Fibro-Architectonics of Human Temporomandibular Joint

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Summary: 1. This study has been done with following three methods to elucidate the fibro-architecture of human temporomandibular joint. (a) Whole joint was embedded in Histosec (Merck) and the sections were made by Reichert-Jung Heavy-duty Mikrotome K type with tungsten knife and stained. (b) Small part of joint was sectioned and embedded in styrene and sections were made into requisite direction with glass knife and stained. Then (c) after block (the whole) staining has been done, the film-preparation (Häutchen-präparat) of synovial membrane has been made.

2. Structure of the disc in the temporomandibular joint by the film-preparation and fibro-architecture depending on passive movement of synovial membrane have been reported. (a) Typically stratum synoviale consists of synovial cells, lamina propria synovialis and tela subsynovialis but at the central portion of the disc lamina propria and tela subsynovialis agree with disc fibers. At the peripheral portion of the disc and the part which shifts to articular-cartilage in the peripheral portion lamina propria, tela subsynovialis and disc fibers are present, and lamina propria and tela subsynovialis thicken distinguishably. Especially at the reflection both of them become thickest. (b) Synovial cells become extremely squamous at the part with fibro-cartilage of the disc i. e., at the central portion of the disc but at the part without fibro-cartilage in the peripheral portion of the disc they become cuboidal.

3. Running of the synovial membrane fiber by the film-preparation has been described. (a) Collagen fibers of lamina propria run in concentric circle toward the central portion of the disc. (b) Collagen fibers of tela subsynovialis run radially from the central portion of the disc. (c) Elastic fibers generally run in concentric circle toward the center of the disc but cubic network structure is shown in the anterior extension, bilaminar zone and peripheral of insertion at lateral pterygoid muscle in the medio-peripheral portion of the disc.

4. It was assumed that the structure of the synovial membrane above-mentioned provides temporomandibular joint movement including disc movement caused by mechanic-function.

Form and structure of the temporomandibular joint (articulatio temporomandibularis) have been studied in many animals with many methods. Concerning architecture of fiber which constructs the greater part of the joint, any work has not been done caused by difficulty of obtaining the human material although new embedding methods have developed. As a matter of course the film-preparation (Häutchen-präparat) carried out in this study has not been tried, either.

We introduce the new result on architecture of fiber in the human temporomandibular joint with staining film-preparation (Vogt, 1935) and styrene method. Besides, characteristic of muscle function is being clarified concerning movement of the temporomandibular joint by the result from each E.M.G. on masticatory muscles. However, there has been some controversies on the movement of the lateral pterygoid muscle which inserts in the articular disc as it lies in the deep part of the disc in human. The result of this structural study of ours will contribute to the interpretation of movement on the human temporomandibular joint.

Materials and Methods

The temporomandibular joints used in this study were collected from 22 cadavers (includes post-pathologico-anatomic cadavers) for anatomy practice and research at Department of Anatomy Gunma University in the 1978, '79 and '80 years. Their ages are between 39 and 77 years. Materials were stored in 10% formol.

1) In 4 examples decalcification for bones with peripheral muscles was carried out with 50% trichlor acetic acid solution and then materials were embedded in high melting point (56°-60°C) paraffin (Histosec. Merck) and made into 20 μ thick serial sections by Reichert-Jung Heavy-duty Mikrotome type K with

tungsten knife. Secions were attached to 50×80 mm slide glasses. Staining has been done by Hansen's hematoxylin (Chroma) eosin, Weigert's resorcin fuchsin (Chroma), and orcein (Merck).

2) In 6 examples the articular disc and the nearest capsular tissue were sectioned radially from the central portion of the disk and were embedded in styrene (Kantokagaku), then from 2 to 3 μ thick serial sections were made by Porter-Blum ultramicrotome with glass knife. After removal of styrene with toluene, sections were stained with Hansen's hematoxylin eosin, Weigert's resorcin fuchsin, orcein and Heidenhain hematoxylin.

3) In 2 examples 20 μ thick frozen sections were prepared and stained with the same methods.

4) Film-preparation (Häutchen-präparat, Vogt, 1935) was prepared. In 5 examples the disc and the peripheral tissue were cut into 5 or 10 parts. Each parts were stained with block staining (Hansen's hematoxylin staining, Weigert's resorcin fuchsin or orcein staining). Under a binocular microscope synovial membrane was stripped off and mounted in glycerin, and observed through synovial membrane surface under the light microscope. Orcein staining was suitable for the observation.

