HISTOPATHOLOGIC ADAPTATIONS TO FUNCTIONAL FORCES IN THE HUMAN TEMPOROMANDIBULAR JOINT MENISCUS

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Abstract

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Ten menisci, surgically removed for internal derangement reasons were examined in regards to gross morphology, collagen fiber orientation, and condition of the elastic and neurovascular components. A postmortem and surgically removed control were utilized. The abnormal menisci presented thicker, and more compact while histologically they displayed many more vertical and transverse fibers than the normal control. The posterior attachment area showed variable concentrations of vasculature. Hypertrophic arteries, two types of fragmented elastic fibers and a paucity of nerve fibers were observed. Unique observations were mentioned and patient histories were presented for correlations with the histological findings. Conclusions were drawn regarding the reversibility of the deformation process and the regeneration potential of collagenous fibers in the posterior attachment of the meniscus.

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DEDICATED

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INTRODUCTION

Although the controversy surrounding pain and dysfunction of the human temporomandibular joint (TMJ) has been discussed in the medical and dental literature for over 100 years, a commonly accepted rationale for etiology, diagnosis, treatment and prevention has never been in such a state of confusion. Consequently, until a few years ago this complex ailment was conveniently explained by the all-inclusive stress-induced theory of the Myofacial Pain Dysfunction Syndrome (MPD).

Prior to the 1950's, treatment for TMJ pain consisted primarily of meniscectomies and condylectomies. In the 1960's surgical intervention lost popularity in favor of nonsurgical approaches. Then, with the advances in arthrography during the 1970's, renewed interest in the internal derangement of the TMJ initiated a resurgence of surgical treatment. Presently, an abundance of etiologic philosophies and palliative treatment approaches are in vogue. Not surprising, the clinicians' understanding of the etiology and the resulting mode of treatment seems to be more influenced by their area of dental interest than by their understanding of the biology of the joint. Only as recently as 1978 has the understanding and confirmation of the anteriorly displaced disc been elucidated. As a result, the age old premise

for ideal occlusion, centric relation, had to be quickly reworded. Still, however, TMJ controversy continues in regards to the etiology, the interpretation of symptoms, and the treatment to a stable result.

Nevertheless, to solve any biological question, a solid groundwork of baseline knowledge must be available. Similarly, in order to understand disorders of the TMJ, and to correctly diagnose and treat them, a firm grasp of the basic biology of the healthy and degenerating joint is necessary. To date extensive investigation has taken place in obtaining a solid base of data on the healthy anatomy and histology of this region. Since the early 1970's interest has been directed more toward the pathologic changes in the joint, using primarily cadaverous material. However, only since the late 1970's and the acceptance of the anteriorly displaced disc, has research been specifically directed at the meniscus and its attachments. Considerable progress has been achieved in refining TMJ radiographic techniques and relating them to both clinical and surgical observations. Much less research has been reported on the histopathology of these displaced discs, with no attempt to relate the micromorphologic changes to clinical histories.

From a clinician's point of view, the information obtained from radiographs, a physical exam of this region and a written record of TMJ symptoms merely infer as to the micromorphology of the affected soft tissue and its ability to be treated. At this

time only educated guesses are made regarding the condition of the meniscus, the reversible or irreversible changes in its architecture, and the long term prognosis of its posterior attachment. Because of the lack of information in this area and the fact that in order to successfully diagnose and treat this malady, these basic, biological questions must be answered.

REVIEW OF THE LITERATURE

Ever since Costen's (1934) classic account of trigeminal neuralgia relating to mandibular dysfunction, investigative research flourished in the temporomandibular joint area. Major contributions in the development of anatomical data on the temporomandibular joint (TMJ) were reported by Rees (1954), Hankey (1954) and Macalister (1954). Besides the anatomy of the joint they described the biconcave structure of the meniscus and its intricate posterior attachment. A description of the embryonic development of the joint was provided by Moffett (1957) and Baume (1962), pointing out its unique origin--the combining of separate blastemas. Griffin and Sharpe (1960), Dixon (1962) and Knox (1967) presented detailed normal histology of the TMJ meniscus and associated attachments, while Moffett in 1964 and Blackwood (1966, 1968, 1969) developed an explanation of the mechanics for adaptive remodeling and degenerative pathology. Then in 1971 Oberg tried to correlate the dentition with gross tissue changes in the joint. Later, Hansson and Oberg (1977) looked at thicknesses of menisci and articular tissue from normal joints and compared them to tissue from joints with deviated forms. With the advent of refined arthrography Solberg and Clark (1980) among others verified the connection between the anteriorly displaced disc and mandibular dysfunction. Most recently, Scapino (1983) aptly described

the histopathology found in menisci, surgically removed for internal derangement reasons. This study is one of a very few dealing with the histopathology of these malposed discs, and no mention was made of presurgical observations. An appropriate step in the continued investigation in this area would be to confirm and expand these histologic findings while relating them to specific presurgical observations.

However, in order to make an appropriate evaluation of histopathologic adaptations of the meniscus, it is paramount to have a strong foundation in the embryonic development of the TMJ, its functional anatomy, the normal histology of related tissues, and most importantly a solid understanding of the intended physiology of these TMJ components. A fine line is drawn for the clinician to differentiate between an irreversibly altered, nonfunctional meniscus and one whose micromorphology has reversibly adapted to functional forces, yet initiates painful symptoms. A clinical judgement such as this requires a knowledgeable base from which to draw.

Development of the Human TMJ

Evolution

The unique nature of the human temporomandibular joint can best be introduced by the fact that in evolutionary terms the TMJ is not an adaption of a previously existing joint but rather is a

replacement of an analagous joint in lower vertebrates. Accordingly, it is the youngest joint in biologic history, and as Moffett (1966) describes it, an anthropologist's delight.

Prior to mammalian evolution the vertebrate mandible consisted of several dermal bony components and one endochondral bone from the first branchial arch that articulated in the joint with another endochondral bone also from the first branchial arch. In the mammal, however, the mandible is composed of only one dermal bone, and the two endochondral bones rather than articulating with each other, have been incorporated into the middle ear as the malleus and incus. At this point Moffett (1966) surmises that the new joint which forms anterior to the ear must occur by a superiorly growing bony process making contact with the skull and creating a synovial joint. This gradually appearing bony process from the mandible can be seen in certain reptilian series and in the developing embryo of mammals and man.

Mammalian Comparative Anatomy

Within the class of mammals, there are four distinct morphological configurations of the temporomandibular joint, each functioning in a different manner. The architecture of the joint evolved in response to the functional mechanics involved in tearing, grinding, grasping and in combining all three of these functions (Moffett, 1966; DuBrul, 1975):

(1) The great tearing and ripping forces of the carnivores, characterized by their prominent canines, necessitate the morphology of their TMJ to have a deep fossa with large anterior and posterior tubercles for maximum stability.

(2) The horizontal movements required by herbivores in the grinding of their food are made possible by the proximity of the anterior and posterior condyles to each other, preventing the considerably larger condylar head from seating deep into the fossae. This allows considerable horizontal freedom.

(3) An impressive example of the morphology of the craniomandibular joint being modified by function is that of the porpoise. This mammal neither bites nor chews its food but merely swallows it whole. Not surprisingly, its muscles of mastication are underdeveloped, even with a long snout. However, the structure of the porpoise TMJ is not a result of its eating habits. The uniqueness of this TMJ is the vertically oriented articular surface on the cranium, in contrast to the more horizontally structured fossa. When this vertical surface is combined with a massive ramus-condyle complex, the craniomandibular joint is able to absorb heavy, horizontally directed, ramming forces without damage to the joint components.

(4) The human condylar-fossa relationship allows for all three functions. It enables man to bite or grasp using a purely hinge movement, or it can allow for the horizontal movements of chewing. As modern man has evolved from ancient man, one has to

wonder how the changing function of the TMJ is modifying the form of the craniomandibular complex. Are these problems associated with the TMJ merely an intermediate chapter in modern man's morphologic evolution?

Embryonic Development

The biologic principle that Ontogeny recapitulates Phylogeny holds true for the human temporomandibular joint as well. Just as the TMJ appeared late in the evolution of vertebrate jaws, it also appears late in the developing embryo when compared to the development of larger joints in the body (Moffett, 1957). As in the phylogenetic sequence, while the immature mandible is extending itself superiorly, its precursor--Meckel's Cartilage formed from the first branchial arch articulates temporarily with the skull. It provides a framework around which the mandible is formed until the TMJ is developed. This intermediate stage in the TMJ development that resembles the normal form of lower vertebrates reinforces the chronology of its late appearance in vertebrate evolution. No other joint in the body passes through this intermediate stage (Moffett, 1957).

A key to understanding the function of temporomandibular components, and their possible etiologic involvement when symptoms arise, is an appreciation for their origin in the developing embryo. The complexity of the adult TMJ is an end product of a delicate beginning.

Again, in contrast to other synovial joints which develop from a single blastema and segment off from a continuous cartilage model to ossify and form a joint, the TMJ is formed by the merging of two intramembraneous blastemas along with an undifferentiated mesenchymal interzone. Baume (1962) labelled these two components the condylar blastema and the temporal blastema. The chronology of the developing components was expertly described by Moffett in 1957. At a month and a half in development, the condyle has not formed but the meniscus, external pterygoid and masseter muscles appear. Within a week's time the external pterygoid joins with the meniscus and attaches itself to the posterior portion of Meckel's Cartilage, which eventually becomes the malleus. Before three months the condylar cartilage is visible on top of the mandible, and the temporal bone is forming but the meniscus with the tendon of the external pterygoid running underneath has not yet been forced to press against the temporal bone. The transfer of the meniscus from Meckel's Cartilage to the temporal bone soon takes place as the Glaserian fissure narrows down around the posterior end of Meckel's Cartilage. Only at five and a half months does the meniscus release itself from the malleus and attach to the edge of the fissure. Meckel's Cartilage continues through the fissure and provides vascularization for the developing malleus and incus. But eventually a remaining portion of Meckel's Cartilage forms the sphenomandibular ligament. As the

meniscus matures it is transformed from a uniform band of connective tissue that is completely vascularized to a meniscus with distinct morphology. The shape, and the fact that its center is both avascular and aneural, is a result of being compressed between the condyle and the temporal bone (Moffett, 1957).

In 1918, Prentiss described embryologically how the meniscus in the knee is solid, but from the pressure of muscles pulling across the joint the center of the disc disappears. In time, as the joint becomes weight bearing, the meniscus retrogrades until only semiluner cartilaginous elements remain. He then hypothesizes that the meeting of teeth or alveolar ridges prevents the pressure on the disc from getting too great and perforating its center.

Post-Natal Development

When does post-natal development end? Is the timing different for each component in the temporomandibular joint? When does growing cease and ageing or remodeling continue? How can environment affect the morphologic outcome? Final answers to these questions seem as elusive today as they were 50 years ago. In 1948, Angle leaned to the side of the geneticists and stated that genes more than environment affect the shape and angle of the eminence. However, he concluded that it is the interaction of the

many genetic and environmental forces that actually determine the morphology. Much earlier, Steinhardt (1933) must have had the same belief, since he described the newborn meniscus as being highly cellular with no bundle arrangement until birth. At this time differentiation of the tissue begins and reaches fibrous structure as in the adult within 15 months time. Carrying this further, Keith (1982) states that the disc changes in shape concomitant with the growth of the articular eminence, all the while maturing by decreasing in cell number and increasing in the amount of collagen. Then when does the eminence stop growing? Keith (1982) feels it stops developing at age 6 years, while Ingervall (1976) says that the signal for the end of tubercular growth is puberty. In searching for causative factors regarding the depth of the glenoid fossa and the angle of the eminence, Angle (1948) could only conclude that a dubious relationship existed between deep overbites and deep glenoid fossae. Ingervall (1976) summarizes generally by reporting that a continuous compact bony layer forms early on the surface of the fossa and tubercle, while the layer of calcifying cartilage on the condyle is not fully developed before 20 years of age.

Cellular Remodeling

A fine line is drawn between growing and cellular remodeling. Then what is aging? Moffett (1966) aludes to aging as the

location of remodeling. When does growth terminate and cellular remodeling continue? Recent studies by Behrents (1984) require one to step back and readdress that question. With regards to cellular remodeling, Blackwood (1966) writes that remodeling of the bony skeleton continues throughout life in response to alterations in the mechanical equalibrium of the skeleton, musculature and metabolic functions of the body. Any change in the skeleton is transmitted to the joints, which may respond by remodeling to maintain congruity between opposing articular surfaces.

Moffett (1964) and Blackwood (1966) utilize three categories of joint remodeling when describing how articular tissue provides for equalibrium maintenance:

1. Progressive remodeling is an addition of tissue to articular surfaces by the proliferating of articular cartilage followed by its mineralization and subsequent replacement by bone.

2. Regressive remodeling is the removal of articular tissue by osteoclastic resorption of sub-articular bone and replacement by new cartilage.

3. Peripheral remodeling is the addition of tissue to the periphery of a joint surface but periosteum may be involved.

The adult condyle is shown by Blackwood (1968) to undergo progressive remodeling. The layer of proliferation is reduced but still retains its activity and forms new cartilage cells which hypertrophy, produce matrix that mineralizes near the bone and is eventually replaced by haversian bone. If this response is excessive, lipping is caused, frequently on the anterior of the con-

dyle. A regressive response also occurs on the condyle, usually on the posterior aspect, causing flattening. Both of these responses may take place at the same time on the condyle, as is often seen in association with large perforations of the meniscus (Blackwood, 1966).

