The palatomaxillary suture revisited:
A histological and immunohistochemical study using human fetuses

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Summary: In human fetuses, the palatine process of the maxilla is attached to the inferior aspect of the horizontal plate of the palatine bone (HPPB). The fetal palatomaxillary suture is so long that it extends along the anteroposterior axis rather than along the transverse axis. The double layered bony palate disappears in childhood and the transverse suture is formed. To better understand the development of the double layered bone palate, we examined histological sections obtained from 25 fetuses of gestational age 9–11, 16–18 and 30 weeks. The double layered palate was seen in all of the specimens examined. Inferior angulation of the posterior end of the HPPB was evident at 9–11 weeks, but the initial palatine aponeurosis did not attach to the angulation but to a slightly anterior site. Both the maxilla and the HPPB were tightly attached to the vomer at 16–18 weeks. In both bones, bilateral plates met at the midline. The palatomaxillary suture was filled with short, randomly arranged collagen fibers. The nasal end of the suture was covered by a tight periosteum. Immunohistochemical examination of 3 fetuses at 16–18 weeks showed: 1) no expression of versican, tenascin-c or type II collagen in the suture; 2) few mitotic cells positive for proliferating cell nuclear antigen; 3) no or few CD34-positive developing vessels; and 4) no CD68-positive macrophages. These findings suggested that the fetal palatomaxillary suture was inactive for reconstruction and growth and that soft palate muscles likely did not contribute to the development of the double layered configuration.

Introduction

In the human fetal hard palate, the palatine process of the maxilla is attached to the inferior aspect of the horizontal plate of the palatine bone (HPPB), forming a double-layered configuration. Thus, in contrast to the morphology in adults, end-to-end contact between the HPPB and maxilla is unlikely in fetuses (Melsen, 1975; Ishimaru, 1984; Fig. 1). A Japanese dentist might first describe the supero-inferior overlapping of the bony plates in the human fetal palate (Kamaya, 1957). The fetal palatomaxillary suture is so long that it extends along the anteroposterior axis rather than along the transverse axis. This double-layered bony palate is maintained until childhood (Melsen and Melsen, 1982). The overlap between the maxilla and the HPPB corresponds to an oral area on the medial side of the fifth deciduous tooth or the fourth-fifth teeth in midterm fetuses (Kim et al., 2016a; Fig. 1). The palatomaxillary suture is likely to contribute considerably to palatal growth.

Many studies have investigated the growth pattern of the palate, a major interest among dentists and head surgeons (Melsen, 1975; Melsen and Melsen, 1982; Njio and Kjaer, 1993; Silau et al., 1994; Sejersen et al., 1996; Rojvachiranonda et al. 2003). These studies provided a basis for understanding partial anomalies of the palate, such as segmental odontomaxillary dysplasia (Becktor et al., 2002; Whitt et al., 2011). Less is known, however,
about the double layered bony palate, such as whether the bony deposition and reconstruction process starts in the fetal palatomaxillary suture.

A clue to understanding the development of the double layered bony palate may be provided by the close relationship of the HPPB with soft palate muscles. Specifically, a developing muscle may mechanically stress the HPPB via the palatine aponeurosis. Many studies have assessed the contribution of fetal masticatory muscles to the growth of the mandibular condyle (Spyropoulos, 1977; Öğütçen-Toller and Juniper, 1993; Carranza et al., 2006).

Although soft palate muscles are likely to pull the HPPB posteriorly, they seemed not to push further upward than the palatine process of the maxilla. Another clue to understanding the development of the double layered bony palate may be provided by the developing vomer, in that it may be tightly connected to the HPPB rather than the maxilla and pull the former upward. Examination of 62 fetuses of gestation age 9–24 weeks found that, in early stages, the vomer attaches inferiorly only to the maxilla, but that it later also attaches to the HPPB (Sandikcioglu et al., 1994). That study, however, did not evaluate the double layered bony palate. This study therefore utilized immunohistochemistry to re-examine the human fetal bony palate, with special reference to its close topographical relationship to soft palate muscles as well as the vomer.

