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The relationship between the temporomandibular joint capsule, articular disc and jaw muscles

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ABSTRACT

The anatomy of the temporomandibular joint capsule and its possible relationships to other structures near the joint are not fully understood. A 3-dimensional analysis based on sagittal, frontal and horizontal serial sections through the human temporomandibular joint region was therefore undertaken. Capsular elements which directly connect the temporal bone with the mandible were seen only on the lateral side of the joint. In the posterior, anterior and medial regions of the joint the upper and lower laminae of the articular disc are attached separately either to the temporal bone or to the mandibular condyle. The shaping of the articular cavities and the texture of the joint capsule permit movements of the articular disc predominantly in the anteromedial direction. On the entire medial side of the joint the articular disc and its capsular attachments are in close contact with the fascia of the lateral pterygoid muscle whereby a small portion of the upper head of this muscle inserts directly into the anteromedial part of the articular disc. Thus both the upper and the lower heads of the lateral pterygoid muscle are likely to influence the position of the articular disc directly during temporomandibular joint movements. Laterally, the articular disc is attached to the fascia of the masseter muscle, and part of the lateral ligament inserts into the temporalis fascia. Since these attachments are relatively weak, neither the temporalis nor the masseter muscles are considered to act directly on the articular disc; instead, via afferents from muscle spindles, they may take part in signalling the position of the temporomandibular joint components, including that of the articular disc.

Key words: Lateral pterygoid muscle; masseter muscle; temporalis muscle; retroartikuläres Polster.

INTRODUCTION

The effects of jaw muscles on the temporomandibular joint depend not only on the structure of the joint capsule and its ligamentous reinforcements but also on how the articular disc is connected with the joint capsule and how both are linked with other structures in the vicinity of the joint. Except for the structure of the lateral wall of the joint capsule, connective tissue arrangements related to the temporomandibular joint are by no means clear. In particular, descriptions of the posterior and anterior parts of the joint capsule are contradictory. So far as the posterior part of the joint capsule is concerned, Rees (1954) described a posterior wall of the capsule connecting the temporal bone with the mandibular condyle. According to his description the posterior part of the articular disc, the so-called bilaminar zone, separates into upper and lower laminae of dense collagen fibres which both insert into the posterior wall. The space between these 2 laminae and the posterior wall is filled with loose connective tissue. In contrast to this description, Zenker (1956) in his preparations was unable to show a posterior wall to the capsule such as mentioned by Rees. Instead, he found that the upper and lower laminae of the posterior part of the articular disc inserted independently, either into the temporal bone or into the mandible. The loose connective tissue separating the upper and lower laminae of the posterior part of the articular disc appeared to be continuous with the loose connective tissue in the retromandibular fossa. Zenker termed this portion of loose connective tissue behind the joint as 'retroartikuläres Polster'. In the anterior region of the joint capsule, illustrations in some generally accepted textbooks of anatomy imply that some kind of anterior wall may exist,

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Fig. 1. Sagittal section of the temporomandibular joint cut through the most medial part of the mandibular condyle. T, temporal bone; M, mandible; D, articular disc; TM, temporalis muscle; UPM, upper head of the lateral pterygoid muscle; LPM, lower head of the lateral pterygoid muscle; MA, maxillary artery; IAN, inferior alveolar nerve; P, parotid gland; TC, tympanic cavity. The loose connective tissue within the retroarticular space comprising a vascular plexus and nerve fibres is indicated by an asterisk. Note collagen fibres running from the articular disc through the petrotympanic fissure (between arrowheads) into the anterior ligament of the malleus (ALM). Bar, 0.5 cm.

extending from the temporal bone to the mandible (Fick, 1904; Pernkopf, 1957; fig. 33, Pernkopf, 1987). Rees (1954), however, mentions only a temporal and a mandibular attachment for the articular disc which are separate from each other. Additionally, it is still controversial as to whether the upper head of the lateral pterygoid muscle inserts into the anterior part of the articular disc (Rees, 1954; Pinkert, 1984). These doubts concerning the anatomy of the temporomandibular joint capsule and the attachments to it of the articular disc are cogent reasons why certain clinical aspects of this joint with respect to dysfunction and dislocation of the articular disc are still poorly understood. In the present study the human temporomandibular joint region has therefore been reinvestigated and a new attempt made to elucidate the attachments of the articular disc to the joint capsule and to other related connective tissue elements in a 3-dimensional manner.

