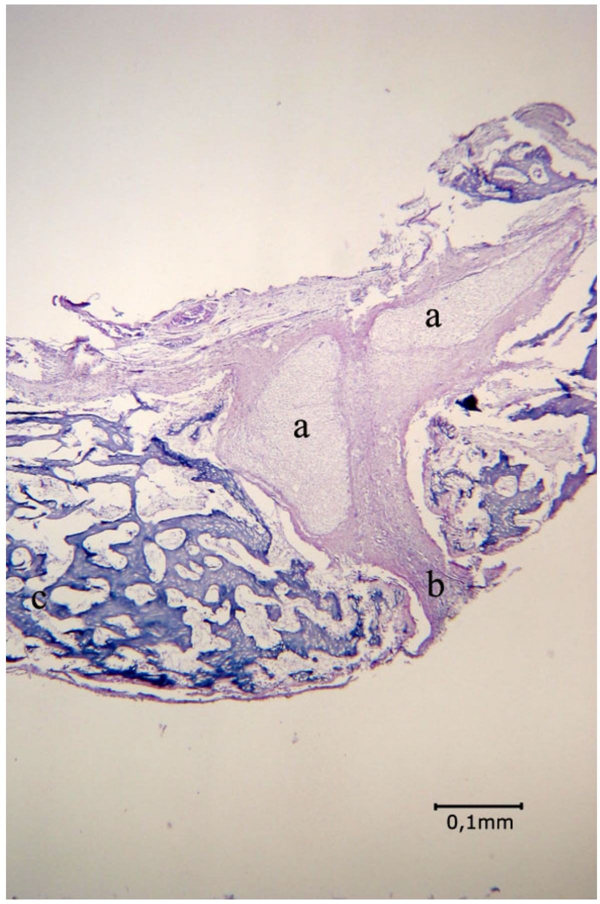

Figure 4. Horizontal section through the symphysis menti of the fetus (CR-L 80 mm). H+E. a — Meckel's cartilage, b — symphysis, c — mandibular bone

Rycina 4. *Poziomy przekrój spojenia bródkowego płodu (CR-L 80 mm). H+E. a — chrząstka Meckela, b — spojenie żuchwy, c — kość żuchwy*

Within the corpus it is included in the bone structure. The alveolar part of the mandible grows, initially in the form of external lamina and since the 10th week — also in the form of internal lamina. Between the laminae of the alveolar process deciduous tooth buds at the cap stage and developing permanent tooth buds can be seen. Only in the incisor teeth region, where during the 9th and 10th week external osseous lamina can mainly be observed, the tooth buds have contact with Meckel's cartilage. In the mandibular symphysis region the structure of the cartilage is almost unchanged and this state could be observed up to the 12th week in spite of the fact that the process of cartilage ossification takes place in the major part of its anterior segment. In the symphyseal region the cartilage can be seen in its central and upper part. Similarly to both halves of the mandible, both cartilages are separated with mesenchyme, which is penetrated by the connective tissue from underneath (**Figure 4**). The mandibular symphysis is pyramidal, where the apex is directed towards the upper and posterior surface of the cartilage.

Between the 13th and 18th week in the mental region the development of marrow cavities and degradation of the mandibular cartilage is visible. Remains of the calcified cartilage can still be seen in the osseous trabeculae in the 18th week. In the midline a band of fibrous tissue separates both the bone and cartilage. One of the characteristics is the fact that in the posterior surface of the upper edge the cartilage does not undergo the changes that can be observed in the entire mental region (**Figure 5**). In the 18th week in the symphyseal region the cartilage can be seen only in the form of small, oval fragments in bone hollows, closer to the upper edge. From that place cartilaginous structure covering the mandibular bone edges begins to develop (**Figure 5**). The other part of the symphysis is filled with fibrous tissue penetrated by numerous blood vessels. The fibres of anterior venters of biventer muscles penetrate the symphysis from the external surface, which can be seen in horizontal sections of the symphyseal region from the period of the 19th to 20th week. In specimens from the 29th week the cartilage running along the mandible could no longer be seen. However, the presence of fragments of Meckel's cartilage in the upper part of the mandibular symphysis was observed till to 19th week (**Figure 6**). Also, the process of development of the mental prominence could be observed. Within the symphysis, from the outside oval ossicles loosely located between both parts of the mandible are visible. The symphysis is filled with the fibrous tissue. The bone has a trabecular structure. Only in the region of the alveolar process it is a plexiform bone. A system of Haversian canals can be seen in specimens from the 35th week. From the outside, near the upper edge of the mandibular symphysis remains of the calcified cartilage can still be observed within the bone (**Figure 7**). In the region a hyaline cartilage covering the symphyseal edges of the bone is also present (**Figure 8**). It is in continuity with the fragments of Meckel's cartilage.