The assumption that the degree of remodeling is a function of age is refuted by Moffett (1966) when he states that there is no correlation between the two. The rates and quantity are rather related to the functional demand on the articular tissue. He evidenced this response by citing a trend relating loss of teeth to progressive remodeling on the anterior of the condyle and medial of articular tubercle, while regressive remodeling occurs on both the posterior of the condyle and the lateral surface of the tubercle. The result is an increase in articular surface, a decrease in the slope of the eminence and a flattened condyle. With the similarity in remodeling between the perforated meniscus example and this loss of teeth trend, it is not surprising that an etiologic connection is made by many between these two occurrences.

Moffett (1966) simplifies this response by relating function to physiologic equalibrium. If the functional load goes beyond the ability of the articular tissue to remodel and correct then the equalibrium is destroyed. This damage to the equalibrium can also result from an alteration in the metabolic response of the joint.

Functional Anatomy of the Temporomandibular Joint

Skeletal Components

The superior surface of the temporomandibular joint is formed by the fusion of the squamous and tympanic portions of the temporal bone. This mediolaterally running squamotympanic fissure is just behind the posterior limit of the temporal articulating surface. Through this fissure pierces the chorda tympani, the anterior tympanic blood vessels and a bony projection of the petrous temporal bone, the tegmen tympani. Anterior to these structures is the height of the fossa which is nonweight bearing and as a result, paper thin. The post-glenoid tubercle marks the posterior boundary of the glenoid fossa while the sloping articular eminence and its bony tip, the articular tubercle, form the anterior boundary (DuBrul, 1975; Hylander, 1979). From a series of autopsy specimens, Oberg (1971) found the articulating surface area of the eminence to be wider medio-laterally than anteroposteriorly, and that the size of the joint did not correlate with body height. He also measured the head of the condyle to be generally twice as wide medio-laterally as compared to its anteroposterior dimension, on the average 20 mm by 9 mm, with the majority of the condyle positioned to the medial side of the ramus. The articular surfaces rather than being covered by hyaline cartilage are covered by dense, nonvascularized, noninnervated fibrous tissue, thickest on the anterosuperior aspect of the

condyle and the posterior slope of the eminence, thus indicating these areas best suited to sustain maximum articular pressure (Bell, 1983).

Beneath this layer on the condyle lies the unique prechondroblastic layer, especially proliferative during the growing years, yet still quite functional for remodeling in adult years. This layer feeds both superiorly to the dense fibrous connective tissue and inferiorly for the endochondral replacement of cartilage by bone, thus possessing a potential to withstand compression while responding to the regional forces directing its growth (Enlow, 1982).

Between these two bony articulating surfaces is an independently functioning fibrous structure that most significantly distinguishes this joint from other synovial joints. This articular meniscus has its own muscle attachment and neurovasculature along with a variety of functions. Steinhardt (1958) remarked on its sagittal morphology, being thicker anteriorly, posteriorly and medially while thinner centrally and laterally. Following up Angle's conclusion in 1948 that there was no correlation between a deep bite and the angle of the fossa, Griffin (1975) explained that the disc smoothes out the incongruity between the eminence and the condyle, and must be thicker in certain areas. A shallow fossa similarly does not need a meniscus with such a thick posterior area. Rees (1954) pioneered the structural anatomy of the

disc. It wraps around the head of the condyle so therefore is concave on its inferior surface, and also widest in a mediolateral dimension. The superior surface, with its thicker posterior portion and thinner intermediate middle zone resembles a saddle. The meniscus firmly attaches to the medial and lateral poles of the condyle which act like an axle, so that the disc can keep a constant position over the condyle when the condyle rotates under it. Anteriorly, besides attaching beyond the articular eminence, and just below to the condylar articulating surface, it also receives insertion fibers of the superior belly of the external pterygoid muscle between these two fibrous attachments. Finally, Rees labels the posterior attachment area as the bilaminar zone since it has a superior and an inferior strata of attachment to the squamo-tympanic suture area of the glenoid fossa and to the posterior-inferior surface of the condylar head, respectively.

Due to the attachments of the meniscus the joint cavity is divided into two, separate, fluid filled compartments. One is superior to the meniscus and a smaller one is between the meniscus and the condyle. These cavities are lined with a synovial membrane and villi which secrete synovial fluid used for metabolic nourishment and lubrication to the nonvascular articulating surfaces (Bell, 1983). According to Hylander (1979) and contrary to Finlay (1964) the interarticular pressure in these spaces decreases on the side where moderate chewing force is required from

the muscles of mastication. The pressure, however, increases on the contralateral side.

In 1960, Boucher compared craniomandibular arthodial or sliding joints with ginglymal or hinge joints. He found that in the arthodial joints, the eminence is more flattened and the post glenoid tubercle less prominent. Using the rat as an extreme example, the eminence is absent. Likewise, in the pure ginglymal joint of the cat, the external pterygoid muscle, primarily involved in protrusion or lateral excursion, was relatively weak. He therefore concluded that the strength of the external pterygoid muscles in the arthrodial joints was greater than the ginglymal joints.

In the ginglymal diarthrodial joint the design allows for rotation of the condyle articulating with the concave underside of the disc, and when greater rotation and protrusion is performed, the coordinated disc-condyle complex translates down the eminence, balances on it or even slides beyond, articulating with its anterior border. The concave superior surface of the meniscus thus provides both stability for the disc-condyle unit pressing against the posterior surface of the eminence in ginglymal function and an advantageous shape with which to balance on the eminence after translation (Rees, 1954; DuBrul, 1975; Bell, 1983). Rees (1954) also makes a brief but interesting observation regarding the mandibular movement from a retrusive position to a protrusive one.

Besides the meniscus sliding 7-10 mm along the articular eminence, the condyle also slides from the posterior band across the intermediate zone, resting just past the anterior band for an additional 8 mm.

The neuromusculoskeletal coordinations required of this ginglymal-diarthrodial joint confirm its level of evolutionary sophistication, but at the same time this greatly increases its areas of vulnerability.

Ligamentous Components

A thin fibrous capsule surrounds the condyle-disc-fossa complex keeping the two synovial cavities separate and provides support for the synovial membrane (Hankey, 1954; Rees, 1954). The lateral aspect of the capsule is especially rich in neurovascular elements (DuBrul, 1975). Reinforcing this capsule Hankey (1954) and Rees (1954) describe a sheet of collageneous fibers from the posterior border of the zygoma back to the neck of the condyle. They call it the lateral or temporomandibular ligament, but DuBrul (1975) and Griffin (1975) differentiate this into two layers. The wider, superficial portion orients downward and backward from the articular tubercle to the posterior of the neck of the condyle. The medial portion is a narrow band also originating from the articular tubercle but orienting horizontally to insert on the lateral pole of the condyle, along with fibers of the meniscus. A

similar but weaker band exists on the medial side of the condyle. Due to the inherent nature of collagenous fibers, these two ligaments resist stretch and tend to prevent severe, posterior displacement of the condyle while holding or suspending the disc-condyle complex against the temporal articular eminence.

There are two other suspensory ligaments that Griffin (1975) and DuBrul (1975) define. One is the before mentioned remnant of Meckel's cartilage, the sphenomandibular ligament, which arises from the of the sphenoid bone and fans out downward to insert on the lingula, at the lower border of the mandibular foramen. The second ligament extends from the styloid process to the posterior angle of the mandible and is named the stylomandibular ligament. Boucher (1960) in his efforts to emphasize the muscular stabilizing component in ginglymal diarthrodial joints points out that even though these two ligaments help prevent inferior dislocation of the mandible, there is no way for them to prevent posterior movements.

Muscular Components

The role of the musculature of the temporomandibular joint as DuBrul (1975) and Bell (1983) see it, is too often simplified by the mere describing of origins, insertions, and particular muscular involvements in gross movements. When an understanding is

reached of the coordinated actions of these muscles in every movement that the mandible makes, a real appreciation can be obtained for the complex nature of this joint. Just the muscular feat of maintaining stability of the disc-condyle complex, while delivering a heavy bite force at the same time that the complex is translating along the eminence is proof enough of the intricate responsibilities of these muscles. DuBrul (1975) further emphasizes the need to understand a few fundamentals regarding basic muscle function. A muscle can have three distinct roles. It can contract and act as a "mover" of the part on which it inserts, or it can tense up and lengthen at a specific rate acting as a "balancer" for a moving part. Finally, it can hold its shape and neither shorten nor lengthen, thereby acting as a "holder". Bell (1983) also includes the fundamentals of conscious and unconscious movements, where a stretch reflex offsets gravity and maintains muscle tone.

DuBrul (1975) and Hylander (1979) do a very thorough job of describing the musculature involved in the functioning temporomandibular joint, but DuBrul categorizes the muscles in a way that lends itself to a better appreciation of the combined coordination necessary in all mandibular movements. Six pairs of muscles control the mandible. Three are elevators, one pair, which is often felt to be really two separate pairs, protrudes the mandible and stabilizes the meniscus, and two pair depress the mandible.

In every movement of the mandible, all twelve of these muscles are in function, some as movers, some as balancers and some as holders.

Of the elevators, two are intimately related at the pterygomasseteric sling with the medial pterygoid having its main origin in the pterygoid fossa, while the masseter originates from the zygomatic arch (Hylander, 1979). The weaker and more simplistic medial pterygoid muscle, due to its fiber orientation is primarily an elevator of the mandible. The masseter, on the other hand, is more complicated, and is practically two different muscles from the same origin. The superficial, rectangular shaped portion with its origin on the lower border of the zygoma inserts around the angle of the mandible. The more powerful the muscle the wider and thicker is its origin as it travels posteriorly along the zygomatic bone, but interestingly never beyond the zygomaticotemporal suture. The deeper, triangular shaped portion, besides inserting on the base of the coronoid process and upper part of the ramus is not restricted by the temporal bone and, in fact originates just in front of the articular surface on the anterior slope of the eminence. To further differentiate these two portions, Gay (1977) using electromyography found that they acted differently during protrusive, retrusive and especially during masticatory movements. Hylander (1979) hypothesized that the fibers of the deep masseter closest to the articular eminence

probably stabilized the condyle against the eminence during biting.

The third member of the elevator group as Hylander (1979) delineates is the fan shaped temporalis originating from the lateral surface of the skull whose anterior limit is practically straight above the muscle's primary insertion, the coronoid process. However, the function of the temporalis is not as straightforward as it appears. The fan is divided into three groups of fibers. The bulk of the muscle is the vertically oriented anterior portion. The fibers of the middle group are oriented more obliquely, while the posterior group directs its fibers almost horizontally until they drop down in front of the articular eminence to insert at the lowest point on the mandibular notch. It is at this point that only DuBrul (1975) expands on the function of the posterior portion. When the condyle is seated properly on the eminence the fibers are oriented at a right angle to the notch area so that by contracting it would pull vertically and hold the condyle-disc complex against the eminence, acting as a stabilizing component. However, when the condyle translates down the eminence the direction of the fibers is no longer vertical, rather more parallel with the angle of the eminence, thus contraction tends to pull the condyle back into the fossa. This function can either move the condyle up and back, or it can slowly lengthen to balance the movement of the condyle out of the fossa,

or it can tense up to prevent the condyle from translating. Gay (1977) noticed that a close relationship existed between the posterior portion of the temporalis and the deep portion of the masseter. Hylander (1979) also noted that since the fibers of the middle portion are oriented obliquely they have a large retraction component of force on the mandible as compared to the pure elevation component of the anterior portion. The terminal tendon of the temporalis inserts onto the apex of the coronoid process and along the crest of the notch. Other of its muscle fibers insert around the process and along the anterior border of the ramus. Still other fibers send a superficial and deep tendon farther down to the third molar region forming the retromolar fossa. Even with this brief overview of the temporalis one can realize the variety of functional roles that this muscle can play during the simple act of biting an apple.

The two pairs of muscles involved in depressing the mandible are the digastric and geniohyoid. The digastric originates with its posterior belly from the mastoid notch dipping down and through a fascial loop off the hyoid bone and travels superiorly as the shorter anterior belly inserting on the latero-lingual of the symphysis, or the digastric fossa. Interestingly, the posterior belly is from the second branchial arch with innervation from the facial nerve whereas the anterior belly is derived from the first arch and is innervated by the mylohyoid nerve. In

function when the stylohyoid and the infrahyoid muscles stabilize the hyoid bone, force from the digastric muscles then pull the mandible back and down. Therefore, the digastric can act in retrusive and opening movements of the mandible. Similar in function, the geniohyoid connects the upper half of the hyoid body to the lateral of the mental spines and is innervated by the first and second cervical branches. It can either pull the hyoid bone upward and forward or the mandible in the opposite direction, depending on which bone is stabilized (DuBrul, 1975; Hylander, 1979).