MATERIAL AND METHODS

Five human heads (2 males, 3 females; aged 38 y and older) fixed by perfusion with a mixture of 4% formaldehyde, 0.5% glutaraldehyde and 60% alcohol were bisected in the sagittal plane and frozen at

−25 °C for about 1 wk. Except for 1 case where the mouth was slightly open with a separation between the upper and lower incisor edges of 15 mm, the mouths were closed with the teeth in complete occlusal apposition. From the frozen hemispheres blocks with edges of about 60 mm containing the temporomandibular joint regions were sawn out. Blocks were dehydrated beginning with several changes of 100% acetone at −25 °C (Schwab & von Hagens, 1981) for about 4 wk. This was followed by 2 wk in 100% acetone at room temperature. Forced impregnation was then performed according to the method of von Hagens (1979) with a mixture of 2 parts of the epoxy resin Biodur E12, 4 parts of Biodur E6 hardener and 0.15% of Biodur E600 accelerator under vacuum conditions over 2 wk. Polymerisation at 50 °C took a further 2 wk. Plasticised blocks of the temporomandibular joint region were cut serially in the sagittal, frontal and horizontal planes. Sections were cut at a thickness of 600 µm using a diamond wire saw (Well W. Ebner, Mannheim, Germany) as described by Brökelmann & Prondzinsky (1985). Each section of the series was mounted on a glass slide using a special mixture of the resin containing 10 parts Biodur E12, 3 parts of Biodur E1 hardener and 4 parts benzylbenzoate which polymerises within 24 h at 50 °C (Fritsch, 1988). During this procedure the upper side of the sections was covered with an adhesive film in order to prevent contact with the fluid resin. After polymerisation the adhesive film was removed. The surfaces of the sections were treated with a grinding machine according to Fritsch & Hegemann (1991) and then polished by hand to total transparency. Sections were stained with methylene blue/azure II and basic fuchsin according to Laszkó & Lévai (1975) as described by Fritsch (1989). With this staining bony elements and muscles appear brownish-yellow, cartilage violet, collagen fibres blue-violet, and blood within filled veins or bone marrow brown.

A 3-dimensional reconstruction was made from 1 series of frontal sections. The reconstruction included the temporal bone, the mandible, the articular disc, the temporalis and lateral pterygoid muscles, as well as the anterior, posterior, medial and lateral parts of the joint capsule. The circumferences of these structures were digitised using the video-interacting semi-automatic image analysis system VIDS V (AMS, Cambridge) which runs on IBM PS2/50. Digitisation was performed for each section of the series. Data were stored as ASCII files and then transferred to a SiliconGraphics work station in order to create 3-dimensional pictures. The software used were GRAPE (Institut für Angewandte Mathematik der Universität Bonn) (Wohlrab 1989) and GOCAD (Ecole Nationale Supérieure de Géologie de Nancy, France).

RESULTS

Sagittal and horizontal sections

The posterior and the anterior parts of the articular disc and of the joint capsule can best be studied in a series of sagittal sections through the temporomandibular joint. Additional aspects are obtained from horizontal sections.

Posterior region of the temporomandibular joint. Sagittal sections cut through the medial part of the mandibular condyle (Fig. 1) show that the upper lamina of the articular disc is strongly attached to the temporal bone near the petrotympanic fissure. Some collagen fibres of the articular disc extend through the petrotympanic fissure into the tympanic cavity and insert into the anterior ligament of the malleus. With its central (Fig. 2*a*) and its lateral portions (Fig. 3) the upper lamina of the articular disc is just as tightly attached to the temporal bone as with its medial portion in the vicinity of the petrotympanic fissure. The lower lamina of the articular disc is thin and, in the extreme medial plane of sectioning shown in Figure 1, it is attached to the fascia of the lateral pterygoid muscle. More laterally it inserts into the neck of the mandible (Fig. 2*a*) or into the mandibular condyle (Fig. 3). In the medial as well as in the lateral sections through the joint, the structure of the articular disc between the upper and lower laminae conforms to the description of Zenker (1956). In the posterior part it becomes gradually looser and is continuous with the loose connective tissue and the fat lobules filling the retroarticular space. The connective tissue behind the articular disc contains a venous plexus and numerous nerve fibres possibly derived from the auriculotemporal nerve (Hromada & Králové, 1960; Thilander, 1961). Collagen fibres of the articular disc which belong neither to the upper nor the lower lamina of the bilaminar zone form thin sheets and extend into the tissue filling the retroarticular space. Sagittal sections through the most lateral part of the mandibular condyle (Fig. 3) reveal that collagen fibres of the lateral part of the bilaminar zone of the articular disc loop around the lateral part of the mandibular condyle, then run anteriorly and insert into the zygomatic process and the fascia of the masseter muscle. These collagen fibres do not run parallel to the muscle fibres of the masseter. In the vicinity of the cartilaginous part of the external auditory meatus the loose connective tissue in the

