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Acknowledgments

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I would like to thank Dr. Terry Tanaka of San Diego, California, for generously sharing his knowledge with me. Over the years, I have come to value Terry's professional and personal friendship more and more. His anatomic dissections have contributed greatly to the profession's understanding of the functional anatomy of our complex masticatory system.

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I would also like to thank the following individuals for allowing me to use some of their professional materials and insights in this text: Dr. Per-Lennart Westesson, University of Rochester, Rochester, NY; Dr. Jay Mackman, Milwaukee, Wisconsin, WI; Dr. Joseph Van Sickels, University of Kentucky, Lexington, KY; Dr. Larry Cunningham, University of Kentucky, Lexington, KY; Dr. Gerhard Undt, Vienna, Austria; Dr. Steve Burke, Centerville, Ohio, OH; Dr. Carol Bibb, UCLA, Los Angeles, CA; Dr. William Solberg, UCLA, Los Angeles, CA; Dr. Douglas Damm, University of Kentucky, Lexington, KY; Dr. Galal Omami, University of Kentucky. I also wish to thank Dr. David Hoffman for helping me acquire some of the patient images used in the text.

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Jeffrey P. Okeson, DMD

About the Author

Jeffrey P. Okeson, DMD

Dr. Okeson is a 1972 graduate of the University of Kentucky College of Dentistry. After graduation he completed 2 years with the Public Health Service in a rotating dental internship and directorship of an outpatient clinic. He joined the faculty at the University of Kentucky in 1974. At present he is Professor and Chief of the Division of Orofacial Pain. He is also Director of the college's Orofacial Pain Center, which he established in 1977. The Orofacial Pain Center represents a multiprofessional effort in the management of chronic orofacial pain problems. Dr. Okeson has developed several postgraduate training programs in the center, including a Master of Science Degree in Orofacial Pain. He led the program in becoming one of the first fully accredited orofacial pain graduate training programs by the Commission on Dental Accreditation in the United States. Dr. Okeson has more than 240 professional publications in the areas of occlusion, temporomandibular disorders (TMDs), and orofacial pain in various national and international journals. Dr. Okeson's textbook, *Management of Temporomandibular Disorders and Occlusion,* is used in the majority of US dental schools and has been translated into 11 languages. In addition to this text, Dr. Okeson is also the author of *Bell's Orofacial Pains*. This text is also widely used in orofacial pain programs throughout the world.

Dr. Okeson is an active member of many TMD and orofacial pain organizations. He holds many offices and serves on numerous committees and boards. He is a past president and founding fellow of the American Academy of Orofacial Pain (AAOP). He is a founding diplomate and twice president of the American Board of Orofacial Pain. He has been active in the AAOP, developing treatment and curriculum guidelines for TMDs and orofacial pain. He edited the third edition of the AAOP guidelines, titled *Orofacial Pain: Guidelines for Classification, Assessment, and Management*, which has been used as treatment standards throughout the world. Dr. Okeson has presented more than 1300 invited lectures on the subject of TMDs and orofacial pain in all 50 United States and 58 foreign countries. At national and international meetings, he is frequently referred to as "the world ambassador for orofacial pain." Dr. Okeson has received several teaching awards from his dental students, as well as the campus-wide University of Kentucky Great Teacher Award. He has received the Provost's Distinguished Service Professorship, the American Academy of Orofacial Pain's Service Award and the first ever "Distinguished Alumni Award" from the College of Dentistry. He is the first and only dentist to be inducted into the University of Kentucky Hall of Distinguished Alumni. Dr. Okeson has also received "The International Dentist of the Year Award" from the Academy of Dentistry International. This is the highest award recognized by this academy and was given to him in recognition of his worldwide efforts in providing education in the area of TMDs and orofacial pain.

Preface

The study of occlusion and its relationship to function of the masticatory system has been a topic of interest in dentistry for many years. This relationship has proved to be quite complex. Tremendous interest in this area accompanied by lack of complete knowledge has stimulated numerous concepts, theories, and treatment methods. This, of course, has led to much confusion in an already complicated field of study. Although the level of knowledge today is greater than ever before, there is still much to learn. Some of today's techniques will prove to be our most effective treatments in the future. Other methods will be demonstrated as ineffective and will have to be discarded. Competent and caring practitioners must establish their treatment methods based on both their present knowledge and their constant evaluation of information received from the massive amount of ongoing research. This is an enormous task. It is my hope that this text will assist students, teachers, and practitioners in making these important treatment decisions for their patients.

I began my teaching career at the University of Kentucky in 1974 in the area of occlusion. At that time, I believed there was a need for a teaching manual that presented the topics of occlusion and temporomandibular disorders (TMDs) in an organized, logical, and scientific manner. In 1975, I developed such a manual to assist in teaching my dental students. Soon, several other dental schools requested use of this manual for their teaching programs. In 1983, the CV Mosby Publishing Company approached me with the concept of developing this manual into a complete textbook. After 2 years of writing and editing, the first edition was published in 1985. I am very pleased and humbled to learn that this text is currently being used in most of the dental schools in the United States and has been translated into 11 foreign languages for use abroad. This is professionally very satisfying, and it is my hope that the true benefit of this text is found in the improved quality of care we offer our patients.

It is a privilege to have the opportunity to update this text for the eighth time. I have tried to include the most significant scientific findings that have been revealed in the past 4 years. I believe the strength of a textbook lies not in the author's words, but in the scientific references that are offered to support the ideas presented. Unreferenced ideas should be considered only as opinions that require further scientific investigation to either verify or negate them. It is extremely difficult to keep a textbook updated, especially in a field in which so much is happening so quickly. Thirty-three years ago, in the first edition of this text, I referenced approximately 450 articles to support the statements and ideas. The concepts in this edition are supported by nearly 2400 scientific references. This reflects the significant scientific growth of this field. It should be acknowledged that as future truths are uncovered, the professional has the obligation to appropriately respond with changes that best reflect the new information. These changes are sometimes difficult for the clinician because they may reflect the need to change clinical protocol. However, the best care for our patients rests in the most scientifically supported information.

The purpose of this text is to present a logical and practical approach to the study of occlusion and masticatory function. The text is divided into four main sections: The first part consists of six chapters that present the normal anatomic and physiologic features of the masticatory system. Understanding normal occlusal relationships and masticatory function is essential to understanding dysfunction. The second part consists of four chapters that present the etiology and identification of common functional disturbances of the masticatory system. Significant supportive documentation has been included in this edition. The third part consists of six chapters that present rational treatments for these disorders according to the significant etiologic factors. Recent studies have been added to support existing treatments, as well as for new considerations. The last part consists of four chapters that present specific considerations for permanent occlusal therapy.

The intent of this text is to develop an understanding of and rational approach to the study of masticatory function and occlusion. To assist the reader, certain techniques have been presented. It should be recognized that the purpose of a technique is to achieve certain treatment goals. Accomplishing these goals is the significant factor, not the technique itself. Any technique that achieves the treatment goals is acceptable as long as it does so in a reasonably conservative, cost-effective manner, with the best interests of the patient kept in mind.

Contents

Part I: Functional Anatomy

1 **Functional Anatomy and Biomechanics of the Masticatory System, 2**

2 **Functional Neuroanatomy and Physiology of the Masticatory System, 21**

3 **Alignment and Occlusion of the Dentition, 47**

4 **Mechanics of Mandibular Movement, 63**

5 **Criteria for Optimum Functional Occlusion, 74**

6 **Determinants of Occlusal Morphology, 87**

Part II: Etiology and Identification of Functional Disturbances in the Masticatory System

7 **Etiology of Functional Disturbances in the Masticatory System, 102**

8 **Signs and Symptoms of Temporomandibular Disorders, 132**

9 **History and Examination for Temporomandibular Disorders, 174**

10 **Diagnosis of Temporomandibular Disorders, 223**

Part III: Treatment of Functional Disturbances of the Masticatory System

11 **General Considerations in the Treatment of Temporomandibular Disorders, 260**

12 **Treatment of Masticatory Muscle Disorders, 296**

13 **Treatment of Temporomandibular Joint Disorders, 324**

14 **Treatment of Chronic Mandibular Hypomobility and Growth Disorders, 372**

15 **Occlusal Appliance Therapy, 385**

16 **Treatment Sequencing, 410**

Part IV: Occlusal Therapy

17 **General Considerations in Occlusal Therapy, 433**

18 **Use of Articulators in Occlusal Therapy, 441**

19 **Selective Grinding, 455**

20 **Restorative Considerations in Occlusal Therapy, 468**

PART I

Functional Anatomy

The masticatory system is extremely complex. It is made up primarily of bones, muscles, ligaments, and teeth. Movement is regulated by an intricate neurologic control system made up of the brain, brainstem, and the peripheral nervous system. Each movement is coordinated to maximize function while minimizing damage to any structure. Precise movement of the mandible by the musculature is required to move the teeth efficiently across each other during function. The mechanics and physiology of this movement are basic to the study of masticatory function. Part I consists of six chapters that discuss the normal anatomy, function, and mechanics of the masticatory system. Function must be understood before dysfunction can have meaning.