Finally, the muscle that has received the most attention as to its etiologic involvement in temporomandibular joint disorders is the external pterygoid. Anatomically, DuBrul (1975) defines the two separate heads of this generally accepted protrusor muscle. Originating from the lateral pterygoid plate, the larger inferior head is directed upward and outward to attach at the neck of the condyle, whereas the superior head has its origin actually above the joint complex. Its fibers run downward and outward until they reach the anterior limit of the joint where they orient horizontally back to the neck of the condyle. At this point only the most medial and superior fibers attach to both the capsule and the medial portion of the meniscus. The majority of the fibers mesh with the inferior head and insert on the neck of the condyle. Up until 1973 it was generally believed that these

two heads worked in tandem pulling the condyle medially downward and forward along the eminence in unison with, or separate from, the contralateral side. However, in 1973 McNamara, using Rhesus monkeys and Lipke (1977) using humans, showed that the two heads function independently. McNamara showed that the inferior head acts synergistically with the depressor muscles in opening movements while the superior head is inactive, but during chewing, clenching and swallowing the superior head is active while the inferior head is inactive. Biomechanically, DuBrul (1975) describes the change in orientation of the fibers of the superior head when the mandible is in an open position, such that the descending fibers are in a position to function. As a biting force is initiated by the elevators the superior belly becomes active as McNamara (1973) points out to position and stabilize the condyle-disc complex against the eminence. Bell (1983) includes the aspect of muscle tonus or passive resistance to stretch in order to maintain contact of articulating parts when the muscles are in their inactive phase. But on the whole as he summarizes muscular function in a variety of mandibular movements, the proposed function of the two heads of the external pterygoid by DuBrul, McNamara and Lipke is the accepted understanding today.

Vascular Component

Through microdissection of the Rhesus monkey, Boyer (1964)

delineated the extensive blood supply to the capsule and disc from all vessels nearby. Sicher (1965) confirmed these findings in the human and reported that the anterior aspect of the capsule was supplied by the masseteric artery while the posterior aspect received its blood supply via the superficial temporal and maxillary arteries. Also noticed was an unusually rich plexus of veins in the posterior area that DuBrul (1975) attributed to the need for pressure equalization as the condyle is moved in and out of the fossa.

Parsons (1966) examined the rich bilaminar zone area. He found that as vessels ran vertically along the posterior aspect of the ramus they eventually separated, with the anterior branches supplying the posterior half of the meniscus and the posterior branches supplying the ossicles of the middle ear via the glaserian fissure. Moffett (1957) ruled out the proposed erectile function of the bilanimar zone, while noting how extremely vascular the area was that supplied branches to the middle ear. He also reported that as the fetal meniscus matures the anastomoses between the posterior branches and the capillaries of the external pterygoid resorb due to mechanical pressure from the condyle and eminence, thus leaving an avascular center.

Neural Components

The more the temporomandibular joint is studied, the

greater is the appreciation for its complexity. It is no wonder that the joint is so heavily innervated. The excellent works of Thilander (1964) and Dixon (1962) are still used today as the basic neuroanatomy for this region. In her studies of the fetus, Thilander (1964) found that the auricular temporal nerve entered the disc-capsule tissue from the posterior as the masseteric and the posterior deep temporal nerves entered from the anterior. They either followed blood vessels or ended as free nerve endings. She reported 1500 sensory nerve fibers in the TMJ and two-thirds were from the auriculotemporal nerve, which terminate as free endings in the capsule, on the periphery of the disc and in the adventitia of the blood vessels. Thilander (1964), Dixon (1962) and Kawamura (1979), all agree that the most abundant nerves are the free nerve endings for pain response, but these fibers also transmit proprioceptive information. Such receptors are the Pacinian corpusles, Ruffini's corpusles and the Golgi tendon organs found in the capsule to monitor changes in mechanical stress. Besides these somatic sensory nerves, autonomic fibers travel with the blood vessels to regulate their diameter. Dixon (1962) refuted the idea that the trunk of the auriculotemporal nerve could be compressed by a displaced condyle, giving rise to the host of TMJ symptoms. Rather he suggested that inflammatory conditions could produce dilation of vascular spaces which could stimulate neighboring nerve bundles to elicit pain. He found all

gradations of fibers, from thin to thickly myelinated in the bilaminar zone but found few nerves beyond this point. One last point was that it had not been possible for him to demonstrate somatic nerve terminations. In other words he found a complete absence of endings of the coiled or encapsulated forms in this zone which are so easily stained in oral mucosa.

Functional Morphology of the Meniscus

If the most severe symptoms associated with TMJ disorders are elicited when the meniscus is malposed, then the correct repositioning of the meniscus should alleviate them. However, if the meniscus changes its morphology after it has been displaced for a certain period of time, the repositioning alone may not be enough, for the meniscus to function under the mechanical demands of this joint. In order to properly evaluate the gross morphologic and histologic changes that can occur in the meniscus, and to fully appreciate the difficulties clinicians have in successfully treating these cases to functionally stable results, a good histologic understanding is necessary of the normal meniscus.

As the morphology of the meniscus was segmentally described by Rees (1954) in terms of anterior and posterior bands, the histology will be reported similarly for each region.

Anterior Band

Whereas Rees (1954) uses the words "densely plaited white

fibrous tissue" and associated flattened fibrocytes in a basophilic matrix, Hankey (1954) actually defines the fibers as "interlacing bundles of collagen". Griffin and Sharp (1960) found these fibers to be markedly parallel in an anterior to posterior direction, especially in the anterior band, whereas Knox (1967) found the strongest antero-posterior orientation in the intermediate zone. The concensus though is for a strong antero-posterior orientation of collegenous fibers with some areas of medio-lateral, and vertically directed fibers. Knox (1967) also found a group of fibers encircling the articular, intermediate zone concentrated in the anterior and posterior. He concluded that the fiber, due to its inherent resistance to stretch, is oriented as a result of function to best prevent stretching of the meniscus laterally and antero-posteriorly. How can the vertical fibers be explained? Tendons of the external pterygoid muscle and some elastic fibers are seen in the anterior band, along with small arteries, arterioles, veins and neural elements (Knox, 1967; Griffin, 1975).

Intermediate Zone

The much thinner intermediate zone as was generally agreed upon by Griffin (1960, 1975) and Knox (1967), has the strongest antero-posterior orientation of collagen fibers, some fine unoriented meshing collagenous fibers, and some elastic fibers.

Neurovascular areas near the medial and lateral poles, with an aneural and avascular center has been confirmed by Hankey (1954), Rees (1954) and Thilander (1964).

Posterior Band

While Griffin and Sharp (1960) and Griffin (1975) maintain that the collagenous fibers in this region are unoriented, Strauss (1960), Thilander (1964) and Knox (1967) report that the medio-lateral or transverse fibers predominate in this widest and thickest band. Knox (1967) found some elastic fibers in the peripheral regions while few in the middle, and no mention was made of any neurovascular bundles.

Thilander (1964) reported that as early as three months in utero, collagen fibers began to orient anteroposteriorly, and starting at three months after birth she noticed vertical and transverse fibers besides the longitudinal ones. With age, cell numbers decreased as did elastic fibers, collagen increased and the cells on the periphery became more flattened as compared to the inner, rounder cells. Finally, she feels that the orientation of fibers in the posterior band implies it being subjected to multidirectional traction. Likewise, Knox (1967) reported that if the function of the disc did not vary, the orientation of its fibers showed little change.

Bilaminar Zone

The Bilaminar zone named by Rees (1954) can best be described by dealing with the superior attachment, the inferior attachment and then the loose connective tissue in between. He states that the upper stratum is loose fibro-elastic tissue attaching the posterior band to the posterior wall of the glenoid fossa and the squamo-tympanic suture. In fetal life it connected the external pterygoid tendon to Meckel's cartilage and eventually the malleus until the squamo-tympanic suture closed. Dixon (1962) and Knox (1967) reported this to be rich in parallel elastic fibers for the accepted purpose of recoiling the disc back into the fossa after translation. Scapino (1983) aptly named this stratum, the temporal posterior attachment (TPA) to differentiate it from its inferior counterpart the condylar posterior attachment (CPA) since this attachment connects the inferior surface of the posterior band to the neck of the condyle. It differs from the TPA in that it is composed of layered collagenous fibers and few elastic fibers (Rees, 1954; Griffin, 1960). The purpose of the collagen fibers is to resist severe displacement of the meniscus. A synovial membrane covers both the TPA and the CPA and since its function is to provide lubrication and nutrients to the nonvascular articular surfaces of their respective joint spaces, this explains the proximity of the lymphatic, venous and arterial capillaries just beneath their synovial membranes (Griffin and

Sharpe, 1960). Between these two attachments is an area predominantly composed of elastic fibers amongst rich neurovascular connective tissue, whose function is to rapidly engorge itself and empty in concert with the movements of the translating condyle. Rees (1954), Griffin (1960) and Griffin and Sharpe (1962) report an especially rich area of neurovascular connective tissue just below the squamo-tympanic suture, and mylenated and unmylenated nerves associated with blood vessels.

Pathophysiology

The accepted rule of anatomy, form from function, should apply when the function is healthy as when it is not. Therefore, when certain required parameters of healthy function are altered beyond a point of compensation it should be no surprise that the form of associated structures likewise changes. The following altered parameters are but a few that need be addressed before understanding any TMJ disorder, not to mention deciding on the appropriate treatment.

One of the most common lesions of the meniscus is the perforation (Blackwood, 1969). For many years, studies continually named loss of teeth and specifically denture wearing as the etiologic factor (Hankey, 1954; Macalister, 1954; Moffett, 1964). Steinhardt (1958) reasoned that teeth reduce the masticatory pressure on the disc and that with their loss the compressive

pressure increases on the disc. Associated with a perforation are articular thickenings most often on the surface of the eminence (Macalister, 1954; Blackwood, 1969). In disagreement with this is Moffett (1964) who states that the perforation causes progressive remodeling on the condyle and regressive remodeling on the eminence, eventually leading to osteoarthritis. However, Blackwood (1969) saw perforations with no changes on articular surfaces, and concluded that it is difficult to say what is cause or effect. The perforations were reported to occur most often in the lateral aspect of the meniscus for possible reasons that the disc is thinnest here and that the lateral pole is higher than the medial pole and thus, closer to the eminence (Oberg, 1971; Hansson, 1977).

Hankey's timeless study (1954) needs little updating today, as it painfully points out how much true progress has been made in 30 years to rid this malady of health. He practically labels the problem of meniscal displacement, when he emphasizes the need for astute diagnosing to keep the condyle from driving too deep into the fossa, while utilizing bite opening splint therapy in the moderarely difficult cases. As etiology, he names not one but the cumulative effects of such combined factors as Class II malocclusions, bite relationships that inhibit lateral grinding, loss of vertical height due to molar extractions, even improper sleeping positions that put lateral strain on the joint.

Hankey went so far as to recommend against long dental appointments. Finally, he appropriately warns that even when a patient has painless clicking to palpation on the capsule and in the ear, a slight injury can precipitate the whole episode of painful symptoms.

Besides unduly stressing the disc complex during bruxing, Kopp (1983) attempts to explain resultant muscle pain as an aseptic inflammatory reaction due to muscular hyperactivity. On the other hand, DuBrul (1975) suggests that painful muscles can be the result of radiating pain from an injured capsule. He also proposes an explanation of ear pain as a spasm in the external pterygoid muscles that impairs blood and lymph drainage of the ear resulting in edema of tubule mucosa.

Histopathology

Compared to the quantity of material written about the normal histology and anatomy of the joint, very little has been reported until recently on the histologic changes occurring in menisci of dysfunctioning temporomandibular joints.

In 1954, Macalister made reference to the anterior migration of the temporal posterior attachment on the temporal bone in patients with protrusive biting. Recently, Scapino confirmed this type of migration of the TPA and the CPA together with progressive remodeling at the site of attachment on the condyle, all found in

a patient confirmed to have the meniscus displaced anteriorly. He attributed these changes to excessive traction of the elastic tissue. Macalister (1954) also reported seeing small numbers of cartilage like cells, calcific changes, and increased vascularity that he felt was indicative of repair. Steinhardt (1958) stated that posterior compression could cause an alteration of blood vessel walls thereby altering the volume of blood in this vascular bed. Blackwood (1969) suggested that repeated compression of retrodiscal tissues causes some attenuation of the disc attachment rendering it more susceptible to rupture. One point that may prove to be quite interesting was made by both Hankey (1954) and Blackwood (1969), and it was that they considered the meniscus to be capable of repair. Scapino (1983), made no mention of islands of cartilage, or calcifications, or increased vascularity, in fact he found a decrease in vascularity in the anterior portion of the posterior attachment. In addition, he found just the opposite as far as attenuation of the posterior attachment area, rather he found an increase in fibrosis and plaited collagen fibers in that new articular area behind the anteriorly displaced meniscus.

Scapino (1983) also made a series of other precident setting observations regarding morphology, collagen orientation, and posterior attachment changes.

When the meniscus is locked ahead of the condyle, it is

reasonable to assume that a larger posterior band would have a direct effect on the inability of the condyle to reposition itself under the disc. However, he found this not to be the case. In some instances even though the meniscus was displaced and often folded over, the three basic zones could still be distinguished, however, in certain specimens the bands coalesced into an amorphic mass with no distinction between parts. Concerning collagen orientation there was an increase in the number of medio-lateral or transverse fibers in the posterior band but they were also found in the intermediate zone, as were vertical fibers, sometimes completely obliterating the sight of the normal A-P fibers. Another unique finding was that when the meniscus folded or flexed from being pushed against the anterior limit of the capsule, the collagen fibers did not keep their orientation parallel to the surface, in fact they were found to be perpendicular to these acute flexures, with transverse fibers interspersed. Lastly, an upward flexure of the meniscus was found more often than a downward flexure.

As was stated above, when the posterior attachment becomes an articular tissue due to the displacement of the disc, collagen fibers were seen to form a more compact mass than normal, while the small vessels usually present near the junction of the posterior attachment and the posterior band either decreased or were

absent. Under normal circumstances the TPA and the CPA are able to be distinguished as they mesh with the posterior band, but in these instances the compact antero-posterior fibers plus transverse and oblique fibers obscured them.