The stereo paired photographs (Figs. 20.20'~28.28') can be taken within the limit of approximately 30 times (original size), therefore the photographs in our study were taken by 100 times tilting the preparation to the right and left (5~6°) under the microscope.

Observation

Gross anatomy

Most characteristic feature of the temporomandibular joint (articulatio temporomandibularis, P. N. A., B. N. A.: artculus mandibularis, J. N. A.) is that the articular

disc (*discus articularis*) lies between glenoid fossa and articular process in the temporal bone and the mandibular head (*caput mandibulare*, P.N.A., B.N.A., *capitulum mandibulae*, J.N.A.) of the condyle (*processus condylaris*, P.N.A., B.N.A.; *processus articularis*, J.N.A.) and in the anterior medial part of the disc the lateral pterygoid muscle is inserted.

The structure of joint is described according to Rees' terminology. The interarticular disc as a dense sheet of fibrous tissue. Its inferior surface is concave everywhere and is oval in shape like as the condyle with which it is contact with its long axis placed transversely. The superior surface is convex posteriorly but it is saddleshaped anteriorly, being slightly convex from side to side and slightly concave from before backwards. From above the disc appears pear-shaped with the apex anteriorly. When jaws are opposed, its general form is that of a schoolboy's peaked cap covering the condyle and extending forwards in front of the condyle with relation to the articular eminence of the temporal bone (Figs. 1-5).

The disc is not equally thick throughout but exhibits five clearly defined transverse ellipsoidal zones. It is transversely divided into as follows from the anterior region. (1) anterior extension (Rees, 1954: *pes menisci*, Griffin and Sharpe, 1960, *qe* in Figs.): is located in the frontal part of the anterior band and frontal lower part of the articular process, and covers the disc. The upper layer is dense fibrous connective tissue and follows from the disc to the frontal margin in the articular process in the temporal bone. The anterior medial part of the lower layer is lateral pterygoid muscle and the peripheral portion of it is connective tissue which includes vessels system. (2) anterior band (Rees, 1954; *hela* (?) of *pes menisci*, Griffin and Sharpe,

1960: *vorderer Wulst*, Lubosch, 1906, *ab* in Figs.): it coincides with the frontal margin in the mandibular head and projects from the lower plane to the transverse axis in the disc. In the anterior medial part lateral pterygoid muscle is inserted. (3) intermediate band (Rees, 1954; *pars gracilis menisci*, Griffin and Sharpe, 1960; *mittlere schmale Zone*, Lubosch, 1906, *ib* in Figs.): it is a thin and narrow part and presents between the anterior and posterior bands. (4) posterior band (Rees, 1954; *pars posterior menisci*, Griffin and Sharpe, 1960; *hinterer Wulst*, Lubosch, 1906, *pb* in Figs.): the upper surface of the mandibular head exhibits crosswise ellipsoidal form toward the transverse axis in the head. The posterior band is located coincident with the upper surface. (5) bilaminar zone (Rees, 1954, *bz* in Figs.): it separates into two strata, the superior stratum (*ss* in Figs.) and the inferior stratum (*ist* in Figs.). The superior stratum indicates the part from the back margin in the posterior band to the posterior temporal attachment (described later) and the inferior stratum indicates the part from the back margin in the posterior band to insert to the mandibular neck.

Between both bones and the disc capsular fibrous attachment tissue lies in the tissue reflecting in the peripheral portion. This tissue reflection is considered to be transitional fold to reserve for motion. The attachments are named as follows: (1) anterior temporal attachment (*aA* in Figs.): the region which lies from the reflection of the frontal margin of the anterior extension in the disc to the temporal bone, (2) posterior temporal attachment (*pA* in Figs.): the region from the reflection of the superior stratum of the bilaminar zone in the disc to the temporal bone, (3) medial temporal attachment (*mA* in Figs.): the region which lies between the reflection of the medio-

peripheral portion in the disc and the temporal bone, (4) lateral temporal attachment (*lt* in Figs.): the region between the reflection of the latero-peripheral portion in the disc and the temporal bone, and (5) anterior mandibular attachment (*mandA* in Figs.): the region between the lower margin of the anterior band in the disc and the frontal margin of the mandibular neck.

The part bending greatly between the disc and the frontal margin in the mandibular neck as well as the part from the disc to the attachment in the temporal bone are called reflection, (1) anterior temporal reflection (*aR* in Figs.): the part bending greatly between the anterior extension in the disc and the anterior temporal attachment, (2) posterior temporal reflection (*pR* in Figs.): the part bending greatly between the superior stratum in the bilaminar zone and the posterior temporal attachment, (3) medial temporal reflection (*mR* in Figs.): the part bending greatly between the medio-peripheral portion in the disc and the medial temporal attachment, (4) lateral temporal reflection (*ltR* in Figs.): the part bending greatly between the latero-peripheral portion in the disc and the lateral temporal attachment and (5) anterior mandibular reflection (*mand R* in Figs.): the part bending greatly between the lower margin of the anterior band in the disc and the anterior mandibular attachment. In these reflections plica synovialis develops well at the part in which lamina propria synovialis and tela subsynovialis are particularly thick.

