Development of Collagen Fibers and Vasculature of the Fetal TMJ

By

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Summary: Using 12 human fetuses, histological development and changes in connective fiber structure and fine vascular patterns have been investigated in various fetal gestational stages by light and scanning electron microscopy.

The main arterial supply of the articular disc was from the bilaminar region and pterygoideus lateralis muscle. The vascular network on the disc surface was related with fluid secretion. When the bilaminar region was compressed, it caused ischemia and fibrosis as the main pathological changes in TMJ derangement. A decrease in fluid from blood vessels might occur in TMJ degeneration. Collagen fibers in the disc passed mainly anteroposteriorly. In the anterior and posterior bands, muscular tendon fibers came from the pterygoideus lateralis muscle and superior stratum of the bilaminar region. In the posterior band three-dimensional structures of collagen fibers suitable for load bearing were observed. The compass network and process on the disc showed the normal structure that is formed gradually and has functions including dispersion, pressure bearing, friction-proofing and storage of the synovial fluid. Attachments of the disc were suitable for disc function. Large elastic fibers in the posterolateral part of the superior stratum of the bilaminar region may be antagonistic to the upper head of the pterygoideus lateralis muscle fibers passing medioanteriorly, indicating that this antagonism is available for disc function.

The temporomandibular joint (TMJ) is the only joint capable of associated movements based on the mandibular movement, which depends on the normal situation of tissues comprising the TMJ and their coordination. Injuries or physical disorders of these tissues cause the TMJ derangement (TMJD). For many years, the research community has conducted research on the macroscopic morphology, histological structure, genesis and development of the TMJ. Similarly, pathological relations between TMJ structures and mandibular movement including TMJD have also been the focus of attention. The present study was undertaken to further understand the development of TMJ structures biologically and pathologically through a series of scanning electron microscopic (SEM) observations and studies of the histology and blood vascular distribution of the fetal TMJ.

Materials and Methods

Twenty-one sides of 12 fetuses were employed for this study. Three sides of the TMJ were damaged during the manipulation. The gestational age and crown-rump length (CRL) of these fetuses, were recorded (Table 1). All samples were observed by the following methods:

| Table 1. Histological management of TMJs of different gestational age groups |
|----------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Months         | 3.5    | 4      | 5      | 6      | 7      | 8      | 9      | 10     | Total  |
| CRL (mm)       | 120    | 140    | 190    | 230    | 270    | 300    | 340    | 360    |        |
| India ink perfusion | 1     | 1      | 2      | 3      | 2      | 2      | 0      | 1      | 12     |
| SEM            | 0      | 1      | 1      | 2      | 1      | 2      | 1      | 1      | 9      |
| Total          | 1      | 2      | 4      | 4      | 3      | 4      | 1      | 2      | 12     |

1. India ink perfusion of blood vessels

All fetal materials were preserved at room temperature for 4 hours after induced labor. The bilateral common carotid arteries were dissected, cannulated and ligated after exsanguination via the internal jugular veins. Pressure washing (about 200 mmHg) was conducted with 60 to 500 ml heparin saline according to the respective gestational age. When the fluid from the internal jugular veins was lucid and the eyelid and labial red were whitening, per-
fusion with 30 to 140 ml of 0.5% glutaraldehyde was performed for ten minutes. Then, 20–40 ml of pure India ink suspension was perfused, followed by another 8–20 ml after ligation of the internal jugular veins. When all these procedures were completed, the common carotid arteries were ligated and the whole body was preserved at 4°C in a refrigerator for 24 hours. The bilateral TMJs were resected and postfixed in 10% neutral formalin for 1–2 weeks. After decalcification, the TMJ was sectioned on sagittal and coronal (frontal) planes. After dehydration and celloidin immersion for 6 weeks, the materials were sectioned at 100 μm in thickness and stained with hematoxylin-eosin, and at 200 μm without staining for stereoscopic and light microscopy.