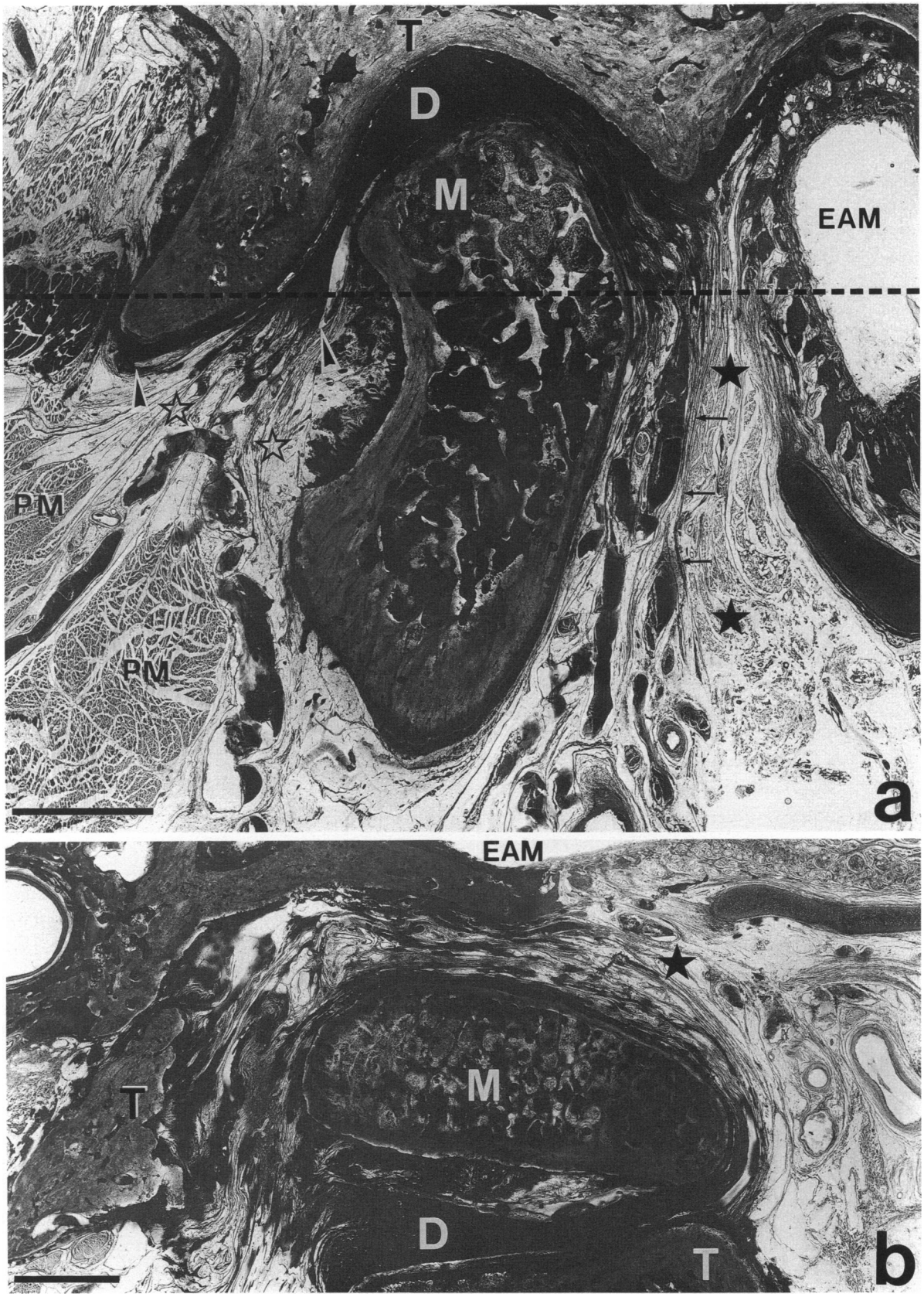

Fig. 2. (*a*) Sagittal section through the temporomandibular joint cut laterally from the insertion of the lateral pterygoid muscle. (*b*) Horizontal section through temporomandibular joint. The plane of sectioning is indicated by the interrupted line in (*a*). T, temporal bone; M, mandible; D, articular disc; PM, lateral pterygoid muscle; EAM, external auditory meatus. Note the venous plexus within the loose connective tissue filling the retroarticular (asterisks) and prearticular (open asterisks) spaces. The arrows in (*a*) indicate small collagenous sheets extending from the posterior part of the articular disc into the retroarticular space. The arrowheads in (*a*) indicate the anterior ends of the superior