Special attention should be paid that the reflection is not present between the disc and the back margin of the mandibular neck, and fibers from inferior stratum in the bilaminar zone insert in the tangent direction of circular arc of the mandibular head in the posterior upper in the mandibular neck. In this

case the name of the posterior mandibular attachment is deferred and this part is named by tangential insertion (*ins* in Figs.).

The superior head of the lateral pterygoid muscle is inserted in the disc. Lateral pterygoid muscle (*LPM* in Figs.) is two head muscle and the superior head (*SH* in Figs.) is inserted in the back margin of ala major ossis sphenoidaris of fossa infra temporalis and the inferior head (*IH* in Figs.) is inserted in fovea pterygoidea in the anterior medial surface of the condyle.

The joint capsule (*cap* in Figs.) is composed of the external layer and the internal layer, termed stratum fibrosum and stratum synoviale. The articular space without the articular cartilage is lined by stratum synoviale.

Vessels and nerves are observed in the peripheral portion of the disc and the attachment. And Zenker (1956) has described that fat tissue with vessels and nerves present in the retroarticular region of the joint as retroarticuläre plastische Polster, and has given functional significance to it.

Microscopic anatomy

Finding in the section preparation: The disc mainly consists of thick fibro-cartilage and collagen fibrous bundles are densely included and run. With respect to its running direction Lubosch (1906), Rees (1954), Griffin and Sharpe (1960, '62), Dixon (1962), Thilander (1964) and Sicher (1966) (Figs. 11, 12) have described. In the sagittal section the authors have divided the disc into anterior, central and posterior parts. They run intersecting backwards and forwards, transversally and vertically in the most part and in the thin part fibers are parallel each other as well as in the anterior and the posterior parts.

The disc is considered as fibrous part of lateral pterygoid muscle i.e., the tendon in the structure (Rees, 1944 Thilander

1964 and Sicher 1966). In section the direction of fibrous bundles is clear except in the fibro-cartilage part but it also can be determined in some degree in the cartilage part. Namely, throughout the disc thick fibrous bundles run radially and thin fibrous bundles run in concentric circle, but in the central portion of the disc some fibrous bundles run vertically as well as the direction of the above-mentioned and all of them mingle irregularly each other. It is considered that in the central portion of the disc (the anterior band, the intermediate band and the posterior band) the center is divided into the anterior and the posterior parts, i.e., two ellipsoidal centers lie in the anterior and the posterior bands (center of anterior is the anterior band and center of posterior is the posterior band). Namely, some fibrous bundles in the central portion of the disc mainly run radially from each center and others run in concentric circle toward each ellipsoidal center but in the intermediate band fibrous bundles run backwards and forwards. In the anterior extension and the superior stratum of the bilaminar zone in the peripheral portion of the disc, fibrous bundles run backwards and forwards, i.e., from the central portion of the disc they run radially. They turn around respectively and insert in the temporal bone. And in the inferior stratum, fibrous bundles running backwards and forwards insert in tangent direction in the back margin of the condyle. In the medio-peripheral portion of the disc, mainly thick fibrous bundles run radially from the central portion of the disc and they run toward the direction of lateral pterygoid muscle (Fig. 15). In the latero-peripheral portion of the disc they run radially from the central portion of the disc and then turn around and insert in the temporal bone (Figs. 13, 14).

The running of fibro-cartilage of the

disc: the presence and the distribution of fibro-cartilage cells (chondrocytes) were observed in serial sections by sagittal and frontal sections of the disc (Fig. 6). In sagittal section chondrocytes are found in the central portion of the disc (the anterior band, the intermediate band and the posterior band). And in the superior stratum of the bilaminar zone chondrocytes distribute within one third of the anterior part and in the inferior stratum and the lower stratum chondrocytes are scarcely observed. In the frontal section chondrocytes are found in the central portion of the disc but they increase toward the inside. Concerning the relationship between distribution of chondrocytes and that of elastic fibers in the peripheral portion, elastic fibers are found in the peripheral portion of the disc without chondrocytes. And especially elastic fibers are rich in the medio-peripheral portion of the disc and poor in the latero-peripheral portion of the disc. This finding seems to have functional significance. In regard to the chondrocytes in the human disc, its presence has been described by Petersen (1930), Schaffer (1930), Baecker (1931), Rees (1954), Griffin and Sharpe (1960), Dixon (1962) and Sicher (1966) and its absence has been described by Lubosch (1906), Thilander (1964) and Suzuki (1971). The discrepancy between the authors can be considered by difference of ages of materials.