1

Functional Anatomy and Biomechanics of the Masticatory System

"Nothing is more fundamental to treating patients than knowing the anatomy."

JPO

The masticatory system is the functional unit of the body primarily responsible for chewing, speaking, and swallowing. Components also play a major role in tasting and breathing. The system is made up of bones, joints, ligaments, teeth, and muscles. In addition, an intricate neurologic controlling system regulates and coordinates all these structural components.

The masticatory system is a complex and highly refined unit. A sound understanding of its functional anatomy and biomechanics is essential to the study of occlusion. This chapter describes the anatomic features that are basic to an understanding of masticatory function. A more detailed description can be found in the numerous texts devoted entirely to the anatomy of the head and neck.

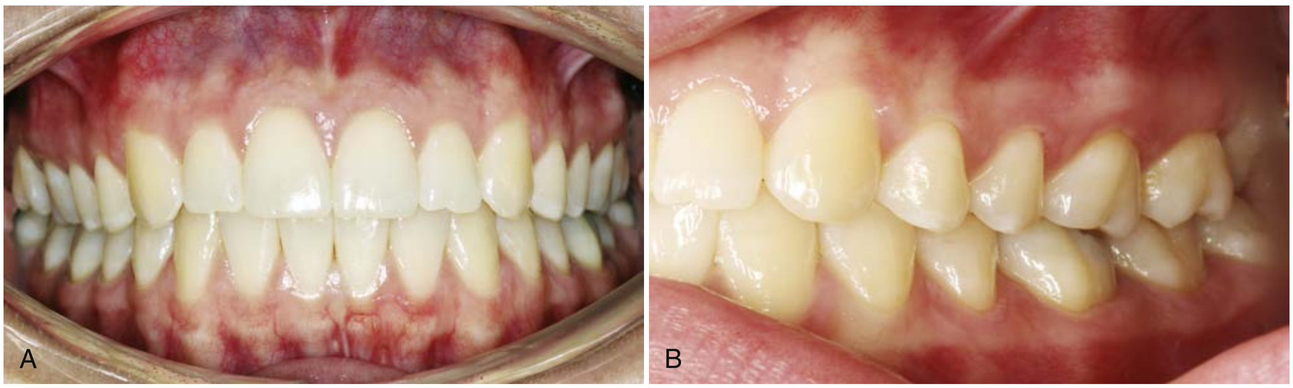
Functional Anatomy

The following anatomic components are discussed in this chapter: the dentition and their supportive structures, the skeletal components, the temporomandibular joints, the ligaments, and the muscles. After the anatomic features are described, the biomechanics of the temporomandibular joint are presented. In Chapter 2, the complex neurologic controlling system responsible for carrying out the intricate functions of the masticatory system will be presented.

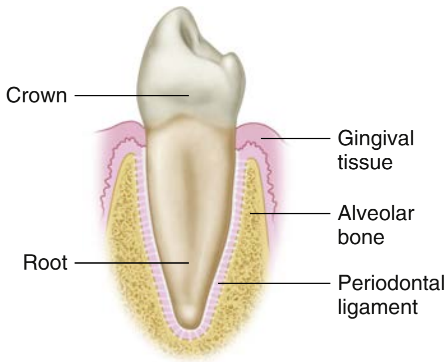
Dentition and Supportive Structures

The human dentition is made up of 32 permanent teeth (Fig. 1.1A and B). Each tooth can be divided into two basic parts: the crown, which is visible above the gingival tissue, and the root, which is submerged in and surrounded by the alveolar bone. The root is attached to the alveolar bone by numerous fibers of connective tissue that span from the cementum surface of the root to the bone. Most of these fibers run obliquely from the cementum in a cervical direction to the bone (Fig. 1.2). These fibers are known collectively as the *periodontal ligament*. The periodontal ligament not only attaches the tooth firmly to its bony socket but also helps dissipate the forces applied to the bone during functional contact of the teeth. In this sense, it can be thought of as a natural shock absorber. The periodontal ligament has specialized receptors that provide information on pressure and position. This sensory information is essential for function as will be described in the next chapter.

The 32 permanent teeth are distributed equally in the alveolar bone of the maxillary and mandibular arches: 16 maxillary teeth are aligned in the alveolar process of the maxilla, which is fixed to the lower anterior portion of the skull; the remaining 16 teeth are aligned in the alveolar process of the mandible, which is the movable jaw. The maxillary arch is slightly larger than the mandibular arch, which usually causes the maxillary teeth to overlap the mandibular teeth both vertically and horizontally when in occlusion (Fig. 1.3). This size discrepancy results primarily from the fact that (1) the maxillary anterior teeth are much wider than the mandibular teeth, which creates a greater arch width, and (2) the maxillary



• **Fig. 1.1. A.** Anterior and, **B,** lateral view of the dentition.



• **Fig. 1.2.** The tooth and its periodontal supportive structure. Note that the width of the periodontal ligament is greatly exaggerated for illustrative purposes.

• **Fig. 1.3.** Note that the maxillary teeth are positioned slightly facial to the mandibular throughout the arch.

anterior teeth have a greater facial angulation than the mandibular anterior teeth, which creates a horizontal and vertical overlapping.

The permanent teeth can be grouped into four classifications as follows according to the morphology of the crowns.

The teeth located in the most anterior region of the arches are called *incisors*. They have a characteristic shovel shape, with an incisal edge. There are four maxillary incisors and four mandibular incisors. The maxillary incisors are generally much larger than the mandibular incisors and, as previously mentioned, commonly overlap them. The function of the incisors is to incise or cut off food during mastication.

Posterior (distal) to the incisors are the *canines*. The canines are located at the corners of the arches and are generally the longest of the permanent teeth, with a single cusp and root (Fig. 1.4). These teeth are very prominent in other animals such as dogs, and hence the name "canine." There are two maxillary and two mandibular canines. In animals, the primary function of the canines is to rip and tear food. In the human dentition, however, the canines usually function as incisors and are used only occasionally for ripping and tearing.

Still more posterior in the arch are the *premolars* (Fig. 1.4). There are four maxillary and four mandibular premolars. The premolars are also called bicuspids since they generally have two cusps. The presence of two cusps greatly increases the biting

• **Fig. 1.4.** Lateral view of the posterior teeth.

surfaces of these teeth. The maxillary and mandibular premolars occlude in such a manner that food can be caught and crushed between them. The main function of the premolars is to begin the effective breakdown of food substances into smaller particle sizes.

The last class of teeth, found posterior to the premolars, is the *molars* (Fig. 1.4). There are six maxillary molars and six mandibular molars. The crown of each molar has either four or five cusps. This provides a large, broad surface upon which breaking and grinding of food can occur. Molars function primarily in the later stages of chewing, when food is broken down into small enough particles that can be easily swallowed.

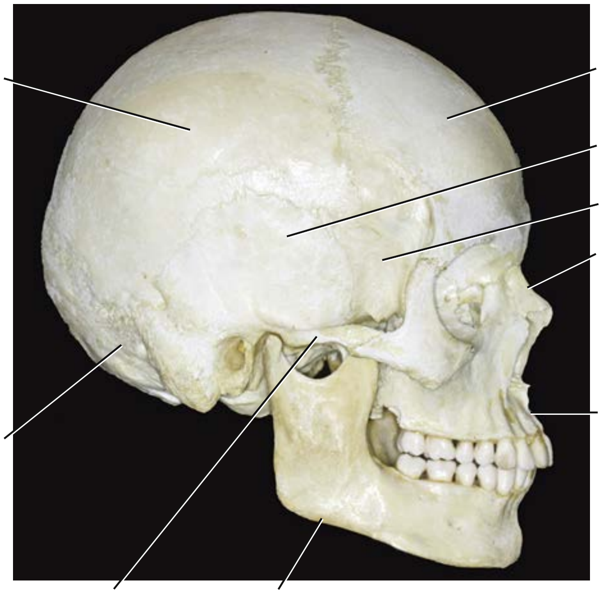
As discussed, each tooth is highly specialized according to its function. The exact interarch and intraarch relationships of the teeth are extremely important and greatly influence the health and function of the masticatory system. A detailed discussion of these relationships will be presented in Chapter 3.