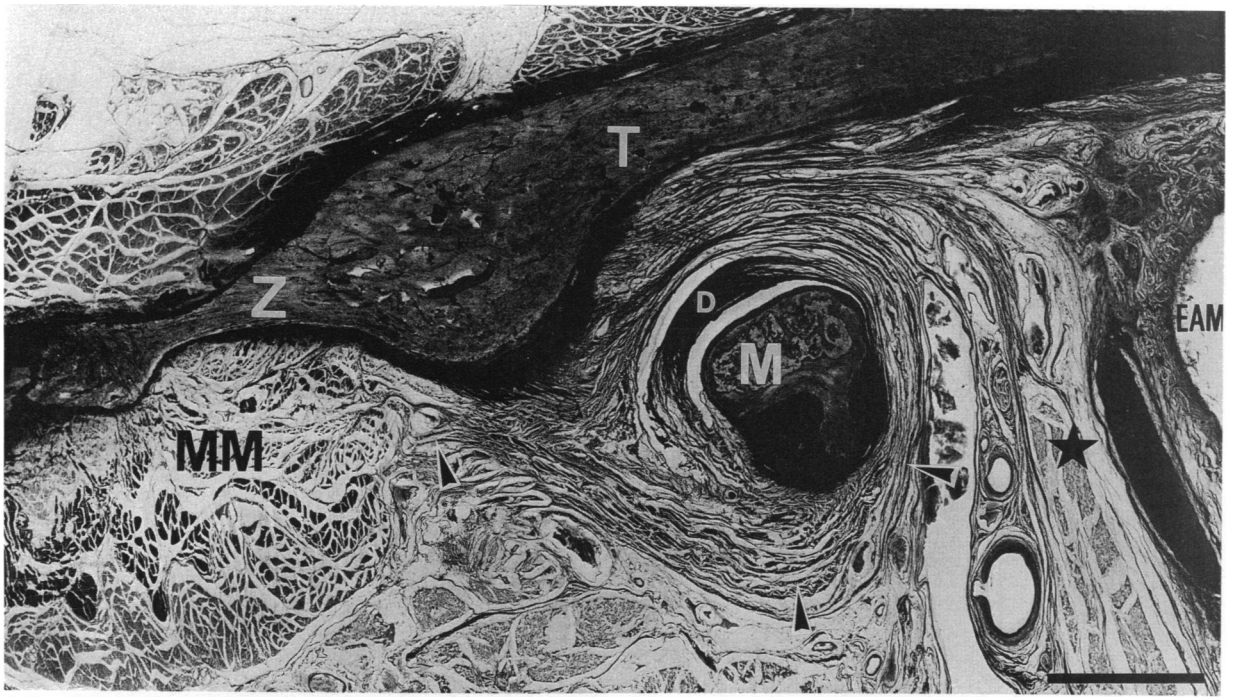

Fig. 3. Sagittal section of the temporomandibular joint cut through the most lateral part of the mandibular condyle. T, temporal bone; Z, zygomatic process; M, mandible; D, articular disc; MM, masseter muscle; EAM, external auditory meatus. The loose connective tissue within the retroarticular space containing a vascular plexus and nerve fibres is indicated by an asterisk. Collagen fibres of the posterior part of the articular disc loop round the lateral part of the mandibular condyle (arrowheads) and insert into the zygomatic process and the fascia of the masseter muscle. Bar, 0.5 cm.

retroarticular space is continuous with the subcutaneous connective tissue of the external ear (Fig. 2*a*). Throughout the series of sagittal sections no ligamentous structures are visible connecting the temporal bone with the mandible behind the temporomandibular joint. Horizontal sections through the external auditory meatus and through the mandibular condyle (Fig. 2*b*) show that there are no horizontal ligamentous structures separating the posterior part of the joint either from the retroarticular space or from the subcutis of the cartilaginous part of the external auditory meatus.

Anterior region of the temporomandibular joint. Serial sagittal sections show that the articular disc is attached on its upper aspect to the temporal bone and on its lower side to the mandibular condyle (Figs 1, 2*a*). In front of the joint ligamentous connections are seen neither medially nor laterally between the temporal bone and the mandible. The relationship of the upper head of the lateral pterygoid muscle to the articular disc is clearly visible only in those series of sagittal sections where the plane of sectioning was in parallel with the fibres of the lateral pterygoid muscle. In these instances sagittal sections cut through the most medial part of the mandibular condyle show that a small part of the upper head of the lateral pterygoid muscle inserts directly into the anterior part of the articular disc between its superior and its inferior attachments to the bony elements of the joint (Fig. 1). However, the predominant part of the upper head of the lateral pterygoid muscle inserts into the inferior attachment of the articular disc and, either by means of its collagen fibres or directly, into the mandibular condyle. Lateral to the insertion of the lateral pterygoid muscle into the mandible, the superior as well as the inferior attachments of the articular disc are very loose (Fig. 2*a*). Between these attachments the structure of the anterior part of the articular disc becomes progressively looser and is continuous with the loose connective tissue and the fat lobules filling the prearticular space. This prearticular connective tissue contains a venous plexus similar to that in the retroarticular region. Collagen fibres of the articular disc extend as thin sheets into the loose prearticular

and inferior articular cavities. Neither behind nor in front of the joint are collagen fibres traceable which connect the temporal bone directly with the mandible. The retroarticular space is continuous with the subcutaneous layer of the skin in the external auditory meatus. Bar, 0.5 cm.