Finally, Scapino suggests that as the posterior attachment fills in with collagen fibers the effective length of functioning elastic fibers is therefore decreased, causing an increase in strain on the remaining fibers. To compensate for this greater demand the TPA migrates anteriorly along the back of the fossa, as probably does the CPA.

STATEMENT OF THESIS

This study is designed to evaluate the gross and histopathologic adaptations caused by forces of function in the malpositioned, human temporomandibular joint meniscus, and to relate clinical histories to these observations. Two general areas will be addressed regarding displaced meniscus. One is the collagen structure and orientation in the deformed meniscus because this should aid in understanding its morphology and inability to remain in position for function. The other area is the posterior attachment, since it is subjected to interarticular pressures, and is the primary tissue attempting to maintain the meniscus in its proper position. The condition of its elastic fibers, vasculature and neural elements will be examined.

METHODS AND MATERIALS

The malposed temporomandibular joint menisci examined in this study numbered 10 and were obtained from 9 living humans. Two surgeons performed the meniscectomies and confirmed the displacement of each meniscus resulting in internal derangement of the TMJ. One other meniscus was also obtained from a cadaverous source, an 82 year old female, and was processed along with the others. Each meniscus was fixed in 95% formalin, photographed, marked with India ink on the posterior-inferior, and sagittally sectioned every 2 mm in an antero-posterior direction perpendicular to the condylar poles, then photographed again. Each section was embedded in celloidin, cut at 5-10 microns in depth, and stained with hematoxylin and eosin. Two representative sections from each meniscus were also stained with Masson's trichrome stain for collagen fibers, and a Weigert-resorcin-fuchsin stain for elastic fibers. Eight representative sections of the entire sample were stained with an S-100 immuno-peroxidase stain for neural tissue. All slides were examined, but representative slides of each disc were included in the data gathering table. Photomicrographs were taken of all significant findings.

Also examined for the purposes of understanding meniscus orientation, aged morphology and joint functional anatomy, were 7 temporomandibular joints removed by block dissection from cada-

verous sources, as well as 11 other individually dissected menisci. All menisci were photographed and 6 of the 7 block sections were photographed showing various anatomical relationships between the articular eminence, meniscus and condyle.

The hematoxylin and eosin stain is universally used because of its simplicity and its ability to stain clearly a very large number of tissue structures. The hematoxylin component stains cell nuclei and calcium deposits blue-black, while the eosin stains cell cytoplasm and most connective tissue fibers varying shades of pink, orange and red. Muscle fibers are deep pinky red, collagen is pale pinky red, red blood cells are orange and fibrin appears deep pink.

Masson's trichrome stain is a sequential procedure starting with a plasma stain, followed by a phosphomolybdic-phosphotungstic acid mixture, and then a collagen-fiber stain. The exact mechanism of how the stain works is unknown, however, some theories exist. Biebrich scarlet is a common acid dye to stain cytoplasm, muscle fibers and collagen, but collagen is much more permeable than the others due to its loose texture. Therefore, this stain can diffuse out or be substituted by the phosphomolybdic-phosphotungstic acid while being retained in the more selectively permeable cytoplasm and muscle. This enables the subsequent addition of aniline blue to stain only the collagen fibers. The result is red cytoplasm, red muscle with black nuclei, and blue collagen.

The Weigert-resorcin-fuchsin stain begins with a nuclear staining by Weigert's iron hematoxylin, then onto the iron attaches the resorcin-fuchsin solution forming a complex that renders the elastic fibers blue black. The mode of attachment is unknown but Hydrogen bonds with the resorcin are suspected. A Van Gieson counterstain follows, staining collagen red and other tissues yellow. A summary is the elastic fibers and nuclei are black, collagen is pink-red and other tissues are yellow.

The S-100 immunoperoxidase staining technique uses the S-100 protein found in nerve tissue as the primary antigen for a series of rabbit and goat antibody reactions. The final peroxidase-antiperoxidase (PAP) bridging antibody is utilized to bind with the staining agent, diaminobenzidine tetrahydrachloride (DAB). The cytoplasm of the nerve cells stain brown against an unstained background.

The normal meniscus observations with which to compare were gleaned from the literature and observed in one meniscus that presented with a fair degree of normal gross morphology and histology. The cadaverous meniscus was ideally positioned in the fossa and possessed excellent morphology. It was also for comparison, but as a normal aged meniscus.

Areas evaluated were:

1. Gross cross-sectional morphology
2. Distinguishable histologic zones

3. Collagen fibers and orientation
4. Chondrocyte morphology and concentration
5. Elastic fiber morphology and concentration
6. Vascular elements
7. Neural elements

A data gathering table was constructed to systematically evaluate the middle two-thirds of each meniscus. The concentration of fibers or cells and the degree of change in the area of examination were quantified by using a range of 0-2. "0" represented normal, "1" represented moderate and "2" represented excessive. When areas to be examined were surgically not included in the specimen, the letter "N" was utilized. The representative sections were evaluated in the following areas:

1. Zones markedly deformed--Anterior band (AB); Intermediate zone (IZ), Posterior band (PB), 0-2 to quantify degree of deformation.
2. Thickness of intermediate zone--N for not included, 0-2 to quantify degree of thickness in an inferior to superior dimension.
3. Vertical fibers in anterior band--N, 0-2 to quantify the degree of concentration of fibers.
4. Vertical fibers in intermediate zone--same as above.
5. Vertical fibers in posterior band--same as above.
6. Transverse fibers in intermediate zone--same as above.
7. Amorphic orientation of fibers--presence of such fibers confirmed, and areas observed were designated with AB, IZ, PB.

8. Flexure present--same as above.

9. Fiber orientation at flexure--fibers parallel, disrupted or perpendicular to surfaces in the flexure.

10. Increase surface concentration of chondrocytes--arrows directed superiorly or inferiorly, confirm the presence of such chondrocytes designate the area and surface on which they were found.

11. Elastic fibers present and degree of fragmentation--0-2 both confirms the fiber presence and quantifies the degree of fragmentation.

Patient histories were obtained for the purpose of relating age, sex, duration and location of pain, type of click or lock, dental occlusion, systemic condition, and treatment history to the histologic observations.

RESULTS

Normal Specimens

General Appearance

The postmortem meniscus, representing the aged normal control, was light brown in color, smooth, glistening, biconcave in morphology and had considerable posterior, lateral and anterior attachment (Appendix I). Designated as Meniscus #11, it was removed from an 82 year old Caucasian female, who was partially edentulous with bilateral dental occlusion in the premolar area. Meniscus #10, representing the other normal control, was greyish-white in color, smooth and glistening with the medial one-third exhibiting ideal biconcave morphology. The intermediate zone of the postmortem specimen was thinner and longer in an anteroposterior dimension than meniscus #10.

Collagen Fiber Orientation

The anterior band, intermediate zone and the posterior band demonstrated a strong predominance of horizontal fibers, especially in the intermediate zone (Table I, Appendix II). Some transverse and oblique fibers were observed in the anterior band and the posterior band, while almost no vertical fibers were evident (Appendix III and IV). The chondrocytes of the postmortem meniscus appeared flatter than those in meniscus #10, and there

was no evidence of any excessive increase in collagen matrix in either specimen.

Within the posterior attachment area the temporal posterior attachment and the condylar posterior attachment could be differentiated with the looser packed collagenous fibers in between.

Elastic Fiber Orientation and Morphology

Two types of elastic fibers were observed. A thinner and straighter fiber type was observed in all zones of the meniscus and paralleled the orientation of the collagen fibers. The second type of elastic fiber was much thicker and most often wavy in configuration. These also paralleled collagen fibers but were demonstrated only in the most anterior extent of the anterior band and throughout the posterior attachment. More elastic fibers were observed in meniscus #10 than in meniscus #11. Both types of elastic fibers exhibited their specific morphology consistently throughout the meniscus.

Neurovascular Elements

Large arteries and distended veins were observed in the anterior and posterior attachments of meniscus #11. These were filled with red blood cells. Vascular elements were also observed in the posterior attachment of meniscus #10 but did not seem

hypertrophied or distended in any way. A few neural elements were observed and seemed to be associated exclusively with blood vessels.

Abnormal Specimens

General Appearance

All the surgically removed menisci were greyish-white in color and with the exception of the medial one-third of meniscus #10 had very little resemblance to the normal biconcave shape. The anterior to posterior dimension between the posterior band and what appeared to the the anterior band was always shortened, and the area in between, the intermediate zone, was thickened. Usually the superior surface was smoother than the roughened inferior side, and the posterior attachment area could often be identified by its spongy, more elastic properties even in spite of the stiffening effects of the formalin. The meniscus with the most roughened superior and convoluted inferior was meniscus #8. During the meniscectomy the attachment of the meniscus to the medial pole of the condyle is left in place due to its inaccessible location. In cross-section all four zones showed marked changes. The posterior band almost always became thicker or taller in an inferior to superior direction and also longer from its anterior junction with the intermediate zone to the start of the posterior attachment (Appendix V). The intermediate zone also became thicker and

shorter in an anterior to posterior dimension. The thicker that the intermediate zone became the more difficult it was to distinguish between the anterior band and the intermediate zone (Appendix VI).

Collagen Fiber Orientation

Vertical and transverse fibers were generally observed in all three zones, and it seemed that the thicker the zones became the more vertical fibers were observed (Appendix VII). These fibers appeared in varying degrees of thickness and length, even within the same meniscus. In menisci #1, 4, 5, 6, 7 and 8, a mor amorphic looking, unoriented collagen fiber morphology was observed. Vertical fibers were usually absent in this area. Menisci #1, 4 and 9 presented with a flexure in the intermediate zone and the fibers associated with this flexure had a disrupted orientation (Appendix VIII). The tendency was for these fibers to radiate in a perpendicular direction from the flexure rather than to stay parallel to the surface (Appendix VII).

There were also many instances where concentrations of chondrocytes were present near articular surfaces of the meniscus, most often along the inferior of the posterior band. This was evident in menisci #2, 4, 7, 8, 9 and 10.

Elastic Fiber Orientation and Morphology

The thin, type-one elastic fibers were consistently obser-

ved throughout all the zones of these menisci, but in meniscus #1, there was evidence of some "broken" disoriented type-one elastic fibers in the posterior band and intermediate zone. The type-two fibers were observed in the posterior attachment area to have fairly good morphology in menisci #2, 4, 5, 9 and 10, but menisci #3 and 7 showed some moderate fragmenting of fibers and menisci #1, 6 and 8 exhibited marked fragmenting and disorientation of fibers. In regards to concentration of elastic fibers in the posterior attachment, they appeared in just slightly more concentration in the temporal posterior attachment than in the condylar posterior attachment.

Neurovascular Elements

The number of blood vessels in the abnormal specimens appeared to be about the same as observed in the normal. However, in menisci #4, 7 and 8 the vessels seemed to be more hypertrophied with meniscus #7 possessing an artery and vein three to four times the size of any other vessels seen in the study.

The S-100 immunoperoxidase stain showed a sparse number of neural tissue in the posterior attachment area which were associated only with the blood vessels. No nerves were stained in the posterior band, intermediate zone or the anterior band.

Unique Observations

1. No calcifications or perforations were noted.

2. Meniscus #4 exhibited layers of collagen fibers in the posterior attachment area, extending the posterior band. These layers also seemed to have entrapped an artery just posterior to the posterior band. Three to four millimeters medial to this section showed in the same area an increase in vascularity, with many arterioles and perivascular red blood cells. Also in meniscus #4, a concentration of chondrocytes appeared to be filling in the flexure, and could be followed through a number of sections.

3. Meniscus #6 showed a definite vertical invagination of chondrocytes from the superior surface of the posterior band to the middle of the band. Nearby this invagination was another smaller one.

4. Of all the menisci in the study, the posterior attachment of meniscus #7 appeared to be the thinnest in an inferior to superior dimension.

5. Meniscus #8, having undergone a surgical repair three years earlier, showed a marked foreign body reaction in progress around the sutures in the posterior attachment area. Also present were scar tissue adhesions on the superior surface of the posterior band and unusual folds and tags on the inferior surface at the junction of the posterior band and the condylar posterior attachment.

6. Lastly, an artery was repeatedly observed at the junction of the posterior band and the condylar posterior attachment, as was another prominent vessel in the middle of the posterior attachment directed toward the posterior band.

Clinical Data

All the patients presented to the two oral surgeons in pain and in mandibular dysfunction. Their ages ranged from 17 to 53 with an average age of 35 years (Table II). They were Cauca-

sian and had a sex ratio of one male to 8 females. Most of the menisci were confirmed at surgery to have been displaced anteriorly or antero-medially. However, meniscus #1, which was from the only male was displaced laterally.

The dental occlusions seemed to be fairly well distributed between Class I, II and III occlusions. The type of pain was also distributed evenly between the classifications of sharp and dull. The location of the pain was most often reported to be on the capsule and in the muscles of mastication, but about half the patients reported ear symptoms. Generally, the duration of pain was two years or more with the exceptions being the 55 year old or meniscus #7 who was in pain for 12 months and the 26 year old of meniscus #9 who had the previous repair on meniscus #8 and who was symptomatic with meniscus #9 for only 6 months. The extreme durations were found in the male boxer with 6 years of symptoms and the meniscus picked for its normal anatomy, meniscus #10 with 10 years of painful symptoms.

Splint therapy was attempted on almost all the patients as 8 out of 9 patients were diagnosed as having a late click. Half of the patients at some point in their history had developed a closed lock situation. The duration of treatment with splint therapy was not obtained.

Fingernail and pencil biting, along with a history of bruxism was reported in 6 of the 9 patients, while trauma to

the head region was reported by 5 out of the 7 patients who responded to the history questionnaire.