Materials and Methods

Specimens

This study was performed in accordance with the provisions of the Declaration of Helsinki 1995 (as revised in Edinburgh 2000). Paraffin-embedded, frontal or sagittal sections of 25 fetuses were examined: 1) 10 of crown-rump length (CRL 45–70 mm) or approximate gestational age (GA) 9–11 weeks; 2) eight of CRL 125–170 mm or approximate GA 16–18 weeks; and 3) seven of CRL 250–270 mm or approximate GA 30 weeks. Frontal sections were prepared from 11 fetuses (three each of GA 9–11 and 16–18 weeks and five of GA 30 weeks), while sagittal sections were prepared from the other 14 fetuses (seven of GA 9–11 weeks; five of GA 16–18 weeks and two of GA 30 weeks).

Previously, 15 specimens (seven of GA 9–11 weeks and six of GA 18–20 weeks) had been processed for sagittal or frontal sections. All of these fetuses were part of the large collection kept at the Embryology Institute of the Universidad Complutense, Madrid, being the products of urgent abortion, miscarriage or ectopic pregnancy managed at the Department of Obstetrics of the University. Approval for the study was granted by the ethics committee of the University (B08/374).

The other midterm fetuses (three of GA 9–11 weeks and two of GA 16–18 weeks) were used for immunohistochemical experiments. These fetuses had been donated by their families to the Department of Anatomy, Yanbian University Medical College, Yanji, China, and their use for research was approved by the university ethics committee in Yanji (No. BS-13-35). These fetuses had been obtained by induced abortion, after which the mother was orally informed by an obstetrician at the college teaching hospital of the possibility of donating the fetus for research; no attempt was made to actively encourage the donation. After the mother agreed, the fetus was assigned a specimen number and stored in 10% w/w neutral
formalin solution for more than 1 month. Because of specimen number randomization, there was no possibility of contacting the family at a later date. After dividing each fetal body into parts, head samples were decalcified by incubating them at 4°C in 0.5-mol/L EDTA (pH 7.5) solution (Decalcifying Solution B; Wako, Tokyo, Japan) for 3–5 days, depending on the size of the sample. The head specimens were sectioned sagittally at 20 micron thickness, 5 µm.

All seven late stage fetuses (GA around 30 weeks) were part of a collection kept at the Department of Anatomy, Akita University, Akita, Japan. They had been donated to the Department by their families during the period 1975–1985, and preserved in 10% w/w neutral formalin solution for more than 30 years. The available data were limited to the date of donation and GA. There were no related documents providing family name, the name of the attending obstetrician or hospital, or the reason for abortion. The use of these specimens for research was approved by the ethics committee of Akita University (No. 1378). The head specimens were incubated at room temperature in Plank-Rychlo solution (AlCl(2)2H2O, 7.0 w/v%; HCl, 3.6; HCOOH, 4.6) for 1–2 weeks. The specimens were embedded in paraffin by routine procedures, followed by semiserial sectioning (7–10 µm thickness; with intervals of 0.1 or 0.5 mm) and staining with hematoxylin and eosin (HE).

Immunohistochemistry

Following their decalcification with EDTA, sagittal sections from four Chinese fetuses were used for immunohistochemistry using primary antibodies against matrix constituents, including 1) mouse monoclonal antibody against versican core protein (12C5) (1:25 dilution; Developmental Studies Hybridoma Bank); 2) rabbit polyclonal antibody against rat tenascin-c (1:100 dilution; Chemicon, Temecula, CA, USA); 3) rabbit polyclonal antibody against collagen type II (1:200 dilution; LSL, Tokyo, Japan); 4) rabbit monoclonal antibody against human CD68 (1:100 dilution; Dako, Glostrup, Denmark); 5) mouse monoclonal antibody against proliferating cell nuclear antigen (PCNA) (1:50 dilution; Thermo Fisher Scientific, Fremont, CA, USA); 6) rabbit polyclonal anti-human S100 protein or S100 (1:100 dilution; Dako N1573; Dako, Glostrup, Denmark); and 7) mouse monoclonal antibody against human CD34 class II (1:100 dilution; Dako M7165), a marker of developing blood vessels in the head (Katori et al., 2011). Before immunostaining with antibodies to versican, tenasin and collagen, the sections were pretreated with testicular hyaluronidase (25 mg/ml; Sigma type I-S; Sigma Chemicals, St Louis, MO, USA) in phosphate-buffered saline for 30 min at 37°C (Shibata et al., 2003). The specimens were subsequently incubated for 30 min in Histofine Simple Stain Max-PO (Nichirei, Tokyo, Japan) to detect the reaction of diaminobenzidine (DAB) with horseradish peroxidase (HRP), with a dark brown color being positive. As negative controls, specimens were incubated with normal rabbit or mouse IgG (10 µg/ml) rather than primary antibodies. Sections stained using the DAB method were counterstained with hematoxylin and were examined and photographed under a Nikon Eclipse 80 microscope.