2. Observation of elastic fibers
After induced labor, the fetuses were preserved in a refrigerator for histological study. The bilateral TMJs were dissected and immediately fixed in 10% neutral formalin for two weeks. Then, the specimens were washed and decalcified for 3 days. The TMJ was sectioned on sagittal and coronal planes and embedded in paraffin. Serial sections of 10 μm in thickness were stained with Weigert's method for microscopic examination.

3. Scanning electron microscopy (SEM)
After 0.5% glutaraldehyde perfusion for 30 minutes, the bilateral TMJs were resected and washed in phosphate buffer and fixed with 2.5% glutaraldehyde at 4°C for 48 hours and decalcified by 15% EDTA solution at 4°C for 1–2 weeks. The TMJ was sectioned sagittally and coronally into blocks (10 × 15 × 15 mm) and postfixed with 1% osmium tetroxide. Following ethyl alcohol dehydration, the specimens were dried at a critical point and coated with gold palladium for scanning electron microscopy (S-520, HITACHI) using an accelerating voltage of 15 KV.

Results

1. India ink perfusion
1) TMJ capsule
At 3.5 months of gestational age, there already were many blood vessels supplying the primary capsule (Fig. 1). This was more obvious at 4–5 months. In full-term fetuses, it appeared as follows: a) In the posterior part of the capsule, large blood vessels (about 260 μm in diameter) passed vertically around the condylar neck and were superoanteriorly distributed to the bilaminar region. There were few fine branches anastomosing with the main large vessels. b) In the anterior and medial parts of the capsule, there were mainly fine vessels (about 40 μm in diameter) and a few large vessels (about 200 μm in diameter) coming from the pterygoideus lateralis muscle. c) In the lateral part of the capsule, fine vertical vessels were scarcely found. d) There were obvious fine vessels supplying the villous processes in the upper articular cavity (Figs. 2, 3, 4).

2) Articular disc and its attachments
At 3.5 months of gestational age, there were no blood vessels in the disc. Only the primary bilaminar regions were supplied by vessels coming from the capsule (Fig. 1). At 4 months, vessels passing superoanteriorly were arborescently distributed to the bilaminar and lateral attachments. They formed a capillary network at the upper and lower surfaces, respectively, of the posterior and lateral attachments. The network facing to the articular fossa was fairly rich and was accompanied with fine medioanterior vessels in the central part of the disc. At the anterior band and medial part of the disc there were mainly vessels coming from the pterygoideus lateralis muscle. They were distributed postolaterally to the upper and lower surfaces of the disc, forming capillary networks with a few fine vessels. No blood vessels were found in the thinnest intermediate zone (central band), which enlarged with gestational age (Figs. 2, 3, 4).

3) Condyle
There were no blood vessels at 3.5 months of gestational age. But by 4 months blood passages could be observed and, as the fetus has grown, fine vessels (about 40 μm in diameter) passed into the fibrocartilage layer of the articular surface of the condyle. They were accompanied with superiorly passing vessels that came back from the condyle periosteum and synovium to form a vascular network in the fibrocartilage layer (Figs. 2, 4).

4) Fossa
There were no blood vessels in the primary fossa at 3.5 months of gestational age. At 4 months, bone trabeculae were formed and blood sinusoids appeared. Fine blood vessels (about 25 μm in diameter) passed vertically from the blood sinus onto the superficial fibrous layer lining the fossa. As the fetus has grown, the sinusoids decreased in number (Figs. 1, 2, 4).

2. Elastic fibers in the disc
At 4 months of gestational age, little elastic fibers appeared in the bilaminar region and increased in number with gestational age. Small bundles of elastic fibers were distributed in this central segment. The serial sections showed that the lower stratum was thick and included more elastic fibers.
Discussion