Skeletal Components

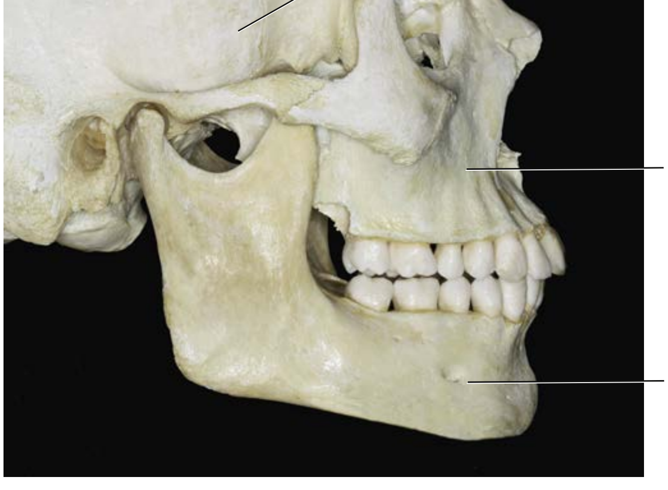
The skeletal components of the human head are the skull and mandible (Fig. 1.5). The skull is composed of several bones connected together by fissures. The major components are the temporal bone, the frontal bone, the parietal bone, the sphenoid bone, the occipital bone, the zygomatic bone, the nasal bone, and the maxilla. The mandible is a separate bone suspended below the cranium in a muscle sling. The three major skeletal components that make up the masticatory system are the maxilla and mandible, which support the teeth (Fig. 1.6), and the temporal bone, which supports the mandible at its articulation with the cranium.

The Maxilla

Developmentally, there are two maxillary bones, which are fused together at the midpalatal suture (Fig. 1.7). These bones make up the greater part of the upper facial skeleton. The border of the maxilla extends superiorly to form the floor of the nasal cavity as well as the floor of each orbit. Inferiorly, the maxillary bones form the palate and the alveolar ridges, which support the teeth. Since the maxillary bones are intricately fused to the surrounding bony components of the skull, the maxillary teeth are considered to be a fixed part of the skull and therefore make up the stationary component of the masticatory system.



• **Fig. 1.5.** The lateral view of the cranium and the mandible. The separate bones that make up the skull are labeled.



• **Fig. 1.6.** Skeletal components that make up the masticatory system: maxilla, mandible, and temporal bone.

The Mandible

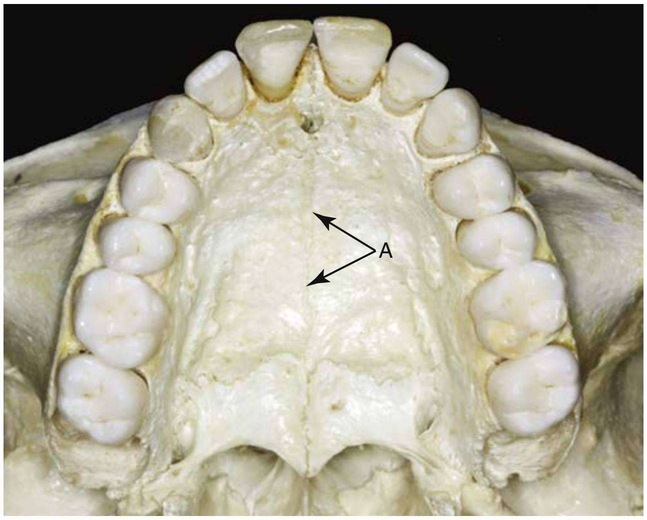
The mandible is a U-shaped bone that supports the lower teeth and makes up the lower facial skeleton. It has no bony attachments to the skull. It is suspended below the maxilla by muscles, ligaments, and other soft tissues, which therefore provide the mobility necessary to function with the maxilla.

The superior aspect of the arch-shaped mandible consists of the alveolar process and the teeth (Fig. 1.8). The body of the mandible extends posteroinferiorly to form the mandibular angle and posterosuperiorly to form the ascending ramus. The ascending ramus of the mandible is formed by a vertical plate of bone that extends upward as two processes. The anterior of these is the coronoid process. The posterior is the condyle.

The condyle is the portion of the mandible that articulates with the cranium, around which movement occurs. From the anterior view, it has a medial and a lateral projection called poles (Fig. 1.9). The medial pole is generally more prominent than the lateral. From above, a line drawn through the centers of the poles of the condyle will usually extend medially and posteriorly toward the anterior border of the foramen magnum (Fig. 1.10). The total mediolateral length of the condyle is between 18 and 23 mm, and the anteroposterior width is between 8 and 10 mm. The actual articulating surface of the condyle extends both anteriorly and posteriorly to the most superior aspect of the condyle (Fig. 1.11). The posterior articulating surface is greater than the anterior surface. The articulating surface of the condyle is quite convex anteroposteriorly and only slightly convex mediolaterally.

The Temporal Bone

The mandibular condyle articulates at the base of the cranium with the squamous portion of the temporal bone. This portion of the temporal bone is made up of a concave mandibular fossa, in which the condyle is situated (Fig. 1.12), and which has also been called the articular or glenoid fossa. Posterior to the mandibular fossa is the squamotympanic fissure, which extends mediolaterally. As this fissure extends medially, it divides into the petrosquamous fissure anteriorly and the petrotympanic fissure posteriorly. Immediately anterior to the fossa is a convex bony prominence called the articular eminence. The degree of convexity of the articular eminence is highly variable but important since the steepness of this surface dictates the pathway of the condyle when the mandible is positioned anteriorly. The posterior roof of the mandibular fossa is quite thin, indicating that this area of the temporal bone is not designed to sustain heavy forces. The articular eminence, however, consists of thick dense bone and is more likely to tolerate such forces.



• **Fig. 1.7.** The midpalatal suture *(A)* results from the fusion of the two maxillary bones during development.

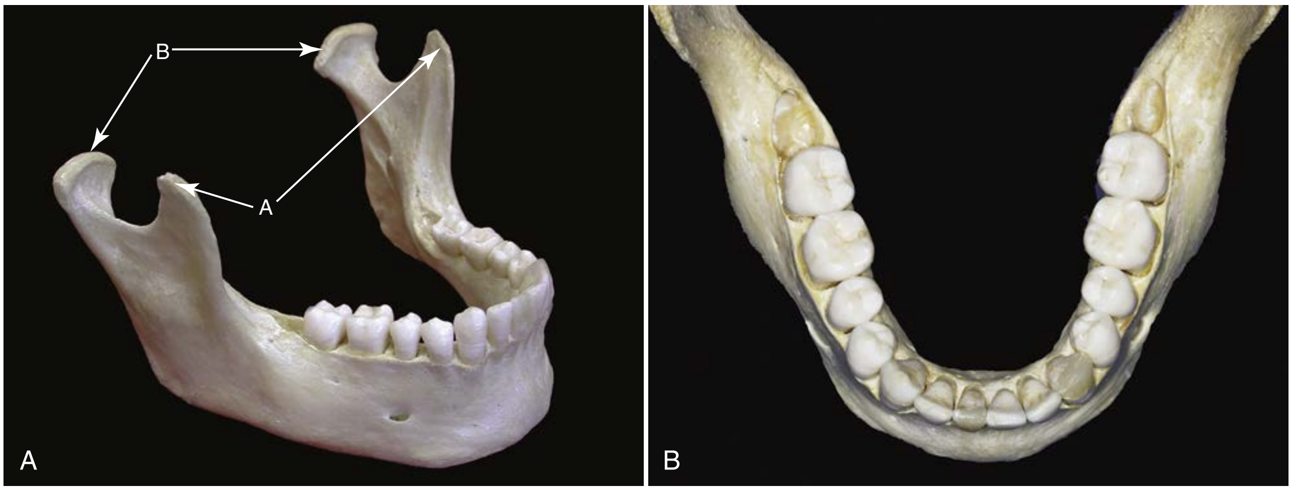
Temporomandibular Joint

The area where the mandible articulates with the temporal bone of the cranium is called the temporomandibular joint (TMJ). The TMJ is certainly one of the most complex joints in the body. It provides for hinging movement in one plane and therefore can be considered a *ginglymoid joint*. However, at the same time it also provides for gliding movements, which classifies it as an *arthrodial joint*. Thus, it has been technically considered a *ginglymoarthrodial joint*.

The TMJ is formed by the mandibular condyle fitting into the mandibular fossa of the temporal bone. Separating these two bones from direct articulation is the articular disc. The TMJ is classified as a compound joint. By definition, a compound joint requires the presence of at least three bones, yet the TMJ is made up of only two bones. Functionally, the articular disc serves as a nonossified bone that permits the complex movements of the joint. Since the articular disc functions as a third bone, the craniomandibular articulation is considered a compound joint. The function of the articular disc as a nonossified bone will be described in detail later in this chapter under the section on the biomechanics of the TMJ.