Histological structure of the synovial membrane has been described by Hammer (1882), Davis (1945) and Caster (1960). According to nomina histologica (1970, '75, '77), stratum synoviale consists of lamina propria synovialis and cellula synovialis and is differentiated pars villosa from pars plana depending on the degree of concavo-convex on the surface. Namely, the part possessed plica synovialis and villus synovialis, which

can be considered as deformity of plica synovialis on the surface, is pars villosa and the part without them is pars plana. In nomina histologica tela subsynovialis is not adopted but Bloom and Fawcett (1976) employed this. Tela subsynovialis is recognized in stratum synoviale of the temporomandibular joint by the present authors. In regard to the synovial membrane Cawdry-Key (1932) classified it into (1) loose connective type, (2) dense connective type and (3) adipose type. These terms seem to take tissue included in tela subsynovialis into consideration.

Stratum synoviale is thick in the peripheral portion of the disc and becomes thin toward the central portion of the disc. The stratum synoviale in the sagittal and frontal section of the joint is thin in the part with fibro-cartilage (Fig. 6) and thick in the part without it; markedly thick 0.4-0.5 mm in the anterior mandibular reflection approximately five times as thick as the others (Figs. 13, 17). The synovial cells are squamous in the central portion of the disc and cuboidal in the peripheral portion of it (Figs. 17, 18) i.e., squamous in the thin part of stratum synoviale. Lamina propria synovialis is found on the surface of stratum synoviale facing to articular space. It becomes thicker as it transfers from the anterior extension to its reflection. In the lower frontal part it becomes thick in the anterior mandibular attachment. At bilateral sides it becomes thicker as it transfers from the central to peripheral portion of the disc. In the central portion of the disc it is thin in the part with fibro-cartilage and covers the disc together with fibro-cartilage (Figs. 15, 17). Tela subsynovialis appears just under lamina propria synovialis and it becomes thick in the peripheral portion of the disc and thickest in the reflection in the same as lamina propria synovialis. It also consists

of loose connective tissue (Figs. 13, 14, 15, 16, 18). Plica synovialis, which appears as membraneous in the medial articular space, develops near the reflection of the peripheral portion. These are well developed near the anterior extension in the anterior part, near the superior stratum in the bilaminar zone, in the posterior part and near the reflection in both sides. Plica synovialis has villus synoviale in some places (Figs. 17, 18).

Vessels are rich in the reflection in the peripheral portion of the disc but in the central portion they are hardly observed. These occur in lamina propria synovialis in the peripheral portion of the disc and in tela subsynovialis.

With respect to elastic fibers in the temporomandibular joint, Rees (1954), Griffin and Sharpe (1960, '62), Thilander (1964) and Suzuki (1971) have described that they are rich in the superior stratum and poor in the inferior stratum. According to Thilander (1964), running of elastic fibers in the disc is coexistent with collagen fibers in the embryonic stage but elastic fibers are not observed in the adult. In the section preparation elastic fibers are hardly observed in the central portion of the disc. In the peripheral portion distribution of elastic fibers varies in each part. In the anterior extension elastic fibers are rich all over. In the posterior part elastic fibers are rich from the superior stratum to the posterior temporal attachment but they are poor in the inferior stratum. In the medial peripheral portion of the disc elastic fibers are abundant from the pterygoid muscle to the medial temporal attachment. In the anterior mandibular attachment and the lateral peripheral portion elastic fibers are insufficient. These fibers are recognized as thin curly fibers among collagen fibrous bundles (Figs. 18).

Finding in the film preparation:

The serous tissues are stripped off as

the film preparation after separating the joint as small parts and carrying out block staining, and then observed microscopically from the surface. In these preparations Vogt (1935) and Takisawa (1949, '50) have applied to the human peritoneum and can obtain the findings which are impossible to expect from the section preparation. The present findings are as follows: Fig. 19, for example, is the section preparation of medio-peripheral portion of the disc, but the film preparation looks like Fig. 18, 19. From this it is clear that under large magnification synovial cells, fibers of lamina propria synovialis and tela subsynovialis are clearly observed from the surface and that elastic fibers are seen network state with elastic fiber staining. Staining with hematoxylin first and then elastic fiber staining (Weigert's resorcin fuchsin or orcein) have been carried out. Orcein staining is preferable for the elastic fibers; as collagen fibers are stained lighter than elastic fibers, discrimination between these fibers becomes more apparent, in addition plica and villi are seen under small magnification.