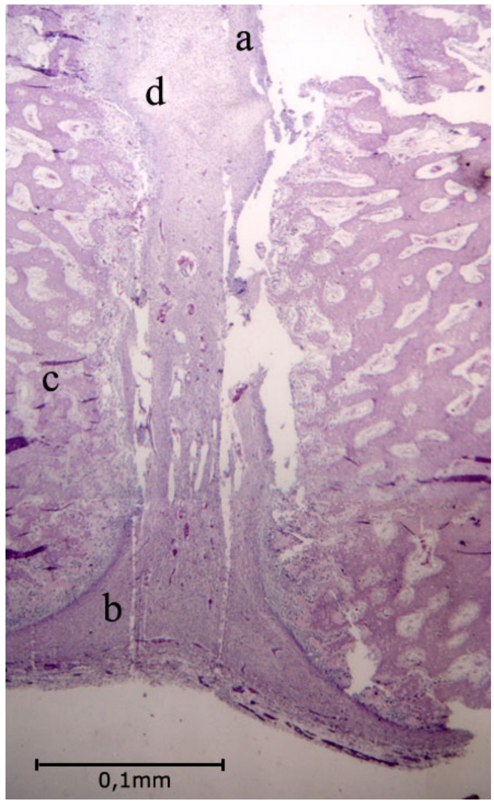

Figure 5. Frontal section through the symphysis menti of the fetus (CR-L 175 mm). H+E. a — hyaline cartilage, b — fibrous tissue, c — trabecular bone, d — Meclel's cartilage

Rycina 5. *Czołowy przekrój spojenia bródkowego płodu (CR-L 175 mm). H+E. a — chrząstka szklista, b — tkanka włóknista, c — kość beleczkowa żuchwy, d — chrząstka Meckela*

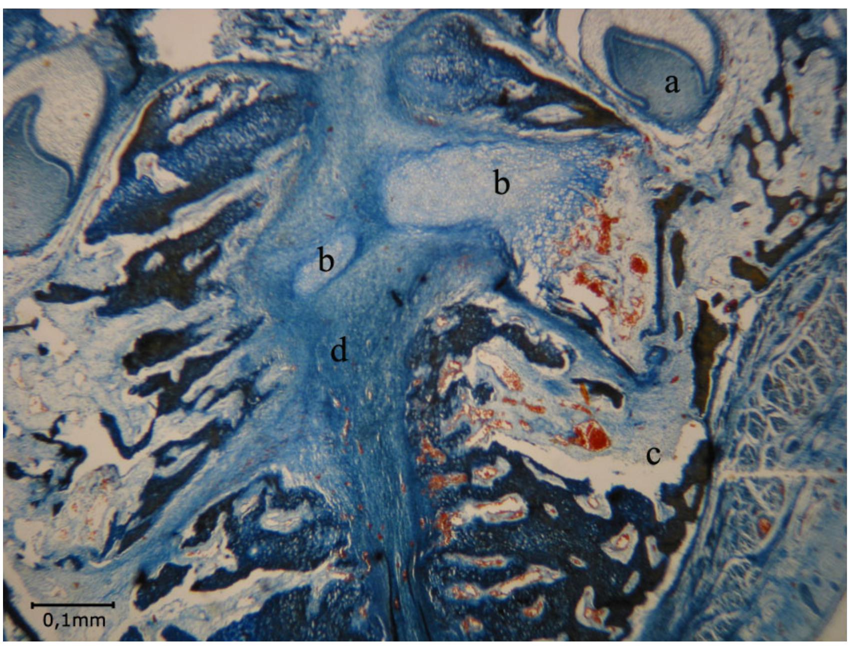

Figure 6. Frontal section through the symphysis menti of the fetus (CR-L 183 mm). Mallory stain. a — central incisor germ, b — Meckel's cartilage, c — mandibular bone, d — symphysis

Rycina 6. *Czołowy przekrój spojenia bródkowego płodu (CR-L 183 mm). Barwienie Mallory. a — zawiązek centralnego siekacza, b — chrząstka Meckela, c — kość żuchwy, d — spojenie*