Other findings were numbness of the first two branches of the trigeminal nerve (V_1 and V_2) on the affected side of the boxer, which disappeared after the surgery. Shoulder bursitis was present in patient #2 and mild scoliosis in the 17 year old patient.

TABLE I

HISTOLOGICAL AREAS OF EVALUATION

Evaluated Areas		Meniscus										
		1	2	3	4	5	6	7	8	9	10	11
		Section										
		3 5 7	3 5 7	2 4 8	3 6 8	4 6 8	3 5 7	3 5 7	4 6 8	3 6 9	3 5 7	5 7 10
Zones markedly deformed	AB	1 0 0	2 2 N	N 0 0	1 2 2	0 0 0	N 0 0	1 1 2	N N 1	N N 1	N N 0	0 0 0
	IZ	2 0 0	2 2 N	0 0 1	2 2 2	1 1 0	N 1 1	1 1 2	2 2 2	2 2 0	1 1 0	0 0 0
	PB	0 0 0	1 1 1	0 0 0	2 1 1	0 0 0	1 0 1	0 0 1	1 1 1	1 1 1	1 1 0	0 0 0
Thickness of intermediate zone	N*		X X X				X					
	0-2	2 2 1		0 0 1	1 1 0	1 2 1	1 1	1 1 2	2 2 2	2 2 0	1 1 0	0 0 0
Vertical fibers in anterior band	N	X	X X X	1	X X		X		X X		X X	
	0-2	1 0		0 0	0 0 0	0 0 0	0 1	1 1 1	1 1 1	1 1 0	1 1 0	0 0 0
Vertical fibers in posterior band	0-2	2 2 1	1 2 1	0 0 1	0 0 0	1 1 0	1 0 1	1 1 1	1 1 1	1 1 0	1 1 0	0 0 0
Transverse fibers in intermediate zone	N		X X				1					
	0-2	1 0 1	0	0 0 1	0 2 0	0 0 0	0 1	1 1 1	1 1 1	1 1 0	1 1 0	0 0 0
Amorphic orientation of fibers	Yes	X			X X X	X X	X X X	X X	X			
	No	X X	X X X	X X X		X		X	X X	X X X	X X X	X X X
	Area	PB			IZ IZ PB PB PB	IZ IZ	PB PB IZ IZ	IZ PB IZ	PA			
Flexure present	Yes	X			X X					X		
	No	X X	X X X	X X X	X	X X X	X X X	X X X	X X X	X X	X X X	X X X
	Area	IZ			IZ IZ					AB IZ		
Fiber orientation at flexure	Parallell				X							
	Disrupt	X			X					X		
	Perpend											
Increased surface†↓ concentration of chondrocytes	O	X	X X	X X X	X	X X X	X X X	X	X X	X X	X X	X X X
	AB				↑							
	IZ				↓ ↓			↑ ↑				
	PB		↓						↑	↓	↓	
	PA				↑			↓				

(continued on next page)

TABLE I

HISTOLOGICAL AREAS OF EVALUATION

Evaluated Areas		Meniscus										
		1	2	3	4	5	6	7	8	9	10	11
		Section										
		3 5 7	3 5 7	2 4 8	3 6 8	4 6 8	3 5 7	3 5 7	4 6 8	3 6 9	3 5 7	5 7 10
Elastic fibers present and degree of fragmentation	AB	1	N N	N 0	0 0	0 2	1 1	0 N	N 1	N N	0 0	0
	IZ	1	N N	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
	PB	1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
	TPA	1	0 0	1 1	0 0	0 1	2 1	1 1	2 1	0 0	0 0	0
	CPA	2	0 0	1 1	1 0	0 1	2 1	1 1	2 1	1 0	0 0	0
Neural elements	AB			-	-		X	-	-	-	X	X
	IZ			-	-		-	-	-	-	-	-
	PB			-	-		-	-	-	-	-	-
	TPA			X	X		X	X	X	X	X	X
	CPA			X	X		X	X	X	X	X	X

* Not included in surgical section.

- Not observed.

TABLE II

PATIENT HISTORIES

Patient Information	Patient				
	1	2	3	4	5
Age	39	37	35	17	28
Sex	M	F	F	F	F
Duration of Pain (mos.)	76	30	42	36	24
Occlusion (Class)	III	II	II	I	I
Type of Pain Sharp		X		X	
Dull	X		X		X
Location of Pain Capsule	+	+	+	+	+
Ear	-	+	+	-	-
Muscles of Mastication		+	+	+	+
Late Click	+	+	+	-	+
Closed Lock		+			+
Splint Therapy	+	+	+	+	+
Habits		Bites Fingernails	Pencil Biter; Telephone Shoulder		Bruxism
History of Trauma	Boxer	Husband beating; Intubation	Husband beating; Blow to head	Auto Accident	Concussion at 8
Other Observations	Numbness of V_1 and V_2	Shoulder bursitis	Tomography shows changes in condyle	Mild Scoliosis	

(continued on next page)

TABLE II

PATIENT HISTORIES

Patient Information	Patient 6	7	8	9	10
Age	29	55	26	26	32
Sex	F	F	F	F	F
Duration of Pain (mos.)	84	12		6	120
Occlusion (Class)			I	I	I
Type of Pain Sharp	X		X	X	X
Dull		X			
Location of Pain Capsule	+	+	+	-	+
Ear	+	-	+	-	+
Muscles of Mastication	+	+	+	+	+
Late Click	+	+	+	+	+
Closed Lock	+		+	+	+
Splint Therapy	+	-			+
Habits	Bruxism; Telephone shoulder	Tongue probing	Bruxism	Bruxism	None
History of Trauma			Auto accident	Fell off horse	None
Other Observations	Finger joint problem		Previous surgery; root canal therapy		Equilibration

DISCUSSION

Morphologic Evaluation

Comparisons between Postmortem Menisci and Abnormal Menisci

Nothing in this study was more striking than the difference in gross morphology between the majority of the postmortem menisci and the 10 surgical menisci. Granted a certain degree of aging had taken place in the postmortem specimens, and some had perforations, but in general, the older menisci presented with much more ideal anatomy. Even when inspecting them apart from the joint, their orientation and functional anatomy was obvious. This was in stark contrast to the surgical specimens with the exception of meniscus #10. These were so thick, and shortened anterior to posterior, with so little biconcave anatomy that it was no wonder the previous splint therapy in many had proven unsuccessful in stabilizing the meniscus between the condyle and the eminence. There was no concave area into which the condylar head could fit.

Comparison of Normal Postmortem to Normal Surgical

Differences were also apparent between the normal postmortem specimen and the portion of the surgical specimen that possessed the normal anatomical morphology. From a gross view-

point, the major difference was that the intermediate zone of the postmortem menisci was thinner and definitely longer between the anterior and posterior bands. This impression was reinforced histologically, as was another difference. This was the degree of definition and predominance of horizontal fibers found in the postmortem menisci. Another surprising observation was the paucity of arteries or arterioles found in the posterior attachment of the postmortem meniscus compared to all the other specimens. The normal surgical specimen was again shorter anteroposteriorly and showed a few more transverse fibers, but exhibited no vertical fibers and fell well within the normal range as is described in the literature.

Comparisons within the Normal Surgical Meniscus

A unique comparison existed within this partly normal surgical specimen. It seemed that the lateral two-thirds of the meniscus had been displaced anteriorly and undergone structural deformation, or possibly the meniscus had rotated anteriorly from the medial pole stretching the lateral attachment and allowing the lateral pole of the condyle to compress the posterior attachment in that area. Regardless, the lateral two-thirds of the meniscus was grossly and histologically more abnormal than the medial one-third. The abnormal portion showed all the signs of a malposed meniscus being pushed against the capsular limit of the

joint space. It was thicker, the IZ was narrower, and vertical fibers were observed throughout the AB, IZ and PB.

Comparison of Normal to Abnormal

Before discussing the various histologic adaptations found in the abnormal menisci, it is understandable to question the validity of the control, which then leads to question of what is normal. A meniscus that functions for 82 years and presents with such a smooth, glistening display of functional anatomy almost brings forth contemporary suspicions of it being abnormal. Ideally, a meniscus from a 35 year old female with meniscal anatomy similar to that of the postmortem, but just a little thicker and narrower in the IZ, would best be suited for a control. However, by using the copious descriptions from the literature and the preserved portion of meniscus #10, a fairly strong normal control can be obtained.

In attempting to explain the presence of the all too familiar vertical fiber in the deforming meniscus an interesting explanation was proposed in a personal discussion with Sorensen (1984). It was suggested that as collagen matrix is produced in response to an abnormal type of stress, the buildup between horizontal collagen fibers moves them apart from each other, eventually leaving the fibers oriented in a vertical or oblique direction. The accepted explanation for the fibers is that they are formed in

a direction to best utilize their potential to resist stretch, thereby implying by their orientation those directions from which forces of traction are emanating.

As presented by Scapino (1983), areas of layered collagen fibers were observed in the posterior attachment area that was functioning no longer as a recoil tissue but rather as an inter-articular tissue, or an intermediate zone.

This study was unable to concur with Scapino (1983) regarding the decrease in vascular elements just posterior to the PB, as would understandably be expected. However, comparing numbers of vessels in this area to numbers in a similar area of a control is difficult, especially when the aged control also shows a tendency towards a decrease in vascularity. Finally, definite evidence of hypertrophied arteries in the posterior attachment area were observed.

Considering the degree of innervation of the capsule and the meniscus as described by Thilander (1968), and the severity of pain many patients with displaced menisci experience, this study was undertaken in anticipation of finding a rich plexus of nerves in the PA or at least nerves with schwann cell proliferation. The S-100 stain consistently showed few nerve cells or Schwann cells and most were associated with blood vessels. Other nerve stains should be utilized before drawing too many conclusions regarding the innervation of this area.

There were two observations that were not anticipated following a study of the literature. First was the observation of two types of elastic fibers found in the meniscus, and the second was of their fragmenting and disorientation in many of the malposed menisci. Furthermore, these elastic fibers were also found in areas of adaptive regeneration in the vertical fibers and in areas of the posterior attachment where collagen was being layed down. The degree of fragmentation did however vary between menisci but almost exclusively, the fragmented fibers occurred in either the anterior attachment or the posterior attachment.

Unique Observations

Although no perforations of the meniscus or its attachments were observed, and only a relatively thin posterior attachment was found in meniscus #7, surgeons do report perforations in the attachment area posterior to the line of incision.

The fairly large and consistently observed artery found at the junction of the CPA and the PB could be the artery or plexus reported by Griffin (1961) named the "genu vasculosis", which he states travels superiorly and once in the middle of the bilaminar zone directs posteriorly.

Flexures were observed in three specimens and the apexes of these flexures all pointed superiorly, but meniscus #4 exhibited a regeneration response in the apex of the flexure, which

could be followed through a number of sections. This activity which seems to fill in the flexure may be the process involved in the eventual coalescing of the AB and the PB resulting in an amorphic mass. In this area of regeneration and others along certain articular surfaces, prolific activity was observed such as increased matrix formation and cloning of cells. In contrast to this response meniscus #5 presented with an area of mixoid degeneration within the PB itself. There was a high concentration of chondrocytes present with resorption of matrix and cell bodies causing the area to stain lighter than the surrounding tissue. A response such as this is often said to be a result of trauma (Sorensen, 1984).

Clinical Evaluation

Patient Information

Simply due to the small sample size in this investigation, limitations are obvious in drawing firm correlations from the patient information presented. However, the average age and sex dominance in this study does coincide with the epidemiology in the literature, and many interesting relationships do exist.

There seems to be a mild trend regarding trauma and habits in many of these cases. It is easy to understand how a common factor such as trauma could be all that is needed to initiate an episode of pain in an individual who is predisposed to this func-

tional disorder in the first place due to other factors. Even the continual activity in the external pterygoid during fingernail biting or bruxing can predispose an individual to such disorders and also make treatment more difficult.

It was curious to note that of all the menisci, only meniscus #1 showed fragmenting of the elastic fibers, not only in the posterior attachment area but also within the usually protective AB, IZ and PB areas. This meniscus also had a fair amount of prolific amorphic collagen formation. The patient from which the meniscus was removed was an amateur boxer and the only male in the study. Could it be the continued trauma from boxing that caused the fragmenting of the type one elastic fibers, or could it have been the fact that the meniscus was displaced laterally, or is there an inherent weakness in the male elastic fibers compared to the female?

Meniscus #4 was removed from a 17 year old patient who had been undergoing splint therapy for two to three years until a car accident precipitated the final episode of pain. This meniscus showed the most active areas of regeneration both in the filling in of the flexure and in the layered collagen formation in the posterior attachment area. Could there be more of a normal regenerative potential in a younger person compared to the thinner posterior attachment found in the 55 year old patient of meniscus #7. Or could the fact that the 55 year old did not undergo splint

therapy following her initial episode of pain, possibly be significant in her lack of a regenerative response in the posterior attachment area. The duration of her symptoms was also only 12 months versus 36 months in the 17 year old. It seems reasonable to conclude that with proper splint therapy, even if the meniscus cannot be properly repositioned or if its deformed shape does not provide a good concave seat for the head of the condyle, a regenerative possibility does exist that might increase the length of the posterior band, remodel its shape and provide a new functional equivalent to the normal meniscus. It also seems reasonable to conclude that just as these menisci changed shape when they were in malposition to the condyle and eminence, the same remodeling process could be utilized to regain a functional form if the meniscus can be properly re-positioned and maintained.