Findings in the film preparation in which the joint is separated into small parts have been reconstructed as follows: in the upper space of the joint collagen fibers of lamina propria run in concentric circle around the disc (Figs. 20.20', 21.21', 22.22', 24.24', 25.25', 27.27', 28.28') and tela subsynovialis is not present in the disc (Figs. 26.26') (described previously) but it consists of loose connective tissue in the peripheral portion of the disc and becomes thick as it develops toward the peripheral portion. And collagen fibers run radially from the disc (Figs. 7, 8). Disposition of collagen fibers is different from each other in lamina propria and in tela subsynovialis. Synovial cells are squamous in the central portion (Figs. 26.26') but cuboidal in the peripheral portion (Figs.

24.24'). Running of elastic fibers is different from that of collagen fibers and impossible to distinguish clearly in lamina propria from in tela subsynovialis. Elastic fibers run mainly in concentric circle around the disc but a few of them run radially. In the anterior extension (Figs. 20.20'), the bilaminar zone (Figs. 21.21') and near the insertion of lateral pterygoid muscle (Figs. 23.23') they show irregular cubical network. This irregular network is different from the elastic fibers in the arteries and it is not one layer of network but many layers of network (Figs. 20.20', 21.21', 23.23'). Fenestrated membrane is not observed.

In the section preparation more elastic fibers are seen in the medial side than in the lateral side and this agrees with film preparation. In the film preparation numbers of elastic fibers are observed: (1) Thickness of elastic fiber is $1\sim5\mu$, and (2) lateral twigs branch out from one thick fiber in places. And (3) in the section preparation it is observed as a thin, short and curly fiber, but in the film preparation it is observed as a long fiber with fixed direction. In addition to the findings the above-mentioned, as plica synovialis transfers toward the peripheral portion of the disc, small folds (height $10\sim20\mu$) become gradually larger. Small folds are present on the structure of large folds. Running of collagen fibers of lamina propria agrees with that of this plica. Plica develops best around the reflection and forms large folds (Figs. 13, 14, 15).

Discussion

There are the controversies on the function of human lateral pterygoid muscle on the mandibular joint (Moyers, 1950, Carlsöö, 1956 and Basmajian, 1974). They studied the function of the muscle with E.M.G. and described that the lateral pterygoid muscle has the single function

that worked only in opening of mouth. On the other hand, Zenker and Zenker (1955, '56) have observed the clear impulses of lateral pterygoid muscle in closing as well as in opening. Moreover, in E. M. G. experiment on monkey (*Macaca mulatta*), Grant (1973-A) and McNamara (1973) have reported that the superior head of lateral pterygoid muscle and inferior head work independently each other; activity of the superior head was observed in closing, especially during chewing and clenching of teeth and during deglutition.

The finding that the inferior stratum of the bilaminar zone inserts tangentially in the mandibular neck supports the Grant's and McNamara's studies. It has been already clarified by Triepel (1908) and Benninghoff (1961) that fibro-architecture is to be mechanic-functional structure. The present authors consider that mechanic-functional relationship is clear between such temporomandibular joint movement and fibroarchitecture; (1) To the upper and lower joint spaces lamina propria is the supporter of synovial cells and (2) tela subsynovialis may neutralized discontinuity between lamina propria and the disc. (3) The disc is regarded as an extension of lateral pterygoid muscle and seemed to play the role of the pad between the joint spaces. (4) Presence of the attachment and plica may neutralized the gap between the disc and the articular capsule in which stratum fibrosum provides the place for the vessels and nerve tissue. It may be considered that following joint movement including disc movement are observed by presence of fibro-architecture the above-mentioned.

At first, as the condylar head moves forwards in open movement, inferior stratum in the bilaminar zone is united with the condylar head and they move forwards each other without slipping off. Then the anterior mandibular attachment inserted from the anterior band to the

frontal margin of the mandibular neck is accompanied with protrusion movement of the condylar head and the anterior mandibular reflection is missed. On the contrary, at the anterior extension the anterior temporal reflection moves forwards taking the frontal margin into the anterior temporal reflection. In superior stratum in the bilaminar zone, it is taken in the superior stratum at the posterior temporal attachment, and the posterior temporal reflection transfers extremely to the insertion of the temporal bone. In close movement the opposite action of open movement works. Inferior stratum in the bilaminar zone connected with the condylar head and moves backwards, but the anterior mandibular attachment relaxes and makes the anterior mandibular reflection, then returns to the original state. During open and close movement lamina propria synovialis is stretched at Rugae rather than plicae. And fibers of tela subsynovialis run deeply toward the junction between tela subsynovialis and stratum fibrosum of the articular capsule and the disc. And when the disc returns to the original position, the superior head of lateral pterygoid may work and prevent the disc from slipping off.