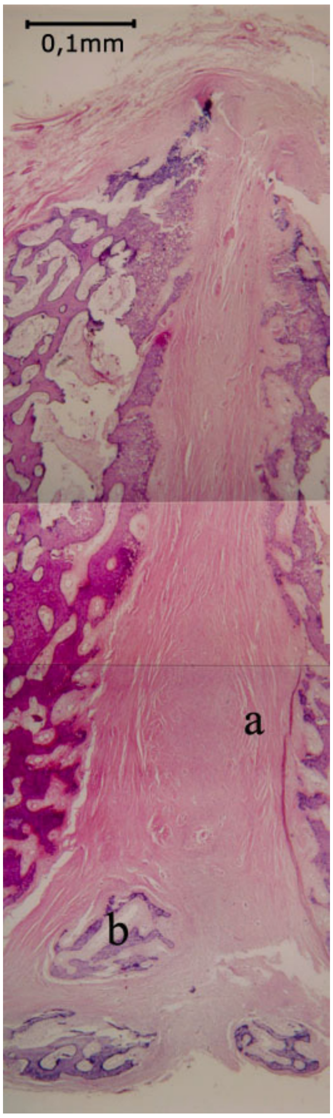

Figure 7. Frontal section through the anterior surface of symphysis menti of the fetus (CR-L 270 mm). H+E. a — fibrous tissue, b — mental ossicle

Rycina 7. *Czołowy przekrój przedniej powierzchni spojenia bródkowego płodu (CR-L 270 mm). H+E. a — tkanka włóknista, b — kosteczki bródkowe*

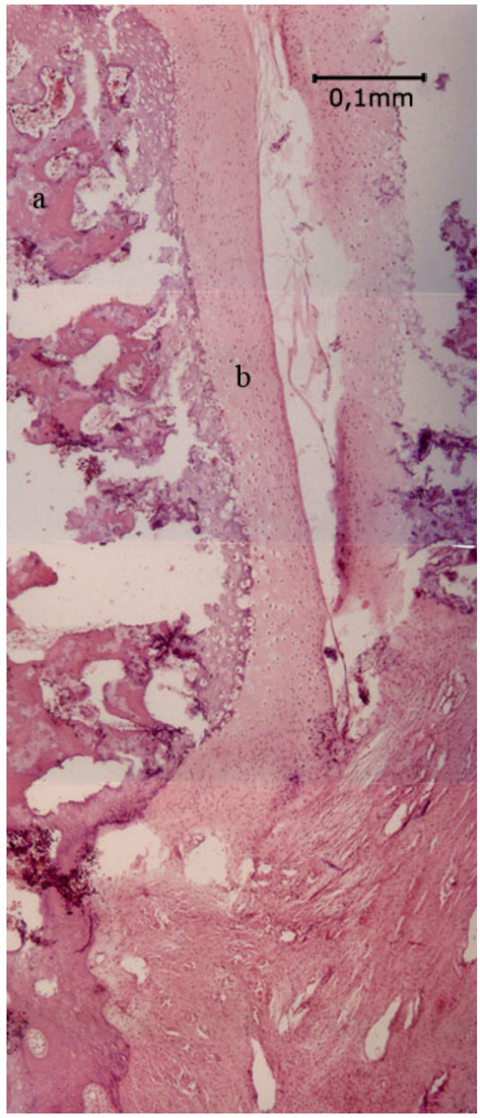

Figure 8. Frontal section through the posterior surface of symphysis menti of the fetus (CR-L 350 mm). H+E. a — remnants of calcified Meckel's cartilage, b — mental cartilage

Rycina 8. *Czołowy przekrój tylnej powierzchni spojenia bródkowego płodu (CR-L 350 mm). H+E. a — pozostałości kostniejącej chrząstki Meckela, b — chrząstka spojenia*

Discussion

Our studies show that Meckel's cartilage appears in the anterior part of the mandibular prominence on the 32nd day of development and starting from the 39th day of development it extends from the otic vesicle to the symphysis menti. Most of the investigators observed the presence of Meckel's cartilage between the 38th–40th day of development [6–8].

In the literature there are only few studies on the changes in the shape of the anterior segment of Meckel's cartilage at stages 19–23. It is suggested that the modifications of the shape in this segment are influenced by the muscles [3]. In the embryonic period the muscles forming the floor of the mouth attach to the cartilage. Our previous investigation showed that the fibres of geniohyoid, genioglossus and mylohyoid muscles attach to the cartilage in an embryo aged about 44-days [9]. The same observations were reported by Doskocil [10], but either the exact time or places of insertion are specified. Early differentiation of the suprahyoid muscles would elucidate the early mouth-opening capacity and may be fundamental to normal development [11]. Most studies show that the activity of these muscles causes changes in the location and S-shaped flexion of Meckel's cartilage [12] in the 7th