The articular disc is composed of dense fibrous connective tissue, for the most part devoid of any blood vessels or nerve fibers. The extreme periphery of the disc, however, is slightly innervated.[1,2] In the sagittal plane, it can be divided into three regions according to thickness (Fig. 1.13). The central area is the thinnest and is called the intermediate zone. The disc becomes considerably thicker both anterior and posterior to the intermediate zone. The posterior border is generally slightly thicker than the anterior border. In the normal joint, the articular surface of the condyle is located on the intermediate zone of the disc, bordered by the thicker anterior and posterior regions.

From an anterior view, the disc is generally thicker medially than laterally, which corresponds to the increased space between the condyle and the articular fossa toward the medial of the joint. The precise shape of the disc is determined by the morphology of the condyle and mandibular fossa (Fig. 1.14). During movement, the disc is somewhat flexible and can adapt to the



• **Fig. 1.8. A.** The ascending ramus extends upward to form the coronoid process *(A)* and the condyle *(B)*. **B.** Occlusal view.

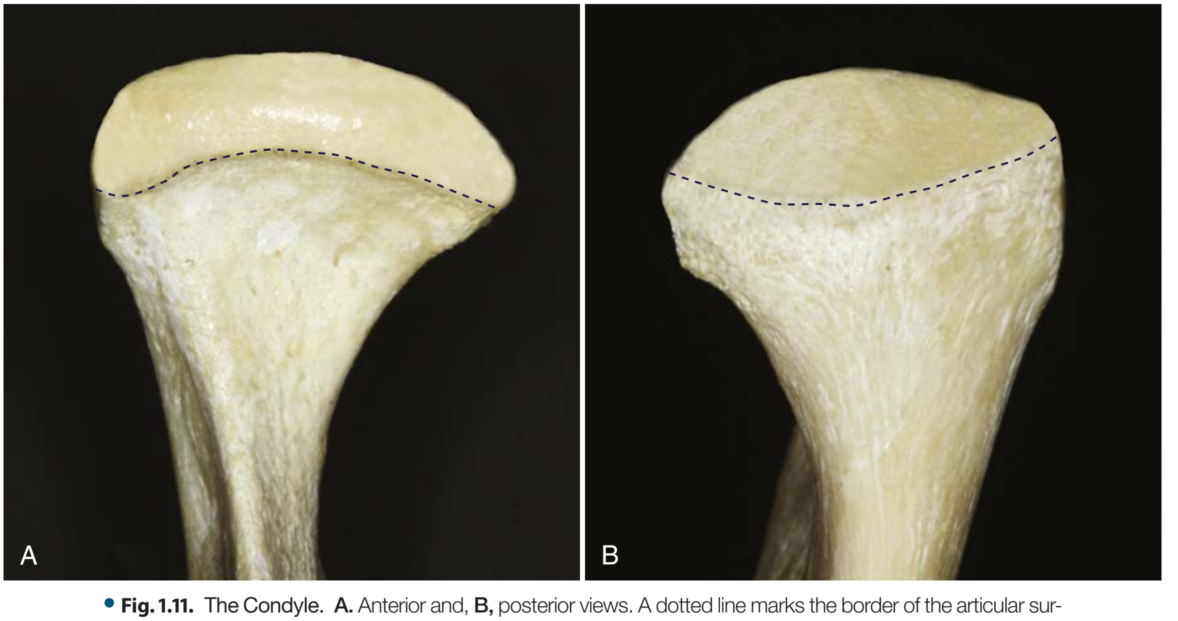
• **Fig. 1.9.** The Condyle (Anterior View). Note that the medial pole *(MP)* is more prominent than the lateral pole *(LP)*.

• **Fig. 1.10.** An Inferior View of Surface of the Cranium and Mandible. Note that the condyles seem to be slightly rotated so that if an imaginary line were drawn through the lateral and medial poles it would extend medially and posteriorly toward the anterior border of the foramen magnum.

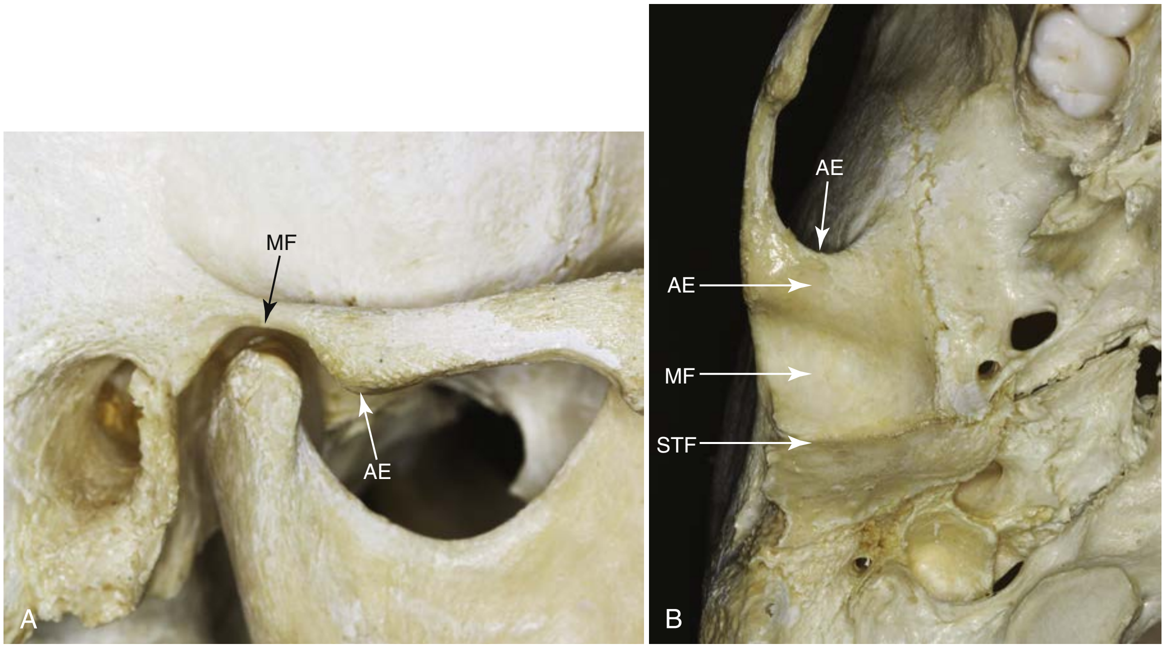
functional demands of the articular surfaces. Flexibility and adaptability do not imply that the morphology of the disc is reversibly altered during function, however. The disc maintains its morphology unless destructive forces or structural changes occur in the joint. If these changes occur, the morphology of the disc can be irreversibly altered, producing biomechanical changes during function. These changes will be discussed in later chapters.

The articular disc is attached posteriorly to a region of loose connective tissue that is highly vascularized and innervated (Fig. 1.15). This tissue is known as the *retrodiscal tissue* or posterior attachment**.** Superiorly, it is bordered by a lamina of connective tissue that contains many elastic fibers, the superior retrodiscal lamina. The superior retrodiscal lamina attaches the articular disc posteriorly to the tympanic plate. At the lower border of the retrodiscal tissues is the inferior retrodiscal lamina, which attaches the inferior border of the posterior edge of the disc to the posterior margin of the articular surface of the condyle. The inferior retrodiscal lamina is composed chiefly of collagenous fibers, not elastic fibers like the superior retrodiscal lamina. The remaining body of the retrodiscal tissue is attached posteriorly to a large venous plexus, which fills with blood as the condyle moves forward.[3,4] The superior and inferior attachments of the anterior region of the disc are to the capsular ligament, which surrounds most of the joint. The superior attachment is to the anterior margin of the articular surface of the temporal bone. The inferior attachment is to the anterior margin of the articular surface of the condyle. Both these anterior attachments are composed of collagenous fibers. Anteriorly, between the attachments of the capsular ligament the disc is also attached by tendinous fibers to the superior lateral pterygoid muscle.