Unfortunately, the success of this repositioning depends on many factors, two of which are the degree of deformation of the meniscus and the condition of elastic fibers attempting to recoil and maintain the meniscus in its functional position. In evaluating the condition of elastic fibers, a relationship did arise when comparing the degree of fragmentation of elastic fibers to the duration of the patient's symptoms. The three menisci with the most excessive fragmentation were removed from patients who had been symptomatic for considerable lengths of time. For example, the patient of meniscus #1 had a duration of symptoms for

76 months, the patient of meniscus #6 was symptomatic for 84 months and the patient of meniscus #8 had the surgical repair 36 months previous with no record of the duration of symptoms before the surgery. The exception to this relationship is meniscus #10 which exhibited normal elastic fibers but the patient stated 10 years of symptoms. Since the elastic fibers in the other abnormal menisci appeared to still have good morphology, the implication is that even after a few years of late clicking, or moderate anterior displacement, the elastic fibers may still retain their ability to function.

Meniscus #8 and #9 were obtained from the same patient with #8 having undergone a meniscus repair, three years earlier. Certain areas of this PA were markedly thin at the suture proximations with unusual folding of proliferative scar tissue on the inferior surface and adhesions emanating from the superior surface. Active foreign body reactions were in progress around the plicating sutures. How long can a sutured PA resist the strain from the external pterygoid, as a foreign body reaction surrounds the sutures? Is this a typical response of the posterior tissues to nonresorbable sutures? There was however a considerable increase in the concentration of chondrocytes and their collagen matrix. One has to wonder that given enough time, might the compressive forces between the condyle and the eminence be able to functionally induce the fibroblasts in the area to become matrix

producing chondrocytes with an eventual end product of functional interarticular fibrocartilage.

Two other worrisome questions arise when considering the seventeen year old patient. Is there any age limit younger than which a meniscus won't undergo such structural deformation? The answer to this may be quite unsettling. Also, how long need a meniscus be displaced before it is remodeled to the degree observed in this study?

Further studies are needed to verify the regenerative potential of the meniscus to both remodel from a deformed shape back to a functional one, and to extend the length of its posterior band into the posterior attachment when induced by controlled compressive forces. Also the neural and elastic elements in the posterior attachment need investigating as to their location, concentration, morphology and role in TMJ functional disorders.

SUMMARY AND CONCLUSIONS

The postmortem normal meniscus appeared very similar in gross anatomical features to a portion of a surgical meniscus, also picked to represent normal. Three main differences between the two menisci were that the surgical meniscus was thicker in the intermediate zones (IZ), more narrow between the anterior band (AB), and the posterior band (PB), and histologically displayed a few more transverse fibers than the postmortem meniscus. No vertical fibers were observed in either.

Compared in gross terms to the control the abnormal menisci generally appeared thicker in the IZ and the PB, and more compacted in an anterior to posterior dimension often to the degree of being difficult to orient. Histologically, the surgical menisci showed various arrays of vertical and transverse orienting fibers throughout the AB, IZ and PB, often being the predominant fibers rather than the normally dominant horizontal fiber. A few severely deformed menisci presented with an amorphic appearance of collagen fibers dominating the field.

A few flexures were present at the IZ, and areas of regeneration were not only identified at the apex of these flexures but elsewhere in the menisci. A mixoid degenerative process was identified in one specimen. The concentration of vasculature in the posterior attachment area proximating the PB appeared variable

between menisci and even between sections of a single specimen. Hypertrophied arteries were often observed. Surprisingly, few nerve cells were displayed in the PA area, and were viewed only in association with blood vessels. Two types of elastin fibers were observed. A thinner, straight fiber was observed in every zone of all the menisci, and a thicker, usually wavy fiber appeared in the AB and PB only. Both fibers parallel collagen fibers in the control but in the PA of most of the surgical specimens the thicker fibers were observed to be fragmented and without orientation. Patient histories were presented for correlations and interesting relationships. The youngest meniscus showed the most regenerative activity in the posterior band extending into posterior attachment. A meniscus from a boxer, was laterally displaced and was the only one exhibiting elastin fiber fragmentation with the AB, IZ and PB. In a few cases, even though the menisci were severely deformed the elastic fibers in the PA still maintained good morphology and orientation. One meniscus presented with plicating suture material in the posterior attachment and scar tissue folds and adhesions on its articular surfaces.

Conclusions were drawn regarding the regenerative potential of displaced menisci to reverse the process of deformation correctly repositioned and maintained. Also discussed was the potential of the posterior band, when functionally induced by controlled compressive forces, to produce layered collagen fibers

in the posterior attachment area capable of functioning as inter-articular tissue.

LITERATURE CITED

Angel, J.L.: Factors in temporomandibular joint form. Amer. J. Anat., 83: 223-246, 1948.

Baume, L.J.: Ontogenesis of the human temporomandibular joint. 1. Development of the condyles. J. Dent. Res., 41: 1327-1338, 1962.

Behrents, R.: Unpublished Dissertation, 1984.

Bell, W.: Understanding temporomandibular biomechanics. J. of Craniofacial Practice, 1: 28-33, 1983.

Blackwood, H.J.J.: Cellular remodeling in articular tissue. J. Dent. Res., 45: 480-489, 1966.

Blackwood, H.J.J.: Adaptive changes in mandibular joints with function. In: Symposium on Temporomandibular Joint Dysfunction, Dent. Clin. North Am., pp. 559-566, 1968.

Blackwood, H.J.J.: Pathology of the temporomandibular joint. J. Am. Dent. Assoc., 79: 118-124, 1969.

Boucher, L.J.: Observations on arthrodial types of temporomandibular joints. J. Prosth. Dent., 10: 1086-1091, 1960.

Boyer, C.C., Williams, T.W., and Stevens, F.H.: Blood supply of the temporomandibular joint. J. Dent. Res., 43: 224-228, 1964.

Costen, J.B.: A syndrome of ear and sinus symptoms dependent upon disturbed function of the temporomandibular joint. Ann. Otol., Rhin. & Laryng., 43: 1-15, 1934.

Dixon, A.D.: Structure and functional significance of the intra-articular disc of the human temporomandibular joint. Oral Surg., Oral Med. and Oral Path., 15: 48-61, 1962.

DuBrul, E.L.: Sicher's Oral Anatomy, St. Louis, The C.V. Mosby Company, 1975.

Enlow, D.: Handbook of Facial Growth. W.B. Saunders, Co., Philadelphia, 1982.

Finlay, I.A.: Mandibular joint pressures. J. Dent. Res., 43: 140-148, 1964.

Gay, T., Gross, B.D., Lipke, D.P., and Yaeger, J.A.: An electromyographic study of both portions of the masseter muscle. J. Dent. Res., 56 (Special Issue B): abs. no. 714, 1977.

Griffin, C.J. and Sharpe, C.J.: The structure of the adult human temporomandibular meniscus. Aust. Dent. J., 15: 190-195, 1960.

Griffin, C.J. and Sharpe, C.J.: Distribution of elastic tissue in the temporomandibular meniscus especially in respect to "compression" areas. Aust. Dent. J., 7: 72-78, 1962.

Griffin, C.J. and Sharpe, C.J.: The genu vasculosis of the human temporomandibular meniscus. Aust. Dent. J., 2: 35-39, 1961.

Griffin, C.J., Hawthorn, R., and Harris, R.: Anatomy and histology of the human temporomandibular joint. In The Temporomandibular Joint Syndrome, Monographs in Oral Science, Vol. 4, Basel, S. Kargel, pp. 1-26, 1975.

Hankey, G.T.: Temporomandibular arthrosis. Brit. Dent. J., 97: 249-270, 1954.

Hansson, T. and Oberg, T.: Arthrosis and deviation in form in the temporomandibular joint. Acta Odont. Scand., 35: 167-174, 1977.

Hansson, T., Oberg, T., Carlsson, G., and Kopp, S.: Thickness of soft tissue layers and the articular disk in the temporomandibular joint. Acta Odont. Scand., 35: 77-83, 1977.

Hansson, T., and Nordstrom, B.: Thickness of soft tissue layers and articular disc in temporomandibular joints with deviations in form. Acta Odont. Scand., 35: 281-288, 1977.

Hylander, W.L.: Functional anatomy. In Sarnat, B.G. and Laskin, D.M. eds., The Temporomandibular Joint, ed. 3, Springfield, C C Thomas, Chapter 5, 1979.

Ingervall, B., Carlsson, G.E., and Thilander, B.: Postnatal development of the human temporomandibular joint. II. A microradiographic study. Acta Odont. Scand., 34: 133-139, 1976.

Kawamura, Y.: Neurophysiology. In Sarnat, B.G. and Laskin, D.M. eds., The Temporomandibular Joint, ed. 3, Springfield, C C Thomas, Chapter 6, 1979.

Keith, D.A.: Development of the human temporomandibular joint. Brit. J. Oral Surg., 20: 217-224, 1982.

Knox, J.: Fibrillar arrangement in the articular disc of the human temporomandibular joint. Thesis, University of Illinois, 1967.

Kopp, S., Wenneberg, B., and Clemensson, E.: Clinical microscopic and biochemical investigation of synovial fluid from temporomandibular joints. Scand. J. Dent. Res., 91: 33-41, 1983.

Lipke, D.P., Gay, T., Gross, B.D., and Yaeger, J.A.: An electromyographic study of the human lateral pterygoid muscle. J. Dent. Res., 56 (Special Issue B): abs. No. 713, 1977.

MacAlister, A.D.: Microscopic survey of the human temporomandibular joint. N.Z. Dent. J., 50: 161-172, 1954.

McNamara, J.A., Jr.: The independent function of the two heads of the lateral pterygoid muscles. Am. J. Anat., 138: 197-213, 1973.

Moffett, B.C.: The prenatal development of the human temporomandibular joint. Contrib. to Embryol., Carneg. Inst., Wash., 36: 19-28, 1957.

Moffett, B.C., Johnson, L.C., McCabe, J.B., and Askew, H.C.: Articular remodeling in the adult human temporomandibular joint. Am. J. Anat., 115: 119-142, 1964.

Moffett, B.: The morphogenesis of the temporomandibular joint. Am. J. Orthod., 52: 401-415, 1966.

Oberg, T., Carlsson, G., and Fajeis, C.: The temporomandibular joint--a morphologic study on a human autopsy material. Acta Odont. Scand., 29: 349-384, 1971.

Parsons, M.T. and Boucher, L.J.: The bilaminar zone of the meniscus. J. Dent. Res., 45: 59-61, 1966.

Prentiss, H.J.: A preliminary report upon the temporomandibular articulation in the human type. Dent. Cos., 60: 505-512, 1918.

Rees, L.A.: The structure and function of the mandibular joint. Br. Dent. J., 96: 125-133, 1954.

Scapino, R.P.: Histopathology associated with malposition of the human temporomandibular joint disc. Oral Surg., Oral Med., Oral Path., 55: 382-397, 1983.

Sicher, H.: Oral Anatomy. C.V. Mosby Co., St. Mouis, Mo., 1965.

Solberg, W., and Clark, G.: Temporomandibular Joint Problems. Chicago, 1980, Quintessence Publishing Company.

Sorensen, K.: Personal communications, 1984.

Steinhardt, G.: Zur pathologie und therapie des klefergelenk-knackens. Dtsch. Z. Chir., 241: 531-552, 1933.

Steinhardt, G.: Co-report: Anatomy and physiology of the temp-oromandibular joint: Effect on function. Internat. Dent. J., 8: 155-156, 1958.

Strauss, F., Christen, A., and Weler, W.: The architecture of the disk of the human temporomandibular joint. Helv. Odontol. Acta, 4: 1-14, 1960.

Thilander, B.: Innervation of the temporomandibular disc in man. Acta Odont. Scand., 22: 150-155, 1964.

Thilander, B.: The structure of the collagen of the temporoman-dibular disc in man. Acta Odont. Scand., 22: 135-150, 1964.

APPENDIX I

PLATE I

Serial sections of a normal postmortem meniscus. Sections showing the bioconcave morphology of the anterior band, intermediate zone and posterior band with considerable anterior and posterior attachment.

PLATE II

Serial sections of the abnormal surgical meniscus #4. Sections showing marked deformation of the anterior band, intermediate zone and posterior band.