week of development. On the other hand, at this time the mandible retracts and the angle between its parts increases. This process provides space for the tongue and palatine processes during the secondary palate formation [13]. The joining process of both right and left cartilages in humans was studied independently by Goret-Nicaise et al. and Kjaer, as it was different than in animals [12, 14]. It was reported that this connection occurs at the superior margin of cartilages. In this place chondrocytes are elongated and lie transversally to the axis of the cartilage. These observations were documented in histochemical studies that showed the presence of the chondroid tissue in the place of the junction [12]. In our studies close contact of posterior surfaces of the cartilages, near the superior pole, was also observed. This connection was seen only in embryos on the 53rd day, but near the inferior margin of cartilage, between the perichondrial cells single, fusiform mesenchymal cells were observed. In the place of the junction there were no blood vessels reported by Kjear [12]. Most of the investigators stated that there is no connection between two Meckel's cartilages in the midline [15–17]. The joining of both Meckel's cartilages for such a short time is very interesting, all the more because it coincides in time with the development of the temporary temporomandibular joint, i.e. the Meckelian joint, whose development corresponds to the temporal joint in reptiles [18]. In mammals, because of bony trajectories directed posteriorly and dominating hinge (elevating and depressing) movements in the temporomandibular joint, there is no reason for joining of both the right and left cartilages in the midline. Only when the lateral movements dominate, as is the case in humans, the occlusion forces have to be diminished by tight bony junction [19].

The region of mandibular symphysis evokes interest also due to the presence of additional cartilages [20, 21]. Goret-Nicaise and Dhem as well as Dhem alone described the symphysis as a partial synchondrosis with the presence of additional cartilages and immature bone [20, 22]. Martinez et al. defined the aforementioned cartilages as a cartilaginoid fibrous substance (cartilaginoid tissue) [23]. In our own research we observed a fibrous tissue in the symphysis. The blood vessels and fibres of the anterior head of the biventer muscle were also found to penetrate the symphysis. In the 18th week fragments of Meckel's cartilage could be seen on the upper edge of the symphysis. From that place upwards a hyaline cartilage developed and covered the symphyseal edges of the bone and remained in continuity with Meckel's cartilage. This fact gives rise to the suggestion that the anterior part of Meckel's cartilage also takes part in the development of mandibular symphysis. The remains of the cartilage on the upper edge of the symphysis were also described by Grey and Clemente [24]. Mental ossicles, which were observed in fetuses in the 35th week, are another problem. As can be supposed, their development is independent of Meckel's cartilage, on the base of the cartilaginoid tissue. Then they undergo ossification. As well Dhem as Cohen described the structure of additional cartilages as different from Meckel's cartilage and bone [22, 25]. Some researchers are of the opinion that the cartilages visible in the inferior pole are remains of Meckel's cartilage [26–28]. Rodriguez-Vazguez et al think that the remains of Meckel's cartilage in the symphyseal region do not become ossified in the foetal period [20]. However, it has been proved that the infant is born with a stable symphysis and the first movements it makes are above all lateral movements. There is remarkable evolutionary diversity in symphyseal anatomy, which characterises postnatal growth. It varies from the primitive mammalian condition of smooth joint surfaces loosely connected by a fibrocartilage pad and ligaments to a more tightly bound joint with greater sutural complexity and numerous variably calcified ligaments to an ossified joint [29].

Current structure of symphyseal fusion in humans might be a sign of adaptation in order to strengthen the symphysis as a response to increased wishboning stress during unilateral mastication [30]. The suggestion was supported by Gröning et al who stated that wishboning and vertical bending in coronal plane might have affected the evolution of modern human symphysis [31].

Strong correlation between muscular and skeletal development has been observed as well prenatally as postnatally. As it was proved in mammalian embryos absence of muscles significantly affected size and shape of the mandible [32]. The impact of masticatory muscles on craniofacial growth and development has been the object of interest of orthodontists [33, 34]. Contractions of craniofacial muscles must be present to stimulate growth of bone and cartilage. The contractions start between 6th and 8th week of embryonic development. Lack of this activity may cause e.g. microretrognathia, hypertelorism, small and open mouth, flat zygoma, small tongue [35]. In our observations geniohyoid, genioglossus and mylohyoid muscles were well visible with their fibres inserted in the inferior surface of Meckel's cartilage at stage

18 (44 days). Under some circumstances suprahyoid muscles might perform improper function resulting e.g. Class III malocclusion [36].

Conclusions

The mandibular symphysis' formation is a multistage unique process started during embryogenesis and almost completely finished before birth. Considering that these two exclusively human features — mandibular symphysis and mentum are so important due to developmental, functional and aesthetic reasons the effort should be made to fully understand their role.

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Conflict of interest statement

The authors declare that there is no conflict of interest in the authorship or publication of contribution.

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