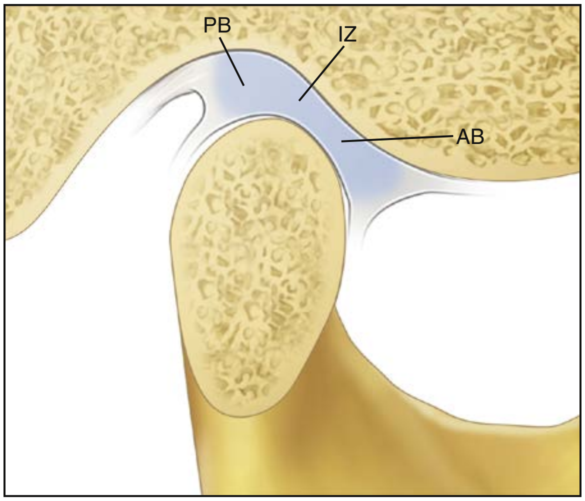
The articular disc is attached to the capsular ligament not only anteriorly and posteriorly but also medially and laterally. This divides the joint into two distinct cavities. The upper or superior cavity is bordered by the mandibular fossa and the superior surface of the disc. The lower or inferior cavity is bordered by the mandibular condyle and the inferior surface of the disc. The internal surfaces of the cavities are surrounded by specialized endothelial cells that form a synovial lining. This lining, along with a specialized synovial fringe located at the anterior border of the retrodiscal tissues, produces synovial fluid, which fills both joint cavities. Thus, the TMJ is referred to as a synovial joint. This synovial fluid serves two purposes. Since the articular surfaces of the joint are



• **Fig. 1.11.** The Condyle. **A.** Anterior and, **B,** posterior views. A dotted line marks the border of the articular surface. Note that the articular surface on the posterior aspect of the condyle is greater than on the anterior aspect.



• **Fig. 1.12.** **A.** Bony structures of the temporomandibular joint (lateral view). **B.** Articular fossa (inferior view). *AE,* Articular eminence; *MF,* mandibular fossa; *STF,* squamotympanic fissure.



• **Fig. 1.13.** Articular Disc, Fossa, and Condyle (Lateral View). The condyle is normally situated on the thinner intermediate zone *(IZ)* of the disc. The anterior border of the disc *(AB)* is considerably thicker than the intermediate zone, and the posterior border *(PB)* is even thicker.

nonvascular, the synovial fluid acts as a medium for providing metabolic requirements to these tissues. Free and rapid exchange exists between the vessels of the capsule, the synovial fluid, and the articular tissues. The synovial fluid also serves as a lubricant between articular surfaces during function. The articular surfaces of the disc, condyle, and fossa are very smooth so friction during movement is minimized. The synovial fluid helps to minimize this friction further.

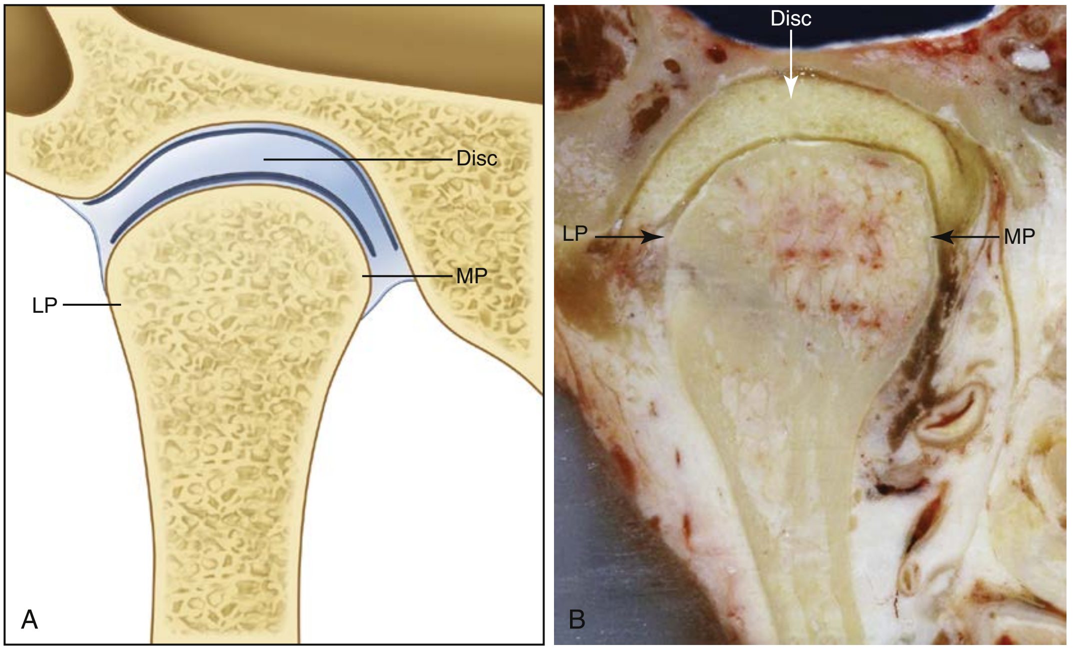
Synovial fluid lubricates the articular surfaces by way of two mechanisms. The first is called *boundary* lubrication, which occurs when the joint is moved and the synovial fluid is forced from one area of the cavity into another. The synovial fluid located in the border or recess areas is forced on the articular surface, thus providing lubrication. Boundary lubrication prevents friction in the moving joint and is the primary mechanism of joint lubrication.

A second lubricating mechanism is called *weeping* lubrication. This refers to the ability of the articular surfaces to absorb a small amount of synovial fluid.[5] During function of a joint, forces are created between the articular surfaces. These forces drive a small amount of synovial fluid in and out of the articular tissues. This is the mechanism by which metabolic exchange occurs. Under compressive forces, therefore, a small amount of synovial fluid is released. This synovial fluid acts as a lubricant between articular tissues to prevent sticking. Weeping lubrication helps eliminate friction in the compressed but not moving joint. Only a small amount of synovial fluid is expressed as a result of weeping lubrication; therefore prolonged compressive forces to the articular surfaces will exhaust this supply. The consequence of prolonged static loading of the joint structures will be discussed in later chapters.

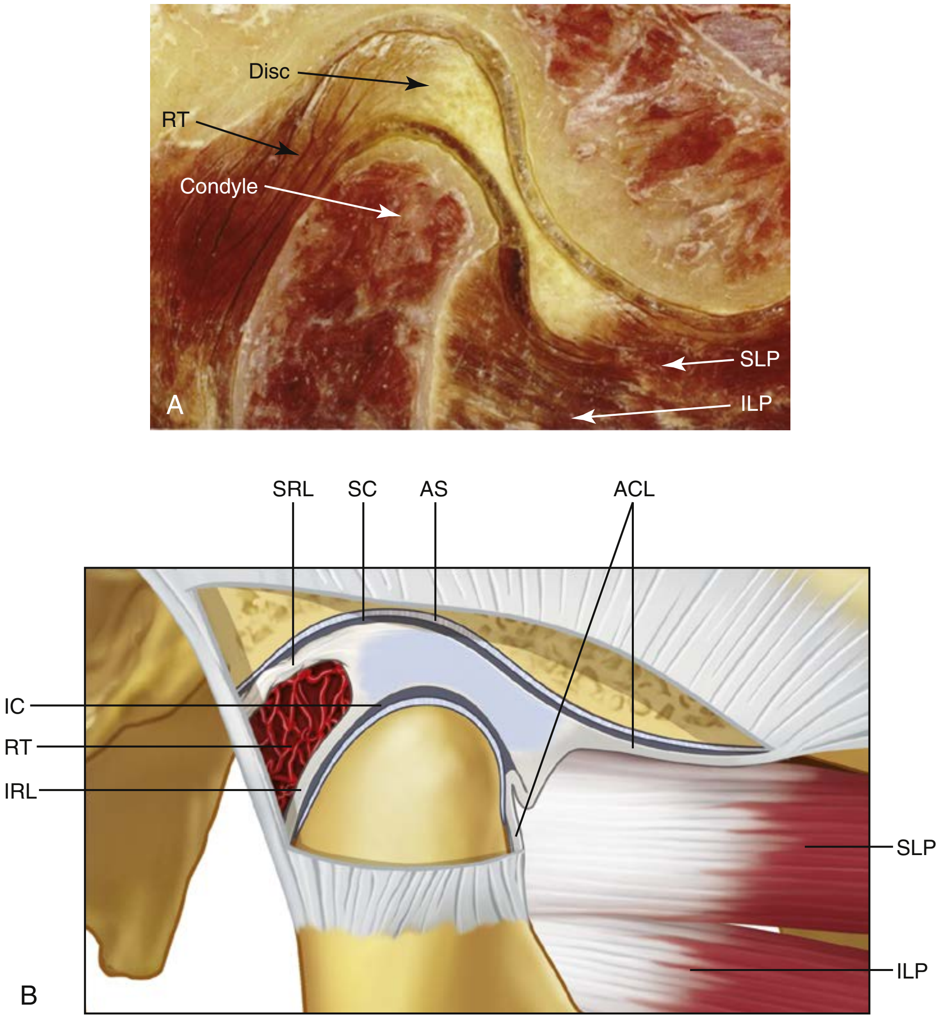
Histology of the Articular Surfaces

The articular cartilage of the TMJ is set up very differently from typical articular cartilage. The reason for this is that the mandible and TMJ form from intermembranous ossification rather than from endochondral ossification. Because of that, the articular fibrocartilage of the TMJ keeps its chondroprogenitor cells buried deep within it, unlike typical articular cartilage, which loses its chondroprogenitor cells. The zones of the articular fibrocartilage are set up differently, which allow for continued TMJ growth, repair, and remodeling.