4
CENTIMETERS
3
2
1
4
CENTIMETERS
3
2
1

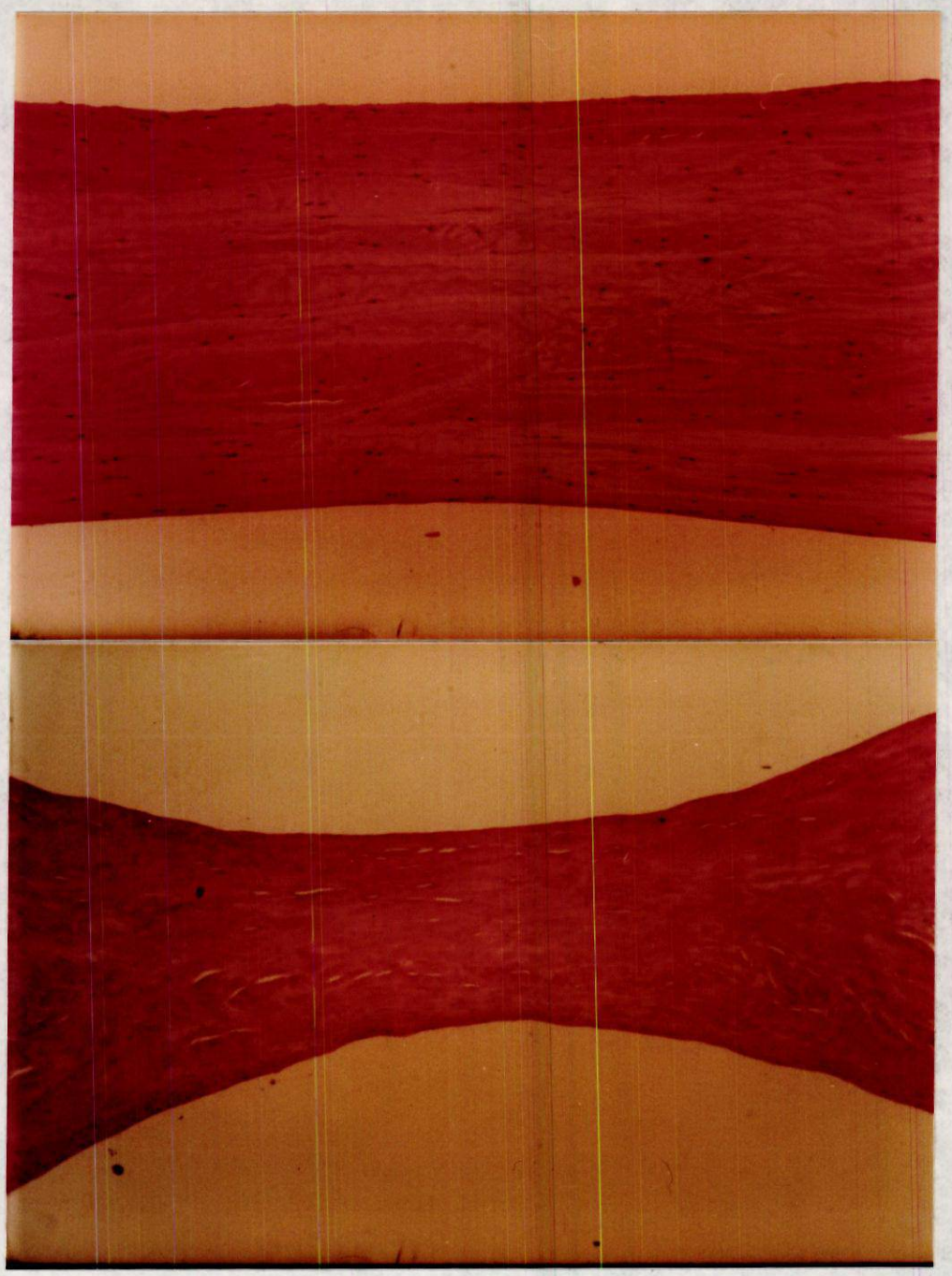
APPENDIX II

PLATE III

Photomicrograph of IZ in the normal postmortem meniscus. Section showing prediminance of horizontal collagen fibers in the intermediate zone. hematoxylin and eosin stain. original magnification 20x.

PLATE IV

Photomicrograph of IZ in the normal surgical meniscus. Section showing predominance of horizontal collagen fibers in the intermediate zone. hematoxylin and eosin stain. original magnification 8x.



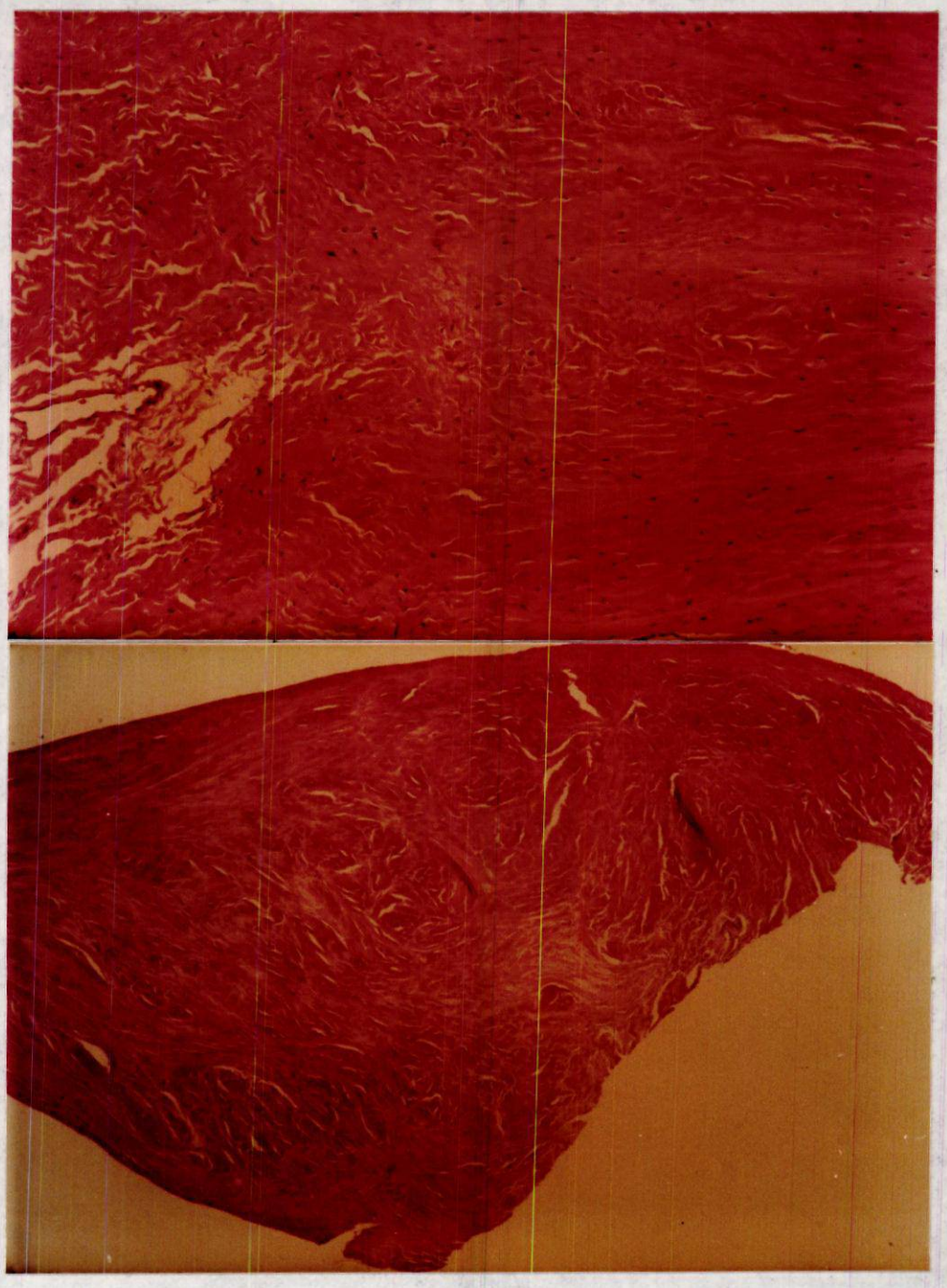
APPENDIX III

PLATE V

Photomicrograph of AB in the normal postmortem meniscus. Section showing predominance of horizontal collagen fibers with some transverse fibers in the anterior band. hematoxylin and eosin stain. original magnification 20x.

PLATE VI

Photomicrograph of AB in the normal surgical meniscus. Section showing predominance of horizontal fibers and some transverse and oblique fibers in the anterior band. hematoxylin and eosin stain. original magnification 8x.



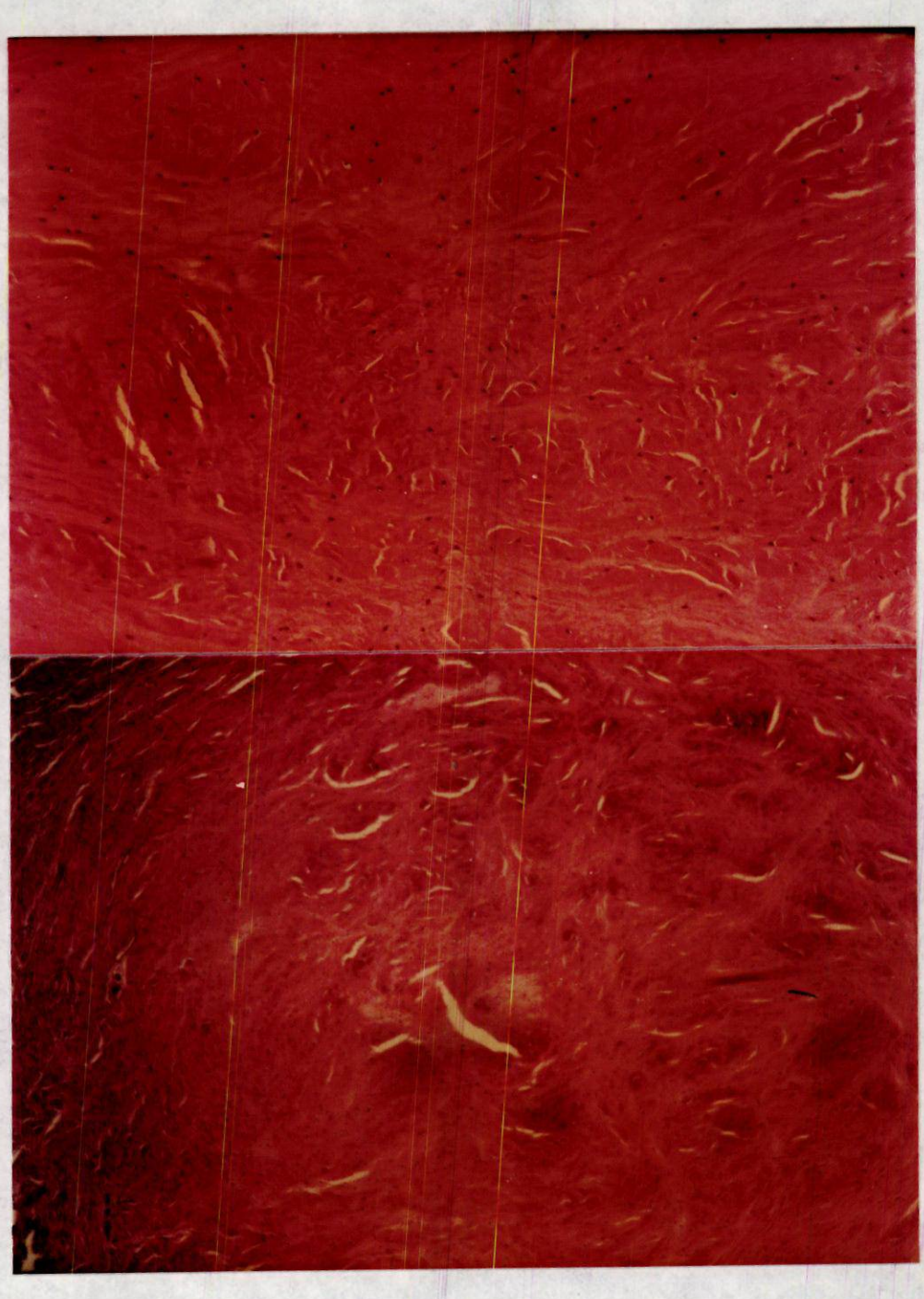
APPENDIX IV

PLATE VII

Photomicrograph of PB in the normal postmortem meniscus. Section showing predominance of horizontal collagen fibers with some transverse and oblique fibers in the posterior band. hematoxylin and eosin stain. original magnification 20x.

PLATE VIII

Photomicrograph of PB in the normal surgical meniscus. Section showing predominance of horizontal collagen fibers with some transverse and oblique fibers in the posterior band. hematoxylin and eosin stain. original magnification 8x.