In lateral movement when the mandibula moves to the right, the left side shows passive movement and when the movement is reversed, the right side shows passive movement. At this time lateral and medial attachments may neutralize.

In the periphery of the disc running manner and amount of elastic fibers are different at the lateral peripheral portion from at the medial peripheral portion. Namely, compared with the lateral temporal attachment there are more elastic fibers are seen in the medial temporal attachment and the running of them are in concentric circle toward central portion of the disc, but they exhibit cubic network

structure at the peripheral of insertion of lateral pterygoid muscle. This finding may indicate that the attachment of the lateral peripheral portion take more passive role than that of the medial peripheral portion. Contrary to this, many elastic fibers are seen in the attachment of the medial peripheral portion, and it is supposed that this portion participate in mechanical power created by the lateral pterygoid muscle and active action to return the disc to its original state. But in the lateral peripheral portion active action may be not considered. Besides in each part of the anterior extension and the anterior temporal attachment, the superior strutum of the bilaminar zone and the posterior temporal attachment, there are similar elastic fiber network structure as seen in the medial peripheral portion or the medial temporal attachment. But it is assumed that they work actively in returning the state in which plicae are possibly stretched or shurnk by opening, closeing and lateral movement to the former state.

References

- 1) Baecker, R.: Zur Histologie des Kiefergelenkmeniskus des Menschen und der Säuger, *Z. mikr.-Anat. Forsch.*, **26**: 223-268, 1931.
- 2) Benninghoff, A.: *Lehrbuch der Anatomie des Menschen*, Erster Band, Lehmannsverlag, München-Berlin, 1961, pp. 481-493.
- 3) Basmajian, J.V.: *Muscles alive*, 3rd ed, Williams & Wilkins Co., Baltimore, 1974, pp. 399-419.
- 4) Bloom, W. and Fawcett, D.W.: *A textbook of histology*, 10th ed, W.B. Saunders Co., Philadelphia, 1975, pp. 282-285.
- 5) Carlsöö, S.: Nervous coordination and mechanical function of the mandibular elevators: an electromyographic study of the activity and an anatomic analysis of the mechanics of the muscles, *Acta Odont. Scand.*, 10 suppl. 11: 1-132, 1952.
- 6) Caster, C.X.: The microscopic structure of normal human synovial tissue, *Arth. and Rheum.*, **3**: 141-151, 1960.
- 7) Carson, D.S., McNamara, J.A. Jr. and Jaul, D.J.: Histological analysis of the growth of the mandibular condyle in rhesus monkey (*Macaca mulatta*), *Am. J. Anat.*, **151**: 103-118, 1978.
- 8) Davies, D.V.: Anatomy and physiology of diarthrodial joint, *Ann. Rheum. Dis.*, **5**, 29: 29-35, 1945.
- 9) Dixon, A.D.: The human temporomandibular joint disc, *J. Anat. (Lond)*, **93**: 568, 1959.
- 10) Dixon, A.D.: Structure and functional significance of the intraarticular disc of the human temporomandibular joint, *O.S. O.M. and O.P.*, **15**: 48-61, 1962.
- 11) Elze, C.: *Braus' Anatomie des Menschen*, 1. Band, 3 Auflage, Springer-Verlag, 1954, pp. 702-719.
- 12) Griffin, C.J. and Sharpe, C.J.: The structure of the adult human temporomandibular meniscus, *Aust. Dent. J.*, **5**: 190-195, 1960.
- 13) Griffin, C.J., and Sharpe, C.J.: Distribution of elastic tissue in the human temporomandibular meniscus especially in respect to "compression" areas, *Aust. Dent. J.*, **7**: 72-78, 1962.
- 14) Grant, P.G.: Lateral pterygoid: two muscles?, *Am. J. Anat.*, **138**: 1-10, 1973-A.
- 15) Grant, P.G.: Biomechanical significance of the instantaneous center of rotation: The human temporomandibular joint, *J. Biomechanics*, **6**: 109-113, 1973-B.
- 16) Hammer, A.: Über den feineren Bau der Gelenke, *Archiv. f. Anat.*, **43**: 266-326, 813-885, 1882.
- 17) Lubosch, W.: Unter den Meniscus im Kiefergelenk des Menschen, *Anat. Anz.*, **29**: 417-431, 1906.
- 18) Lubosch, W.: Über Variation am Tuberculum articulare des Kiefergelenks des Menschen und ihre morphologische Bedeutung, *Gegenbaurs Morph. Jahrbuch*, **35**: 322-353, 1906.
- 19) Moyers, R.E.: An electromyographic analysis of certain muscles involved in temporomandibular movement, *Am. J. Orth.*, **367**: 481-515, 1950.