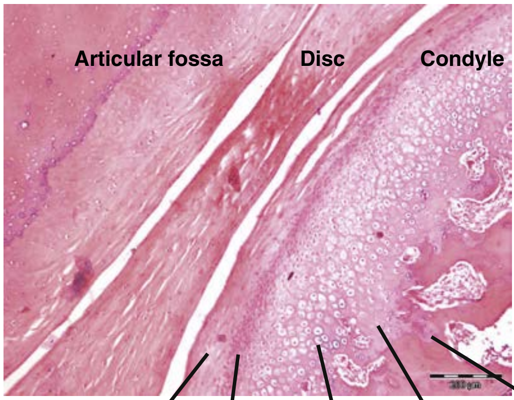
The articular cartilage of the mandibular condyle and fossa are composed of four distinct layers or zones (Fig. 1.16). The most superficial layer is called the articular zone. It is found adjacent to the joint cavity and forms the outermost functional surface. Unlike most other synovial joints, this articular layer is made of dense fibrous connective tissue rather than hyaline cartilage. Most of the collagen fibers are arranged in bundles and oriented nearly parallel to the articular surface.[6,7] The fibers are tightly packed and are able to withstand the forces of movement. It is thought



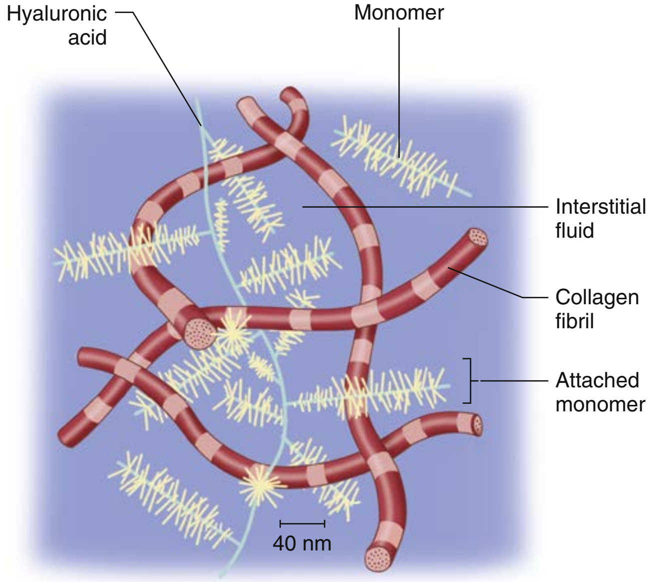
• **Fig. 1.14.** Articular Disc, Fossa, and Condyle (Anterior View). Note that the disc adapts to the morphology of the fossa and the condyle. *LP,* Lateral pole; *MP,* medial pole. (Courtesy Dr. Per-Lennart Westeson, Rochester, NY.)



• **Fig. 1.15.** Temporomandibular Joint. **A.** Lateral view and, **B,** diagram showing the anatomic components. *ACL,* Anterior capsular ligament (collagenous); *AS,* articular surface; *IRL,* inferior retrodiscal lamina (collagenous); *RT,* retrodiscal tissues; *SC* and *IC,* superior and inferior joint cavity; *SLP* and *ILP,* superior and inferior lateral pterygoid muscles; *SRL,* superior retrodiscal lamina (elastic); the discal (collateral) ligament has not been drawn. (**A.** Courtesy Dr. Per-Lennart Westeson, Rochester, NY.)



• **Fig. 1.16.** A histological section of a healthy mandibular condyle showing the four zones: articular zone, proliferative zone, fibrocartilaginous zone, and the calcified zone. ("(c)"Mathias Nordvi, The Faculty of Dentistry/University of Oslo.)



• **Fig. 1.17.** The collagen network interacting with the proteoglycan network in the extracellular matrix forming a fiber reinforced composite. (From Mow VC, Ratcliffe A: Cartilage and diarthrodial joints as paradigms for hierarchical materials and structures. *Biomaterials* 13[2]:67–81, 1992.)

that this fibrous connective tissue affords the joint several advantages over hyaline cartilage. It is generally less susceptible than hyaline cartilage to the effects of aging and, therefore, is less likely to break down over time. It also has a much better ability to repair than does hyaline cartilage.[8] The importance of these two factors is significant in TMJ function and dysfunction and will be discussed more completely in later chapters.

The second zone is called the proliferative zone and is mainly cellular. It is in this area that undifferentiated mesenchymal tissue is found. This tissue is responsible for the proliferation of articular cartilage in response the functional demands placed on the articular surfaces during loading.

The third zone is the fibrocartilaginous zone. Here the collagen fibrils are arranged in bundles in a crossing pattern, although some of the collagen is seen in a radial orientation. The fibrocartilage appears to be in a random orientation providing a three-dimensional network that offers resistance against compressive and lateral forces.

The fourth and deepest zone is the calcified cartilage zone. This zone is made up of chondrocytes and chondroblasts distributed throughout the articular cartilage. In this zone the chondrocytes become hypertrophic, die, and have their cytoplasm evacuated, forming bone cells from within the medullary cavity. The surface of the extracellular matrix scaffolding provides an active site for remodeling activity as endosteal bone growth proceeds as it does elsewhere in the body.

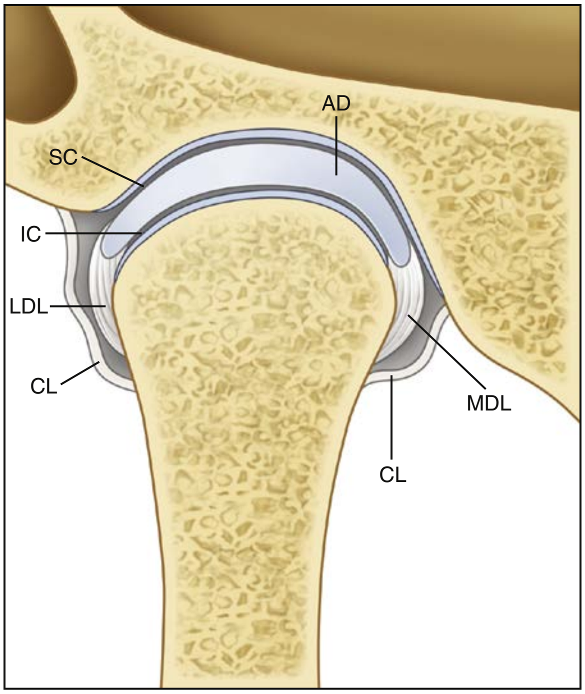
The articular cartilage is composed of chondrocytes and intercellular matrix.[9] The chondrocytes produce the collagen, proteoglycans, glycoproteins, and enzymes that form the matrix. Proteoglycans are complex molecules composed of a protein core and glycosaminoglycan chains. The proteoglycans are connected to a hyaluronic acid chain forming proteoglycan aggregates that make up a great protein of the matrix (Fig. 1.17). These aggregates are very hydrophilic and are intertwined throughout the collagen network. Since these aggregates tend to bind water, the matrix expands and the tension in the collagen fibrils counteracts the swelling pressure of the proteoglycan aggregates.[10] In this way, the interstitial fluid contributes to support joint loading. The external pressure resulting from joint loading is in equilibrium with the internal pressure of the articular cartilage. As joint loading increases, tissue fluid flows outward until a new equilibrium is achieved. As loading is decreased, fluid is reabsorbed and the tissue regains its original volume. Joint cartilage is nourished predominantly by diffusion of synovial fluid, which depends on this pumping action during normal activity.[11] This pumping action is the basis for the weeping lubrication that has previously been discussed and is thought to be very important in maintaining healthy articular cartilage.[12]

Innervation of the Temporomandibular Joint

As with all joints, the TMJ is innervated by the same nerve that provides motor and sensory innervation to the muscles that control it (the trigeminal nerve). Branches of the mandibular nerve (V_3) provide the afferent innervation. Most innervation is provided by the auriculotemporal nerve as it leaves the mandibular nerve behind the joint and ascends laterally and superior to wrap around the posterior region of the joint.[13] Additional innervation is provided by the deep temporal and masseteric nerves.