Results

Observations of frontal sections

Frontal sections were obtained from 11 fetuses. A double layered bony palate was seen in 23 of the 25 specimens, with the HPPB consistently attached to the superior aspect of the posterior part of the maxilla and the inferior part of the maxilla protruded medially. In contrast, the HPPB was absent from the other two specimens (of GA 9–11 weeks; Fig. 2A–C). The perpendicular plate of the palate bone was well developed and had started to ossify. A loose piece of tissue containing epithelial pearls was present in the midline area below the ossified vomer. At this stage, the HPPB reached the midline area in a single specimen (Fig. 2D–F). We did not find any fibrous tissue pulling the HPPB medially toward the vomer. At 16–18 weeks, the vomer was tightly attached to both the maxilla and the HPPB (Fig. 3). Thus, in some sections, the vomer, HPPB and maxilla were tightly piled from the nasal to the oral side. At this stage, the bilateral HPPBs as well as the maxillae met along the midline. The bilateral HPPBs appeared to be triangular in shape, with the anterior apex inserted between the vomer and the bilateral palatal processes of the maxilla like a wedge (Fig. 3B). The palatomialary interface or suture was long, wide, smooth and flat (Fig. 2F and 3B). Between GA 18 and 30 weeks, the supero-inferior length of the nasal septum increased while its thickness decreased; and the inferior part of the vomer became longer and had inserted into a narrow space between the bilateral HPPBs.

Observations of sagittal sections

Sagittal sections were prepared from 14 fetuses with immunohistochemistry performed on sections from four specimens (Figs. 4–7). At 9–11 and 16–18 weeks, the HPPB showed a slight inferior angulation at the posterior end (Figs. 5EF, 6A and 7C). However, this angulation was not seen in the initial palatine bone (Fig. 4AB) or in late stage (GA > 30 weeks) fetuses. The angulated posterior end was located near the oral epithelium, between which was a mesenchymal condensation (Fig. 5DF). The palatine aponeurosis, receiving the levator veli palatini muscle, was connected with a site near the HPPB angulation, slightly distant from the posterior end of the HPPB. The palatomialary suture appeared to be smooth and flat and contained irregularly arrayed collagen fibers (Fig. 7B). A thick and tight periosteum covered the upper surface of the HPPB and extended to the maxilla across the
suture (Fig. 7B). Thus, in contrast to loose tissue within the suture itself, the two bony plates were connected tightly on the nasal side. The shape of the posterolateral part of the HPPB changed drastically after GA 18 weeks, depending on the growth of the pterygoid of the sphenoid bone (Fig. 7C–F). That is, a pterygopalatomaxillary suture was formed near and along the bony canals for palatine nerves from the maxillary nerves. The anterior end of this suture complex corresponded to the double layered bony palate.