- 20) McNamara, J. A. Jr.: The independent function of the two heads of the lateral pterygoid muscle, *Am. J. Anat.*, **138**: 197-206, 1973.
- 21) Norgaard, F.: Arthrography of the mandibular joint, *Acta Radiologica*, **25**: 679-685, 1944.
- 22) Peterson, H.: Die Organe des Skelettsystems, In Möllendorff's Handbuch der mikroskopischen Anatomie des Menschen, 7. Bd, Teil 2, Julius Springer, Berlin, 1930, pp. 684-677.
- 23) Rees, L. A.: The structure and function of mandibular joint, *Brit D. J.*, **96**: 125-133, 1954.
- 24) Ricket, R. M.: Roentgenography of the temporomandibular joint, 2nd ed., Charles C Thomas Publisher, Springfield, 1964, pp. 102-132.
- 25) Schaffer, J.: Die Stützgewebe, In Möllendorff's Handbuch der mikroskopischen Anatomie des Menschen, 7 Bd., Teil 2, Julius Springer, Berlin, 1930, pp. 368-375.
- 26) Shapiro, H. H.: Maxillofacial anatomy with practical application, J. B. Lippincott Co., Philadelphia, 1954, pp. 259-287.
- 27) Sarnat, B. G.: The temporomandibular joint, 2nd ed., Charles C Thomas Publisher, Springfield, 1964.
- 28) Sicher, H.: Orban's Oral histology and embryology, 6th ed., C. V. Mosby Co., Saint Louis, 1966, pp. 335-343.
- 29) Schumacher, G. H.: Funktionelle Morphologie der Kaumusculatur, Gustav Fischer Verlag, Jena, 1961.
- 30) Suzuki, T.: In respect to distribution and functional significance of chondrocyte in the articular disc in various kinds of animals, *Shikagakuho*, **71**(5): 1301-1355, 1971.
- 31) Trierpel, H.: Über mechanische Strukturen, *Anat. Anz.*, **23**: 480, 1903.
- 32) Takisawa, A.: On the taenial fibrosae of the human colon. (Studies on the fibro-architectonics of peritoneum, Part I), *J. Anat. Nippon*, **24**(2): 55-56, 1949.
- 33) Takisawa, A.: On the peritoneum covering the human urinary bladder, (Studies on the fibro-architectonics of peritoneum Part II), *Nishinigaku*, **37**(2): 25-31, 1950.
- 34) Thilander, B.: The structure of the collagen of the temporomandibular disc in man, *Acta Odont. Scand.*, **22**: 135-149, 1964.
- 35) Vogt, W.: Eine Tania fibrosa als Längsspannung am menschlichen Dünndarm, *Vorh. Anat. Ges.*, **43**. Vers, Jena: 274-282, 1935.
- 36) Zenker, W.: Über einige neue Befunde am M. Temporalis des Menschen, *Z. Anat. Bd.*, **118**: 355-368, 1955.
- 37) Zenker, W. und Zenker, A.: Die Tätigkeit der Kiefermuskeln und ihre elektromyographische Analyse, *Z. Anat.*, **119**: 174-200, 1955.
- 38) Zenker, W.: Das retroarticuläre plastische Polster des Kiefergelenkes und seine mechanische Bedeutung, *Z. Anat.*, **119**: 375-388, 1956.

PLATES

Explanation of Figures

aA: anterior attachment	ist: inferior stratum of bilaminar zone
aR: anterior reflection	IA: lateral attachment
ab: anterior band	lR: lateral reflection
ae: anterior extension	LPM: lateral pterygoid muscle
bz: bilaminar zone	mA: medial attachment
C: processus condylaris of mandibula	mR: medial reflection
cap: stratum fibrosum of capsule	mandA: mandibular attachment
cal: lower space of cavum articulare	mandR: mandibular reflection
cau: upper space of cavum articulare	pA: posterior attachment
ch: chondrocytes	pR: posterior reflection
CM: caput mandibulare	pb: posterior band
CN: collum mandibulare	ps: lamina propria synovialis
co: collagen fiber	s: synovial cells
D: articular disc	SH: superior head of lateral pterygoid muscle
e: elastic fiber	sst: superior stratum of bilaminar zone
F: fossa mandibularis of temporal bone	T: temporal bone
fp: fovea pterygoidea muscle	ts: tela subsynovialis
ib: intermediate band	Tu: tuberculum articulare of temporal bone
IH: inferior head of lateral pterygoid muscle	V: blood vessels
ins: insertion	vil: synovial villi