Vascularization of the Temporomandibular Joint

The TMJ is richly supplied by a variety of vessels that surround it. The predominant vessels are the superficial temporal artery from the posterior, the middle meningeal artery from the anterior, and the internal maxillary artery from the inferior. Other important arteries are the deep auricular, anterior tympanic, and ascending pharyngeal arteries. The condyle receives its vascular supply through its marrow spaces by way of the inferior alveolar artery and also receives vascular supply by way of "feeder vessels" that enter directly into the condylar head both anteriorly and posteriorly from the larger vessels.[14]



• **Fig. 1.18.** Temporomandibular Joint (Anterior View). The following are identified: *AD,* Articular disc; *CL,* capsular ligament; *IC,* inferior joint cavity; *LDL,* lateral discal ligament; *MDL,* medial discal ligament; *SC,* superior joint cavity.

Ligaments

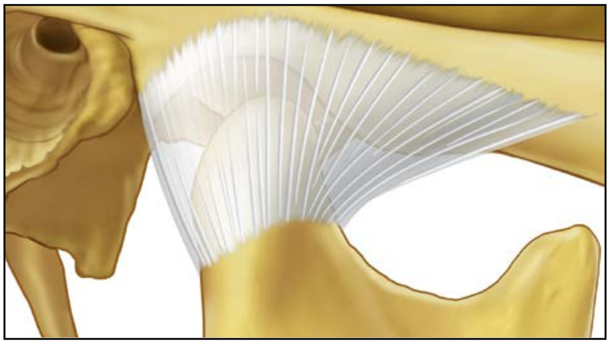
As with any joint system, ligaments play an important role in protecting the structures. Ligaments are made up of collagenous connective tissues fibers that have particular lengths. They do not stretch. However, if extensive forces are applied to a ligament, whether suddenly or over a prolonged period of time, the ligament can be elongated. When this occurs, it compromises the function of the ligament thereby altering joint function. This alteration will be discussed in future chapters that discuss pathology of the joint.

Ligaments do not enter actively into joint function but instead act as passive restraining devices to limit and restrict border movements. Three functional ligaments support the TMJ: (1) the collateral ligaments, (2) the capsular ligament, and (3) the temporomandibular ligament. There are also two accessory ligaments: (4) the sphenomandibular and (5) the stylomandibular.

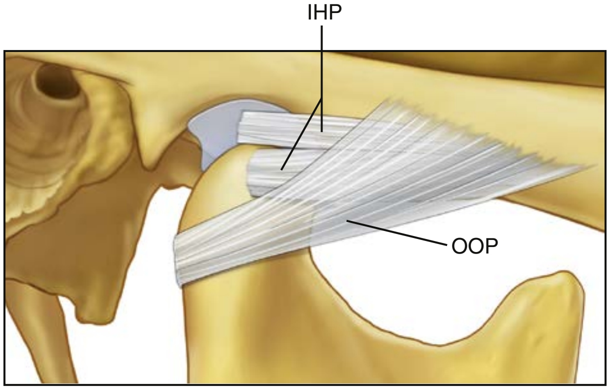
Collateral (discal) Ligaments

The collateral ligaments attach the medial and lateral borders of the articular disc to the poles of the condyle. They are commonly called the discal ligaments, and there are two. The medial discal ligament attaches the medial edge of the disc to the medial pole of the condyle. The lateral discal ligament attaches the lateral edge of the disc to the lateral pole of the condyle (Fig. 1.18). These ligaments are responsible for dividing the joint mediolaterally into the superior and inferior joint cavities. The discal ligaments are true ligaments, composed of collagenous connective tissue fibers; therefore they do not stretch. They function to restrict movement of the disc away from the condyle. In other words, they allow the disc to move passively with the condyle as it glides anteriorly and posteriorly. The attachments of the discal ligaments permit the disc to be rotated anteriorly and posteriorly on the articular surface of the condyle. Thus these ligaments are responsible for the hinging movement of the TMJ, which occurs between the condyle and the articular disc.

The discal ligaments have a vascular supply and are innervated. Their innervation provides information regarding joint position and movement. Strain on these ligaments produces pain.



• **Fig. 1.19.** Capsular Ligament (Lateral View). Note that it extends anterior to include the articular eminence and encompass the entire articular surface of the joint.



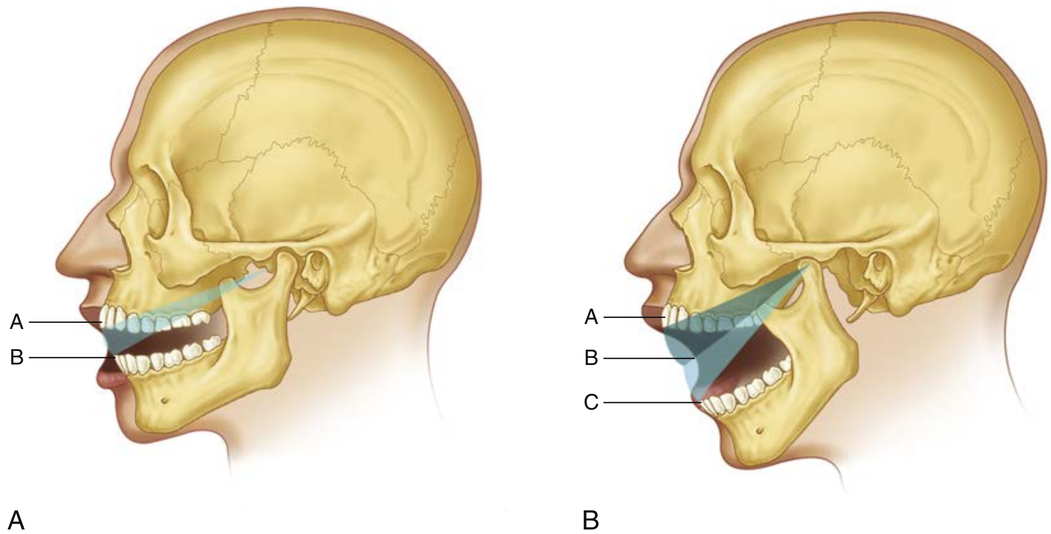
• **Fig. 1.20.** Temporomandibular Ligament (Lateral View). Note that there are two distinct parts: the outer oblique portion *(OOP)* and the inner horizontal portion *(IHP)*. The OOP limits normal rotational opening movement; the IHP limits posterior movement of the condyle and disc. (Modified from Dubrul EL: *Sicher's oral anatomy*, ed 7, St Louis, MO, 1980, The CV Mosby CO, pp 185.)

Capsular Ligament

As previously mentioned, the entire TMJ is surrounded and encompassed by the capsular ligament (Fig. 1.19). The fibers of the capsular ligament are attached superiorly to the temporal bone along the borders of the articular surfaces of the mandibular fossa and articular eminence. Inferiorly, the fibers of the capsular ligament attach to the neck of the condyle. The capsular ligament acts to resist any medial, lateral, or inferior forces that tend to separate or dislocate the articular surfaces. A significant function of the capsular ligament is to encompass the joint, thus retaining the synovial fluid. The capsular ligament is well innervated and provides proprioceptive feedback regarding position and movement of the joint.

Temporomandibular Ligament

The lateral aspect of the capsular ligament is reinforced by strong, tight fibers that make up the lateral ligament or the temporomandibular ligament. The TM ligament is composed of two parts, an outer oblique portion and an inner horizontal portion (Fig. 1.20). The outer portion extends from the outer surface of the articular



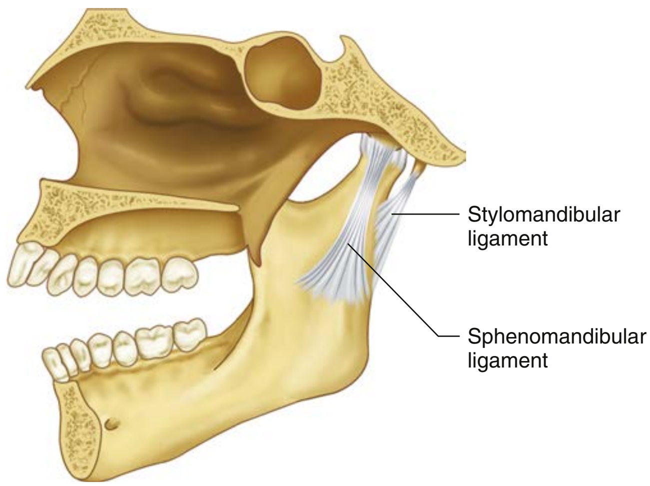
• **Fig. 1.21.** Effect of the Outer Oblique Portion of the Temporomandibular (TM) Ligament. As the mouth opens, the teeth can be separated about 20 to 25 mm (from *A* to *B*) without the condyles moving from the fossae. At *B* the TM ligaments are fully extended. As the mouth opens wider, they force the condyles to move downward and forward out of the fossae. This creates a second arc of opening (from *B* to *C*).

tubercle and zygomatic process posteroinferiorly to the outer surface of the condylar neck. The inner horizontal portion extends from the outer surface of the articular tubercle and zygomatic process posteriorly and horizontally to the lateral pole of the condyle and posterior part of the articular disc.