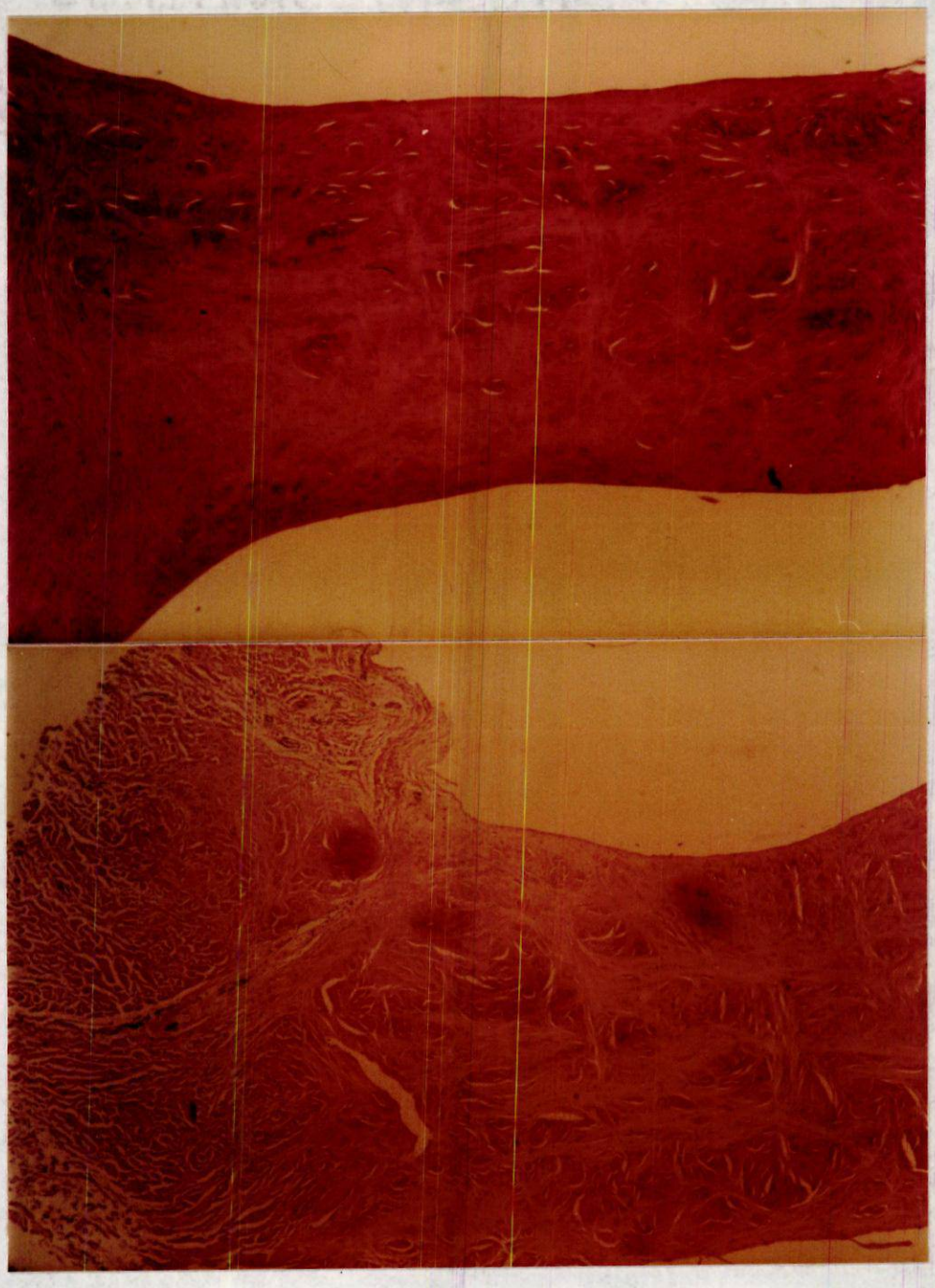
APPENDIX V

PLATE IX

Photomicrograph of mild deformation of AB and IZ in meniscus #10. Section showing mild change in zone distinction, thickening and some vertically oriented collagen fibers. hematoxylin and eosin stain. original magnification 8x.

PLATE X

Photomicrograph of mild deformation of AB and IZ in meniscus #3. Section showing mild change in zone distinction, thickening and vertically oriented collagen fibers. hematoxylin and eosin stain. original magnification 8x.



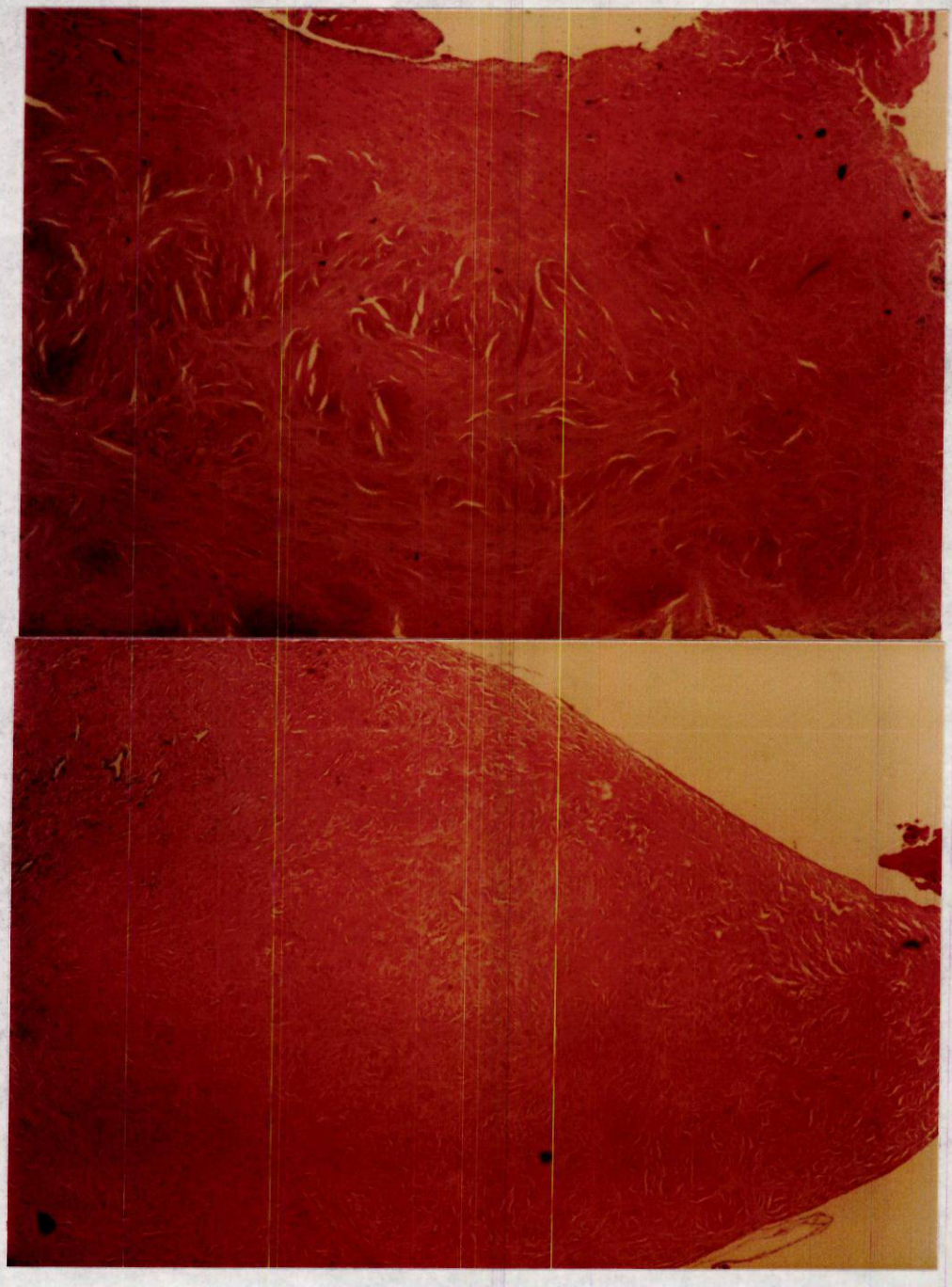
APPENDIX VI

PLATE XI

Photomicrograph of moderate deformation of AB and IZ in meniscus #8. Section showing moderate deformation in zone morphology, thickening and vertically oriented collagen fibers. hematoxylin and eosin stain. original magnification 8x.

PLATE XII

Photomicrograph of severe deformation of AB, IZ and PB in meniscus #4. Section showing severe loss of zone morphology resulting in an increase in size of PB. Note also the amorphic appearance and disorientation of fibers. hematoxylin and eosin stain. original magnification 8x.



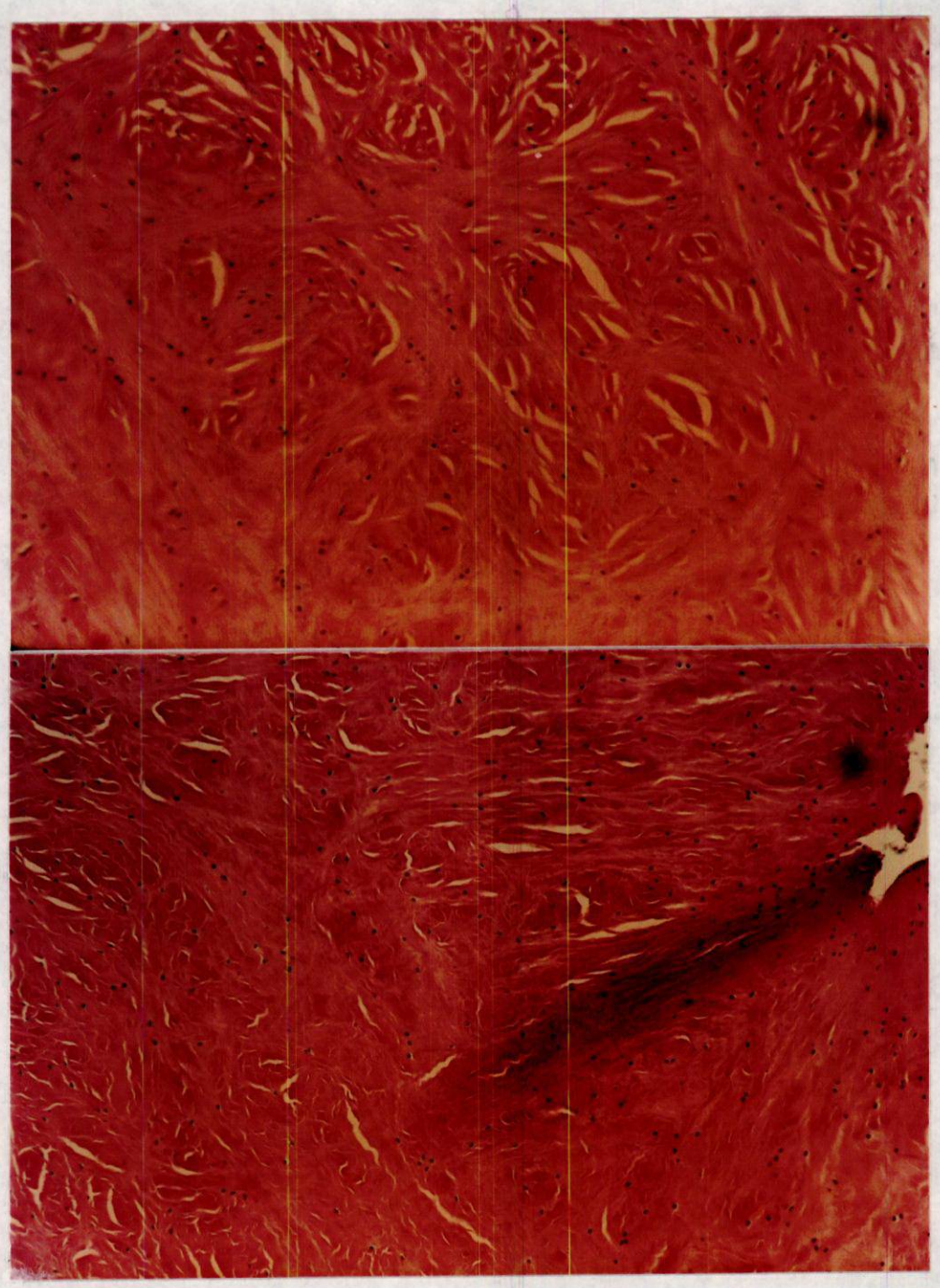
APPENDIX VII

PLATE XIII

Photomicrograph of vertical collagen fibers in the IZ of meniscus #5. Section showing the morphology and vertical orientation of collagen fibers in the intermediate zone. hematoxylin and eosin stain. original magnification 20x.

PLATE XIV

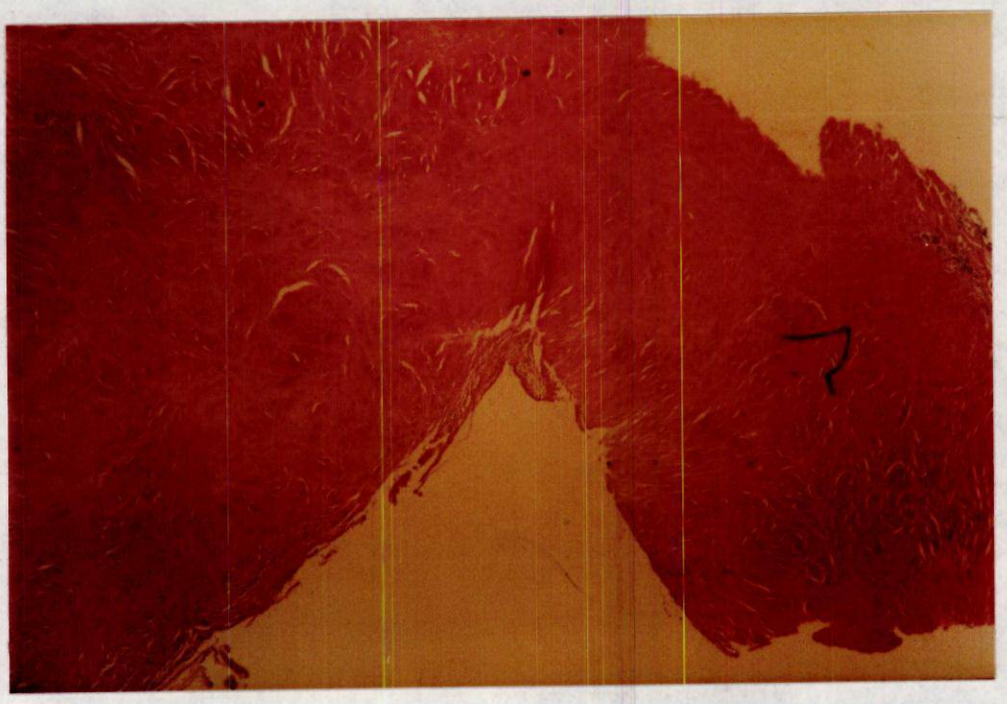
Photomicrograph of fiber orientation near a flexure in meniscus #1. Section showing marked disruption in orientation of collagen fibers near the flexure, involving the AB, IZ and PB. hematoxylin and eosin stain. original magnification 20x.



APPENDIX VIII

PLATE XV

Photomicrograph of flexure in IZ of meniscus #4. Section general morphology of zones involved in a flexure and the change in orientation of collagen fibers. hematoxylin and eosin stain. original magnification 8x.



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