Plate I

Fig. 1. Fig. observed the right side articular disc from above. The attachment of the peripheral from the reflection is enlarged remarkably. $\times 2.5$

Fig. 2. The rough sketch for Fig. 4 (sagittal section). The section Fig. in the line 2 of Fig. 1 and the line ② of Fig. 3. $\times 2.5$

Fig. 3. The rough sketch for Fig. 5 (frontal section). The section Fig. in the line 3 of Fig. 1 and the line ③ of Fig. 2. $\times 2.5$

Fig. 4. The right side temporomandibular joint, sagittal section (approximately 2.5 times as large). Paraffin (Histosec) embedding, sectioned with Reichert-Jung Heavy-duty Mikrotome type K. $\times 2.5$

Fig. 5. The right side temporomandibular joint, frontal section (approximately 2.5 times as large). Paraffin (histosec) embedding, sectioned with Reichert-Jung Heavy-duty Mikrotome type K. $\times 2.5$

Plate II

Fig. 6. Distribution of fibro-cartilage cells. Left Fig. shows saggital section of the right side temporomandibular joint. Right Fig. shows the Fig. shows the Fig. observed the right articular disc from above. $\times 1.5$

Fig. 7. Schema observed the right side articular disc from above.

Fig. 8. Schema observed the right side articular disc from below.

Fig. 7 and Fig. 8 of left Fig. shows running of collagen fibers of lamina propria synovialis. Right Fig. shows running of collagen fibers of tela subsynovialis. By film-preparation. The attachment is remarkably enlarged. $\times 2.0$

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Plate III

- Fig. 9. Anterior extension of the disc (sagittal section). (The arrow directs the anterior). Styrene preparation, H-E, $\times 60$
- Fig. 10. Superior stratum in the bilaminar zone in the disc (sagittal section). Styrene preparation, H-E, $\times 60$
- Fig. 11. The central portion of the disc (horizontal section). (The arrow directs the anterior). Styrene preparation, H-E, $\times 50$.
- Fig. 12. The central portion of the disc (sagittal section). (The arrow directs the anterior). Freeze section preparation, H-E, $\times 170$
- Fig. 13. Peripheral portion of the disc (sagittal section). Styrene preparation, H-E, $\times 90$
- Fig. 14. An enlarged photograph of Fig. 13. Styrene preparation, H-E, $\times 310$

Plate IV

Fig. 15. Medio-peripheral portion of the disc (sagittal section). Styrene preparation, H-E, $\times 140$

Fig. 16. Anterior mandibular attachment of the disc (sagittal section). (The arrow directs the anterior). Paraffin preparation, H-E, $\times 60$

Fig. 17. Insertion to the mandibular neck of the disc (sagittal section). Styrene preparation, H-E, $\times 60$

Fig. 18. Medio-peripheral portion of the disc (Sagittal section). Styrene preparation, Orcein, $\times 310$

Fig. 19. Film-preparation observed Fig. 18 from above (direction of the thick arrow). Film, Orcein, $\times 310$

Plate V

Stereo photograph

Film-preparation, Orcein, standerdized tilting angle ($5\sim 6^\circ$), the upper part of the photography is the posterior part, the right side is medial part. (The arrow directs anterior). $\times 240$

Fig. 20, 20'. The synovial membrane of the anterior extension of the disc.

Fig. 21, 21'. The synovial membrane in the bilaminar zone of the disc.

Fig. 22, 22'. The synovial membrane of the anterior mandibular attachment of the disc.

Fig. 23, 23'. The synovial membrane of the peripheral of insertion at lateral pterygoid muscle inside of the disc.

Plate VI

Fig. 24, 24'. The synovial membrane of the medial temporal attachment of the disc.

Fig. 25, 25'. The synovial membrane in the posterior part of medio-peripheral portion of the disc.

Fig. 26, 26'. The synovial membrane of the central portion of the disc.

Fig. 27, 27'. The synovial membrane of lateral peripheral portion of the disc.

Plate VII

Fig. 28, 28'. The synovial membrane of the lateral temporal attachment of the disc.

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