1. Blood supply, physiology and pathology of the TMJ

It has been believed that the main nutritional sources of the disc and synovial fluid are blood vessels coming from the articular capsule (Parsons and Boucher, 1966; Zarb and Carlsson, 1979; Chang, 1981). Kubota (1966) found a blood vascular network on the articular surface of the disc and condyle. The present study elucidated that large blood vessels in the posterior part of the capsule entered the bilaminar region vertically. Many blood vessels supplied the anteromedial part of the upper head of the pterygoideus lateralis muscle. Blood vessels passing in the lateral and medial attachments of the capsule formed a capillary network on the upper and lower articular surfaces of the disc, respectively. Thus, it can be concluded that blood vessels from the pterygoideus lateralis muscle and bilaminar region are the main sources of disc nutrition. The networks on the upper and lower surfaces of the disc as well as in the villous processes have been believed to be related to the secretion of synovial fluid. The present authors also observed a blood passage and vascular networks reflecting backward from the synovium in the fibrocartilage layer of the condyle in the early fetal period. This implies that the fibrocartilage layer has a very important effect on condyle development. Abundant blood vessels on the fossa’s surface probably contribute to intramembranous ossification.

The blood supply of the TMJ is related to its development. If it were obstructed, pathologic changes would be found in TMJ structures. Weinberg (1984) reported that condyle displacements made up 90% of all TMJD patients, especially posterior displacement. Other pathologic studies concluded that structural disturbances in the TMJ always followed pathologic changes in the bilaminar tissues (Hall et al., 1984 and Westesson, 1985). The present authors consider that when the condyle shows a posterior displacement, the bilaminar tissue is likely compressed and results in ischemia where collagen fibers have gradually increased but elastic fibers have decreased in number. The bilaminar region which is not susceptible to compression could be compressed by posterior displacement of the condyle, as suggested by Ohta and Suwa (1991), the blood vessels of which would be damaged, preventing outflow of blood. These obstructions may lead to gradual fibrosis and hyalinization. A decrease in the elastic fibers in the upper stratum of the bilaminar region would prevent repositioning of the disc during normal function. This region is elongated during its change to fibrosis, and finally takes the place of the posterior band that has just been positioned beyond the condyle, and thereby structural disturbances in the TMJ begin to appear. In addition, TMJ derangement...
caused by compression and fibrosis of the bilaminar region causes a decrease in synovial fluid that induces degeneration of the disc. If the pterygoideus lateralis muscle spasm exists simultaneously, this change will be exacerbated. A rapid decrease in fluid may cause crests or spherical processes to be exposed and friction to increase on the articular surface. Finally, the surface structure will be destructed, the disc will be perforated, and TMJ degeneration will progress.

2. Histologic structure of the disc and its functional significance

1) Collagen fiber distribution in the disc and its mechanism

The growth and direction of collagen fibers in the regions and bands of the TMJ remain to be fully understood. It is believed that the collagen fibers run anteroposteriorly in the central part of the disc, which has been indicated to be the main force-bearing spot (Choukas and Sicher, 1960; Wright and Moffett, 1974; Cohen and Kramer, 1976; Thilander et al., 1976; Zarb, 1979; Jagger, 1980; Taguchi et al., 1980; Bell, 1982; Lambert et al., 1984; Mongini, 1984; Wilson and Gardner, 1984 and Moore, 1985). These investigations showed that the anteroposterior collagen fibers mainly constructed sagittal sections of the posterior band of the disc, with only a few transverse fibers on the condyle surface. At the median sagittal section, most of them passed transversely. Only on the condyle surface were there a few of anteroposterior fibers. In the coronal sections, fibers in the medial part mainly passed medially, and transverse fibers were seen in the lateral part. Temporal attachment could be observed on the sagittal sections and in the postero-lateral part on the coronal sections. Electron microscopy revealed collagen fibers in the superior stratum of the bilaminar region passing from the postero-lateral down to the medio-anterior and into the posterior band of the disc. It disclosed that the collagen fibers in the posterior band were so complicated that they passed postero-anteriorly accompanying similar fibers coming from the superior stratum. It was also observed that the anteroposterior fibers in the posterior band showed an undulant band structure. On the surface of the condyle, “node”-like and vertically spiral structures were visible. The present authors believe that these structures may have the effect of both spiral and linear springs that make the posterior band capable of buffering and dispersing pressure, for example, in the case of bite-on ICP (intercuspal position).