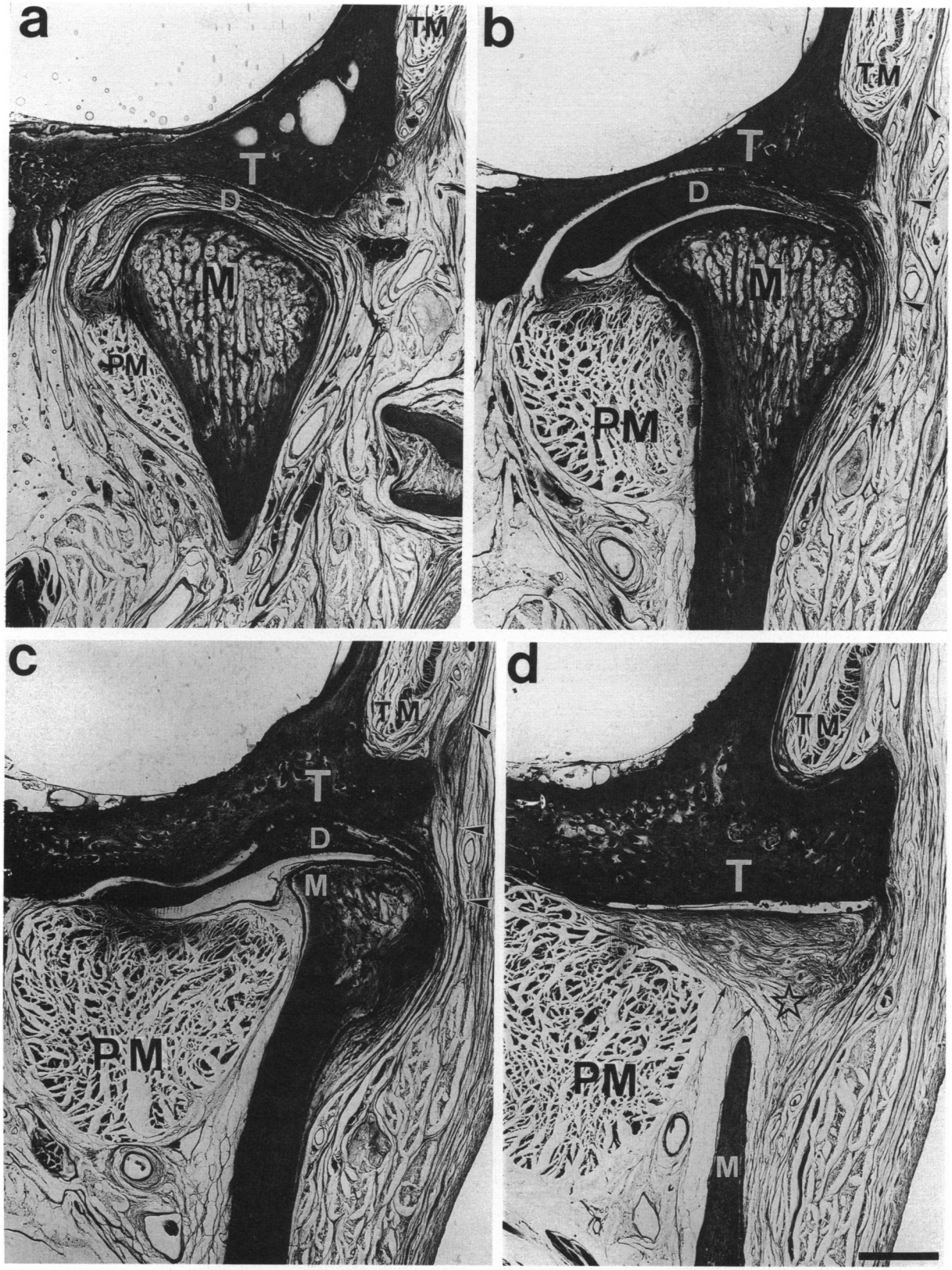

Fig. 4. Series of frontal sections through a left temporomandibular joint. (*a*) Posterior (*b*), central, (*c*) central-anterior and (*d*) anterior plane of sectioning. T, temporal bone; M, mandible; D, articular disc; PM, lateral pterygoid muscle; TM, temporalis muscle. On the medial side, the upper and lower laminae of the articular disc are attached separately to the temporal bone and to the mandibular condyle. Note the close connection of the articular disc and its capsular attachments with the fascia of the lateral pterygoid muscle in all planes of sectioning. The arrowheads indicate collagen fibres separating from the lateral wall of the capsule in order to join the fascia of the temporalis muscle. In (*d*) the loose connective tissue interspersed with a vascular plexus in the anterior part of the articular disc lateral to the insertion of the lateral pterygoid muscle is indicated by an open asterisk. Additionally, collagen fibres of the medial side of the anterior portion of the articular disc extend through the mandibular incisure (arrows) and are attached to the lateral side of the mandibular ramus. Bar, 0.5 cm.

tissue. The superior articular cavity between the temporal bone and the upper side of the articular disc projects beyond the anterior end of the articular disc and terminates only shortly after reaching the deepest point of the articular tubercle (Figs 1, 2*a*, 3). Its anteroposterior distance is seen to be longest in the medial and central planes of sectioning (Figs 1, 2*a*). The inferior articular cavity between the lower side of the articular disc and the mandible in the extreme medial and lateral planes of sectioning closely follows the anterior convexity of the mandibular condyle (Figs 1, 3). Lateral to the insertion of the lateral pterygoid muscle, in the central part of the joint, it maintains a horizontal position, following the lower side of the anterior part of the articular disc and extending into the loose connective tissue filling the prearticular space (Fig. 2*a*). Quantitative data on size differences between the superior and the inferior articular cavities of the temporomandibular joint were given by Lang & Niederfeilner (1977).