Fig. 2. Early stage overlap between the palatine bone and maxilla: frontal sections of fetuses of CRL 46 mm (Panels A–C) and 64 mm (Panels D–F). Panels A and D show the most anterior site in the left and right column of panels, respectively. The 46 mm specimen shows no evidence of a horizontal plate (HP) of palatine bone (PB) or palatine process of the maxilla (MX). The 64 mm specimen shows the presence of these bony plates, which, however, do not reach the midline. Thus, these bones are not connected with the vomer (VM). The arrows indicate a remnant of the midline seam or midline epithelial pearls. The triangles in panel F indicate the future palatomaxillary suture. All panels were prepared at the same magnification (scale bar in panel A, 1 mm). For other abbreviations, see the common abbreviations for figures.
None of the four specimens examined showed expression of versican, tenascin-c or type II collagen in the palatomaxillary suture (Fig. 5G–I). The sutures contained few mitotic cells positive for proliferating cell nuclear antigen (Fig. 6B), no or few CD34-positive developing vessels (Fig. 6C) and no CD68-positive macrophages (Figs. 6D and 7G). The HPPB and maxilla were weakly positive for versican and type II collagen and their surfaces were strongly positive for tenascin-c. Bone trabeculae contained a few or abundant macrophages depending on the site (Figs. 6D and 7H). CD34-positive developing
Fig. 5. Overlap between the palatine bone and maxilla: sagittal sections of a 50 mm-CRL fetus. Panels A and J correspond to the most lateral and medial sides of the figure, respectively. The right-hand side of each panel corresponds to the posterior side of the head. Specimens in Panels A–F were stained with HE, whereas those in panels G–J (sections near panel E) were stained for immunohistochemistry. Panels A–C and E and Panels G–J were prepared at the same magnification. Panels D and I are higher magnification views of panels A and E, respectively. The double-layered bony palate is evident in panels C and E, including the horizontal plate (HP) of the palatine bone (PB) and the posterior end of the maxilla (MX). Triangles indicate future palatomaxillary sutures. The initial palatine aponeurosis, in panels A–F, is attached to the angulated posterior end of the horizontal plate. This posterior end accompanies a mesenchymal condensation (arrowhead in panels D and F). Immunohistochemical staining with antibodies to versican (Panel G), type II collagen (Panel H) and tenascin-C (Panel I) shows that none of these proteins was specifically expressed in the suture between the maxilla and palatine bone. Scale bars: 1 mm in panel A; 0.5 mm in panel D; 0.2 mm in panel G. For other abbreviations, see the common abbreviations for figures.
vessels were distributed along the bony trabeculae, not in the sutures. Finally, neither the HPPB nor the palatine plate of the maxilla contained cartilage elements positive for S-100 (Fig. 4CD).

At all stages examined, the anterior part of the HPPB was consistently located in the superior side of the posterior part of the maxilla. Because of the long interface, the palatomaxillary suture appeared to extend along the anteroposterior axis rather than along the transverse axis. The suture was characterized by the low number of cells, the non-specific extracellular matrices and the irregular arrangement of collagen fibers.

**Discussion**

The developmental stages of the human maxilla have been classified into seven stages (stages I–VII; Kjaer, 1989). Stage VII occurs in fetuses of CRL 80–150 mm CRL, with the maxillary bony band “combining” with ossification centers of the HPPB. That study, however, did not describe the double-layered bony palate. A review of the growth process of the maxilla found that: 1) transverse growth depends mainly on the intermaxillary suture, which is stimulated by the tongue; 2) vertical growth depends mainly on the eruption of teeth; and 3) postero-anterior growth depends on the development of the vomer and occurs along the pterygopalatine suture (Vacher et al., 2010). Although the pterygopalatine suture should include the double layered bony palate, morphological changes in this structure were not considered. The developing vomer appeared to push the palatal process of the maxilla as well as the HPPB downward. Vomer growth is faster than normal in patients with than without cleft lip and palate (Kilmes et al., 1992). Examination of 62 fetuses of GA 9–24 weeks showed that, during early stages, the vomer attaches inferiorly only to the maxilla, but later becomes attached to the HPPB (Sandikcioglu et al., 1994). Near the growing maxilla, vomer and pterygoid, the HPPB seemed to maintain its position on the superior aspect of the palatal process of the maxilla.