The present study revealed that as early as 4 months of gestational age the anteroposterior and mediolateral collagen fibers in the intermediate band of the disc contributed to form a laminar structure, the arrangement of which became more compact at 7–8 months, and at birth, more vertically-arranged fibers appeared. Thus it could be concluded that although the intermediate zone was very thin, the compact lamination and vertically-arranged fibers reinforced this band a great deal.

In the anterior band, undulant, anteroposterior collagen fibers were found on the fossa surface. The transverse fibers increased as viewed from the fossa side to the condyle side with interdigitation of the anteroposterior fibers. These transverse fibers on the condyle side and the insertion of the pterygoideus lateralis muscle on the infero-antero-medial part of the disc indicate that the fibers in the anterior band were basically observed in the direction of the anteroposterior passage with interdigitation of tendon fibers of the muscle, which ran from the medio-anterior to the posterolateral position mainly on the condyle side of the anterior band. Because the anterior band was looser and no force-bearing fibrous element was found by electron microscopes, the anterior band may not have the force-bearing structure. The position of the anterior band also seems not to bear any great load under normal mandibular function.

2) Formation and function of the surface structure of the disc

The surface structure of the disc has been examined recently (Choukas and Sicher, 1960; Jagger, 1980; Wilson and Gardner, 1984). Jagger pointed out that the uniformity of the crest process on the surface of the disc has prevented the TMJ from being well lubricated. The present study elucidated that the disc surface was in the form of an undulant, crest and spherical process. These characteristics were formed by an interweaving of undulant fibers and collagen fibers crawling up on it and served as a network. These undulations formed on the disc surface as a normal structure have developed gradually from 4 months of gestational age. This compact reticular structure and crest process could not only buffer and disperse pressure but also resist friction. Pittings formed by the undulant crest helped in the storage of synovial fluid. Lambert et al. (1984) confirmed that the articular surface, not being touched, had a smooth surface like asphalt pavement. This also supports the idea that the crest is normally covered by synovial fluid so that articular movement is sufficiently lubricated.

References


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Explanation of Figures

Plate I

Fig. 1. 3.5-month fetal TMJ, CRL 100 mm, sagittal section. B: primary bilaminar region, C: condyle, D: disc, F: mandibular fossa. X 23.6.

Fig. 2. 8-month fetal TMJ, CRL 290 mm, sagittal section. B: bilaminar region and posterior band, C: condyle, D: disc, E: pterygoideus lateralis muscle, P: posterior part of capsule. X 12.9.

Fig. 3. 8-month fetal TMJ, CRL 290 mm, sagittal section. D: disc, F: fossa, S: upper articular cavity. X 68.4.

Fig. 4. 8-month fetal TMJ, CRL 310 mm, coronal section. C: condyle, E: pterygoideus lateralis muscle, F: fossa, L: lateral side, M: medial side. X 12.8.
Plate II

Fig. 5. 8-month fetus, CRL 310 mm, sagittal section. Undulant fibers passing from the posterolateral to the anteromedial direction in the upper stratum of the bilaminar region.

Fig. 6. 4-month fetus, CRL 140 mm, sagittal section. Belt-like structures formed by compactly-arranged collagen fibrils passing mediolaterally in the lower stratum of the bilaminar region.

Fig. 7. 8-month fetus, CRL 310 mm, sagittal section. The condyle side of the posterior band of the disc. “Ω” or node-like collagen fibers.

Fig. 8. 7-month fetus, CRL 280 mm, sagittal section. In the central band of the disc, collagen fibrils run anteroposteriorly and mediolaterally, forming dense belt-like structures with interdigitating arrangements.
Plate III

Fig. 9. Full-term fetus, CRL 360 mm, sagittal section. In the anterior band of the disc, collagen fibers pass anteroposteriorly and interlace with transverse fibers.

Fig. 10. 8-month fetus, CRL 310 mm, coronal section. Mainly transverse fibers and many vertical fibers in the center of the disc.

Fig. 11. 7-month fetus, CRL 280 mm, the upper surface of the disc. A dense network appears undulated and forms a ridge process.

Fig. 12. Full-term fetus, CRL 360 mm, the lower surface of the disc. A compact network forms a spherical process.