Frontal sections

The lateral and the medial joint capsule can only be studied in series of frontal sections. For orientation in frontal sections it has to be taken into account that the long axis of the mandibular condyle is not exactly transversely oriented but forms an angle with the frontal plane of about 15°, opening dorsomedially (Fick, 1911). The medial extremity of the mandibular condyle is therefore seen in the more posterior sections of a frontal series whereas the lateral extremity is included in the sections cut through the anterior region of the joint (Fig. 4*a–c*).

Lateral side of the joint. Here the capsule consists of strong collagen fibres running from the lower side of the temporal bone to the mandibular neck. This is seen in all planes of serial frontal sections, i.e. in the sections through the posterior (Fig. 4*a*), central (Fig. 4*b*, *c*) and anterior part of the joint (Fig. 4*d*). Collagen fibres of the articular disc insert into the lateral wall of the capsule and join predominantly the lower part of the capsule which is attached to the mandibular neck (Fig. 4). In the central (Fig. 4*b*) and central-anterior (Fig. 4*c*) parts of the joint, the lateral wall of the joint capsule appears to be much stronger than in the posterior and anterior regions. This reinforcement of the capsule corresponds to the lateral ligament known from macroscopic preparations (Pernkopf, 1987; Williams et al. 1989). In the plasticised sections through the central and central-anterior planes of the joint an additional ligamentous structure is seen. It separates from the mandibular attachment of the lateral wall of the joint capsule and, without being attached to the temporal bone, extends laterally upwards and inserts into the fascia of the temporalis muscle (Fig. 4*b*, *c*). Whereas the collagen fibres extending from the lateral joint capsule into the fascia of the temporalis muscle run from caudal to cranial, the muscle fibres within the respective portion of the temporalis muscle are oriented in the anteroposterior direction.

Medial side of the joint. Here the capsule is much looser than on the lateral side (Fig. 4*a–d*). In the posterior part of the joint (Fig. 4*a*) the medial side of the articular disc is tightly attached by its upper lamina to the border of the petrotympanic fissure. Some collagen fibres separating from the fascia of the lateral pterygoid muscle extend upwards to the lower side of the temporal bone and are attached to the same region as the upper lamina of the articular disc. In the central part of the joint (Fig. 4*b*, *c*) the collagen fibres of the upper lamina of the articular disc are attached to the lower side of the temporal bone as well as to the medial fascia of the lateral pterygoid muscle. The lower lamina of the articular disc along the whole anteroposterior extent of the joint inserts into the mandibular condyle and is in close contact with the cranial fascia of the lateral pterygoid muscle. Neither in the posterior nor in the central or anterior parts of the joint are there collagen fibres that connect the temporal bone directly with the medial side of the mandible and which might be regarded as a medial ligament (International Anatomical Nomenclature Committee, 1989). Instead, collagen fibres of the medial margin of the articular disc which belong neither to the upper nor to the lower lamina of the disc are closely attached to the cranial side of the lateral pterygoid muscle along the entire anteroposterior extent of the joint (Fig. 4*a–d*). The superior articular cavity between the temporal bone and the upper side of the articular disc fits closely to the surfaces of the articulating joint elements and is as large as the upper side of the articular disc. The inferior articular cavity between the lower side of the articular disc and the mandibular condyle, especially in the central-anterior part of the joint (Fig. 4*c*), is up to twice as large as the surface of the mandibular condyle and, together with the articular disc, it projects beyond the medial side of the mandibular condyle. In sections through the most anterior region of the joint (Fig. 4*d*), only the superior articular cavity is seen. The mandibular condyle is not included in these planes of sectioning. Instead, in these sections the relatively loose connective tissue of the most anterior part of the articular disc lateral to the mandibular attachment of the lateral pterygoid