The palatine aponeurosis is composed of expanded tendons of the bilateral tensor veli palatini muscles and receives the levator veli palatini, the palatopharyngeus and other short muscles. The midline sling of the bilateral levator muscles is located just above and behind the aponeurosis (Klueber and Langdon, 1979). At the beginning of this study, we expected that these muscles would contribute to the posterior growth of the HPPB. The HPPB at GA 9–11 weeks was characterized by an inferior angulation at the posterior end. However, developing soft palate muscles were unlikely to provide sufficient mechanical stress to bend the HPPB because the aponeurosis attachment was slightly distant from the posterior angulation. In contrast, the oral epithelium was connected with the
Fig. 7. Palatine bone and maxilla including their lateral parts: sagittal sections of a 150 mm-CRL fetus. Panels A and F correspond to the most medial and lateral sides of the figure, respectively. The left-hand side of each panel corresponds to the posterior side of the head. Specimens in Panels A and C–F were stained with HE and prepared at the same magnification, whereas those in panels G and H (a section near panel A) were stained with antibody to CD68. Panels A–F display the mediolateral changes in shape of the palatine bone (PB) from the medially-located horizontal plate (HP) to the laterally-located bony canal for palatine nerves (PN). Panel B (silver impregnation, higher magnification of a circle in panel A) shows a thick periosteum (arrowheads) extending across the nasal end of the suture. The palatomaxillary suture (triangles) is occupied by irregularly arrayed collagen fibers (panel B). An inferior angulation is seen at the posterior end of the horizontal plate (arrowhead in panel C). The suture contained no CD68-positive macrophages (panel G), in contrast to the osteoblasts along the bony trabeculae in the maxilla (arrows in panel H). The palatine aponeurosis is attached to the palatine bone in panel D. Scale bars: 2 mm in panel A; 0.5 mm in panel B; 0.2 mm in panel G. For other abbreviations, see the common abbreviations for figures.
angulation of the HPPB by a mesenchymal condensation. The epithelium was likely to determine the shape of the posterior end of the HPPB, similar to findings in the middle and external ear, in which the epithelium is thought to determine cartilage morphology (Mallo et al., 2000).

Fetal development of tight connective tissue, with or without cartilage, is liable to occur in a mesenchymal condensation expressing specific matrices such as versican and tenasin-c (Jin et al., 2016). At 16–18 weeks GA, the palatomaxillary suture appeared to be inactive for bone deposition, reconstruction and growth. This was indicated by 1) a tight periosteum across the nasal margin of the suture; 2) filling of the suture with randomly arranged short collagen fibers; 3) lack of suture expression of versican, tenasin-c and type II collagen; and the finding of 4) few PCNA-positive mitotic cells, 5) few CD34-positive developing vessels and 6) the absence of CD68-positive macrophages. Because the periosteum across the nasal end of the suture is tight, the nasal epithelium, in contrast to the incisive fossa (Kim et al., 2016b), was unlikely to invade the suture. Also at 16–18 weeks, the shape of the lateral part of the palatomaxillary suture changed drastically, a change that may be associated with growth of the pterygoid. A case report of a pterygoid anomaly found in a human fetus of 155 mm CRL (GA 18 weeks) showed a figure incidentally displaying the double layered hard palate. The nearby tooth buds (i.e., the fifth or fourth and fifth teeth) also seemed to have no effect on the tight and silent attachment between the maxilla and HPPB. Further investigation of receptors of estrogen and other hormonal factors may help in better understanding silent sutures.

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**Figure legends**

Common abbreviations for figures:

CPS, constrictor pharyngis superior muscle;
EOM, extraocular muscle;
HP, horizontal plate of the palatine bone;
INC, inferior nasal concha;
ION, inferior orbital nerve;
LVP, levator veli palatini muscle;
MC, Meckel’s cartilage;
MH, mylohyoideus muscle;
MM, middle meatus of the nasal cavity;
MNC, middle nasal concha;
MX, maxilla;
MXN, maxillary nerve
NC-PX, nasal cavity and pharynx;
NC, nasal cavity;
NS, nasal septum;
PB, palatine bone;
PP, pterygoid process
PPG, pterygopalatine ganglion;
PTT, pharyngotympanic tube;
SMG, submandibular ganglion;
SP, sphenoid bone;
VM, vomer;
VN, Vidian nerve.
VNO, vomeronasal organ;