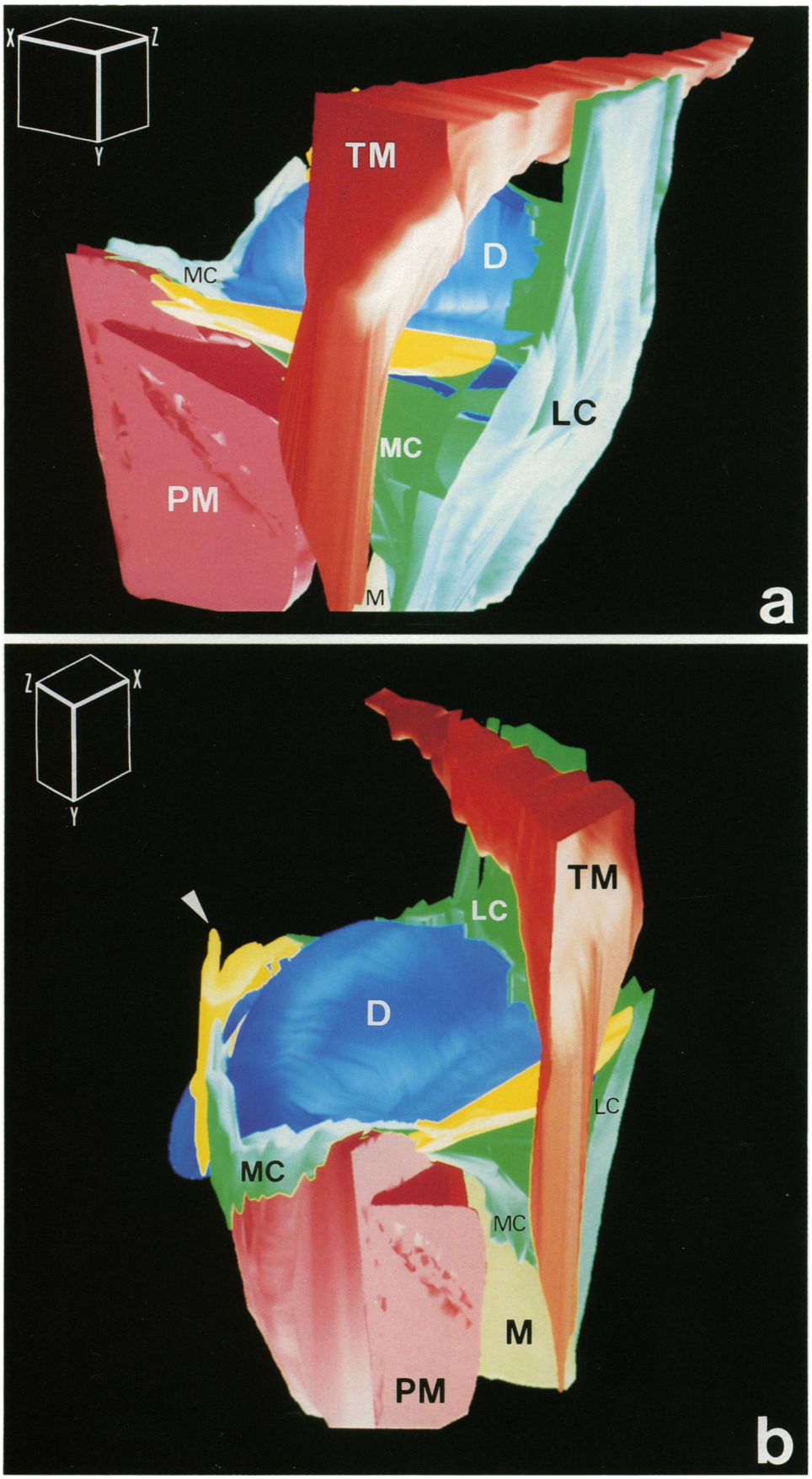

Fig. 5 (*a*) Anterolateral and (*b*) anteromedial views of a three-dimensional reconstruction obtained from an original frontal series of sections through a left temporomandibular joint region. D, articular disc (blue); M, mandible (beige); TM, temporalis muscle (red); PM, lateral

muscle, which has already been mentioned when describing sagittal sections, is observable. With its upper lamina this loose anterior part of the articular disc is still attached to the temporal bone and seen to be in contact with the fascia of the lateral pterygoid muscle as well. Some collagen fibres of the medial side of the loose anterior portion of the articular disc extend through the mandibular incisure onto the lateral side of the mandibular ramus and there become associated with the collagen fibres of the lateral joint capsule.

Three-dimensional reconstruction

The analysis of serial sections cut in 3 different planes through the temporomandibular joint has shown that the structure of the joint capsule is too complicated to be understood from a single sagittal section through the centre of the mandibular condyle, as usually is shown in comparable morphological studies of the temporomandibular joint (Zenker, 1956; Wendler et al. 1989; Fenoll et al. 1992). Therefore any attempt to produce a schematic drawing comparable to those published in the literature and often used for illustrating textbooks would include simplifications or mistakes and would not lead to a real functional understanding of the 3-dimensional structure of the joint capsule. In order to overcome these problems a 3-dimensional reconstruction has been made from a single original series of frontal sections through a left temporomandibular joint. Two different views of this reconstruction are shown in Figure 5: in Figure 5*a* the reconstruction is seen from an anterolateral and in Figure 5*b* from an anteromedial vantage point. These pictures illustrate in a 3-dimensional manner the extensive adhesion of (1) the lateral ligament to the fascia of the posterior part of the temporalis muscle (Fig. 5*a*) and (2) the medial parts of the joint capsule to the cranial side of the lateral pterygoid muscle (Fig. 5*b*).

DISCUSSION

Concerning the appearance of the posterior part of the joint capsule, the articular disc and the retro-articular space, our results are in agreement with the descriptions of Zenker (1956), Dixon (1962) and Wendler et al. (1989). However, the so-called posterior wall as described by Rees (1954) and recently again mentioned by Pinkert (1984, 1992) has now been demonstrated not to exist.

In the present paper, as in numerous earlier descriptions of the anterior joint region (Fick, 1904; Kjellberg, 1904; Rees, 1954; Wright & Moffett, 1957; Dixon, 1962; Wendler et al. 1989), muscle fibres belonging to the upper head of the lateral pterygoid muscle were observed to insert directly into the anterior part of the articular disc. However, this finding contradicts the description of Pinkert (1984) who in his preparations did not find such an insertion. This may be due to the fact that only very few muscle fibres are involved, that these muscle fibres insert only into the anteromedial dip of the articular disc, and that the sections shown by Pinkert were cut obliquely with respect to these fibres (compare fig. 3 in Pinkert, 1984, with Fig. 1 in the present paper). In contrast to various macroscopic illustrations given in some widely accepted textbooks of anatomy (Fick, 1904; Benninghoff, 1985; Pernkopf, 1957, 1987; Rauber Kopsch, 1987; Williams et al. 1989), no anterior wall could be shown linking the temporal bone with the mandibular condyle. This finding is in accordance with the observations reported recently by Fenoll et al. (1992). Lateral to the insertion of the lateral pterygoid muscle, in our preparations loose connective tissue interspersed with a venous plexus was seen in front of the anterior part of the articular disc. This venous plexus is held to be identical with the articular plexus mentioned by Luschka (1867).

From the functional standpoint, the most important result of the present study concerns the medial side of the joint. Whereas in the descriptions of Fick (1904), Rees (1954), Rauber (1987), DuBrul (1988), Williams et al. (1989) and Fenoll et al. (1992), a medial wall (International Anatomical Nomenclature Committee, 1989) consisting of collagen fibres which connect the temporal bone with the mandible is supposed to exist, according to our findings such a structure is definitely lacking. Instead, the medial side of the articular disc and its capsular attachments are in close contact with the fascia of the lateral pterygoid muscle along the entire anteroposterior extent of the joint. This implies that not only the upper head but the entire lateral pterygoid muscle acts on the articular disc.

On the basis of multiple electromyographic studies,

pterygoid muscle (red); MC, medial parts of the joint capsule (green); LC, lateral part of the joint capsule (green). The anterior and the posterior parts of the capsule are printed in yellow. The white arrowhead in (*b*) indicates the tip of the posterior part of the joint capsule which attaches the upper lamina of the articular disc dorsomedially to the petrotympanic fissure. The temporal bone was not included in the reconstruction. The position of the block from which structures have been reconstructed and the orientation of *x*, *y* and *z* is marked in the upper left corners of (*a*) and (*b*).

the upper head of the lateral pterygoid muscle is considered to be active during mouth closure and retraction and lateral movements of the jaw in the ipsilateral direction, whereas the lower head of this muscle acts during mouth opening and protrusion and lateral movements of the jaw in the contralateral direction (Kamiyama, 1961; Grant, 1973; McNamara, 1973; Lipke et al. 1977; Mahan et al. 1983; Juniper, 1984). Both bellies of the lateral pterygoid muscle may contract simultaneously during incisor clenching (Mahan et al. 1983). The present results concerning the various attachments of the temporomandibular joint elements to the lateral pterygoid muscle provide the morphological prerequisite that the lateral pterygoid muscle may play the main role in coordinating movements of the mandibular condyle with those of the articular disc during most kinds of temporomandibular joint function.

The posteromedial tip of the articular disc is tightly fixed to the border of the petrotympanic fissure. Fibres that were observed to extend through the petrotympanic fissure into the anterior ligament of the malleus within the tympanic cavity have already been described by Kjellberg (1904), Pinto (1962) and Coleman (1970) during development. In agreement with Smeele (1988), these fibres are not considered to have any functional relevance but are held merely to be developmental remnants.

On the lateral side of the joint the attachment of the capsule to the fascia of the temporalis muscle and of the posterior part of the articular disc to the fascia of the masseter muscle are much less extensive compared with the attachment of the medial side of the articular disc to the lateral pterygoid muscle. It can therefore hardly be supposed that the temporalis or masseter muscles have a substantial influence on the position of the articular disc. It is possible, however, that both the temporalis and the masseter muscles, because of their extensive complement of muscle spindles (Kubota & Maesegi, 1977), help to register the position of the articular disc. Thus they too would be part of the control system regulating the position of the various elements of the temporomandibular joint.

Painful malfunction of the temporomandibular joint is often combined with a dislocation of the articular disc (Hugger et al. 1992). Most of these dislocations are observed to take place in an anteromedial direction (Körber et al. 1987; Koeck & Lückerath, 1989; Stoller et al. 1989; Beltran, 1990; Schwaighofer et al. 1990). This becomes understandable if the shapes of the joint cavities are considered and, particularly, the actual findings concerning the structure of the joint capsule, its connections with the articular disc and the attachments of both disc and capsule to the jaw muscles.

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