The oblique portion of the TM ligament resists excessive dropping of the condyle, therefore limiting the extent of mouth opening. This portion of the ligament also influences the normal opening movement of the mandible. During the initial phase of opening, the condyle can rotate around a fixed point until the TM ligament becomes tight as its point of insertion on the neck of the condyle is rotated posteriorly. When the ligament is taut, the neck of the condyle cannot rotate further. If the mouth were to be opened wider, the condyle would need to move downward and forward across the articular eminence (Fig. 1.21). This effect can be demonstrated clinically by closing the mouth and applying mild posterior force to the chin. With this force applied, begin to open the mouth. The jaw will easily rotate open until the anterior teeth are 20 to 25 mm apart. At this point, resistance will be felt when the jaw is opened wider. If the jaw is opened still wider, a distinct change in the opening movement will occur, which represents the change from rotation of the condyle about a fixed point to movement forward and down the articular eminence. This change in opening movement is brought about by the tightening of the TM ligament.

This unique feature of the TM ligament, which limits rotational opening, is found only in humans. In the erect postural position and with a vertically placed vertebral column, continued rotational opening movement would cause the mandible to impinge on the vital submandibular and retromandibular structures of the neck. The outer oblique portion of the TM ligament functions to resist this impingement.

The inner horizontal portion of the TM ligament limits posterior movement of the condyle and disc. When force applied to the mandible displaces the condyle posteriorly, this portion of the ligament becomes tight and prevents the condyle from moving into the posterior region of the mandibular fossa. The TM ligament therefore protects the retrodiscal tissues from trauma created by the posterior displacement of the condyle. The inner horizontal portion also protects the lateral pterygoid muscle from overlengthening or extension. The effectiveness of this ligament is demonstrated during cases of extreme trauma to the mandible. In such cases, the neck of the condyle will be seen to fracture before the retrodiscal tissues are severed or the condyle enters the middle cranial fossa.



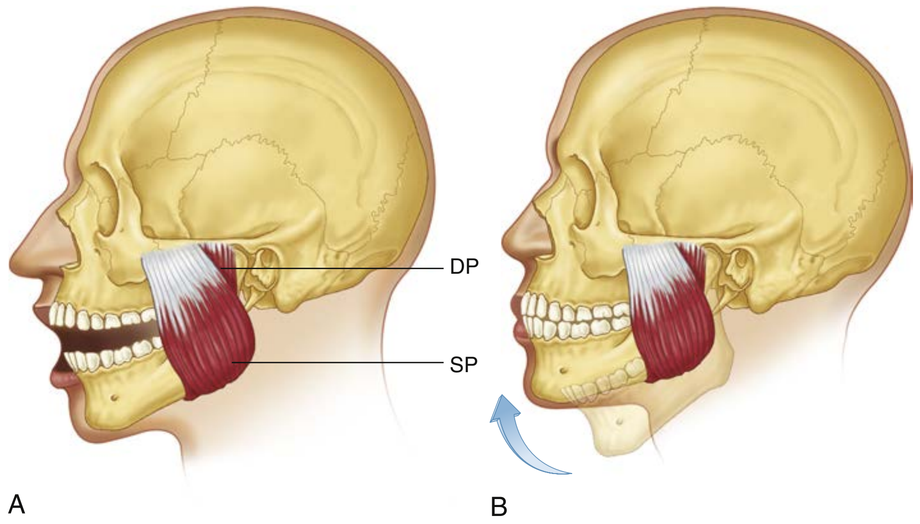
• **Fig. 1.22.** The mandible, temporomandibular joint, and accessory ligaments.

Sphenomandibular Ligament

The sphenomandibular ligament is one of two TMJ accessory ligaments (Fig. 1.22). It arises from the spine of the sphenoid bone and extends downward to a small bony prominence on the medial surface of the ramus of the mandible called the lingula. It does not have any significant limiting effects on mandibular movement.

Stylomandibular Ligament

The second accessory ligament is the stylomandibular ligament (Fig. 1.22). It arises from the styloid process and extends



• **Fig. 1.23.** **A.** Masseter muscle. *DP,* Deep portion; *SP,* superficial portion. **B.** Function: elevation of the mandible.

downward and forward to the angle and posterior border of the ramus of the mandible. It becomes taut when the mandible is protruded, but is most relaxed when the mandible is opened. The stylomandibular ligament therefore limits excessive protrusive movements of the mandible.

Muscles of Mastication

The skeletal components of the body are held together and moved by the skeletal muscles. The skeletal muscles provide for the locomotion necessary for the individual to survive. Muscles are made of numerous fibers ranging between 10 and 80 micrometers in diameter. Each of these fibers in turn is made up of successively smaller subunits. In most muscles, the fibers extend the entire length of the muscle, except for about 2% of the fibers. Each fiber is innervated by only one nerve ending, located near the middle of the fiber. The area where most of these connections are found is called the motor endplate. The end of the muscle fiber fuses with a tendon fiber, and the tendon fibers in turn collect into bundles to form the muscle tendon that inserts into the bone. Each muscle fiber contains several hundred to several thousand myofibrils. Each myofibril in turn has, lying side-by-side, about 1500 myosin filaments and 3000 actin filaments, which are large polymerized protein molecules that are responsible for muscle contraction. For a more complete description of the physiology of muscle contraction, other publications should be pursued.[15]

Muscle fibers can be characterized by type according to the amount of myoglobin (a pigment similar to hemoglobin). Fibers with higher concentrations of myoglobin are deeper red in color and capable of slow but sustained contraction. These fibers are called slow muscle fibers or Type I muscle fibers. Slow fibers have a well-developed aerobic metabolism and are therefore resistant to fatigue. Fibers with lower concentrations of myoglobin are whiter and called fast muscle fibers or Type II fibers. These fibers have fewer mitochondria and rely more on anaerobic activity for function. Fast muscle fibers are capable of quick contraction but fatigue more rapidly.

All skeletal muscles contain a mixture of fast and slow fibers in varying proportions that reflect the function of that muscle. Muscles that are called upon to respond quickly are made of predominately white fibers. Muscles that are mainly used for slow, continuous activity have higher concentrations of slow fibers.

Four pairs of muscles make up a group called the muscles of mastication: the masseter, temporalis, medial pterygoid, and lateral pterygoid. Although not considered to be muscles of mastication, the digastrics also play an important role in mandibular function and therefore are discussed in this section. Each of the muscles is discussed according to its attachment, the direction of its fibers, and its function.

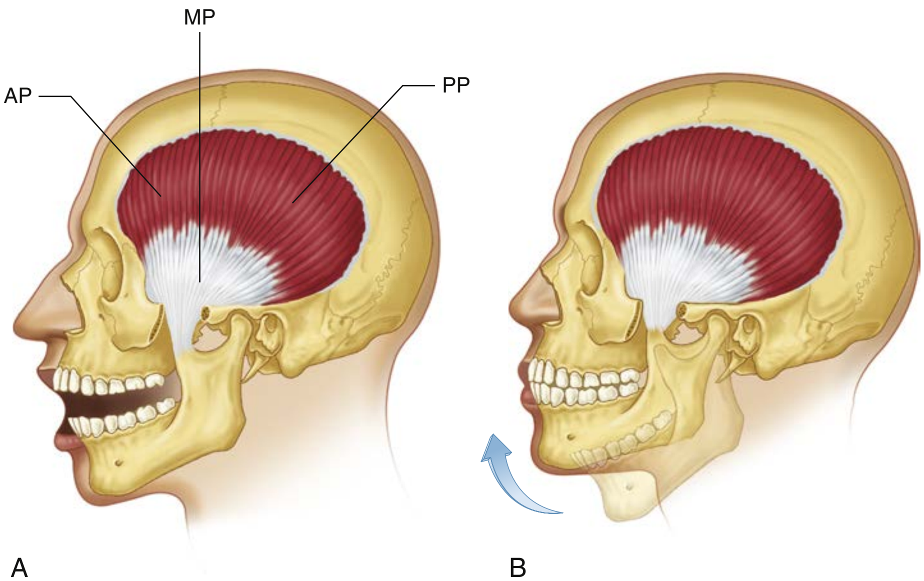
The Masseter

The masseter is a rectangular muscle that originates from the zygomatic arch and extends downward to the lateral aspect of the lower border of the ramus of the mandible (Fig. 1.23). Its insertion on the mandible extends from the region of the second molar at the inferior border posteriorly to include the angle. It is made up of two portions or heads: the *superficial* portion consists of fibers that run downward and slightly backward; the *deep* portion consists of fibers that run in a predominantly vertical direction.

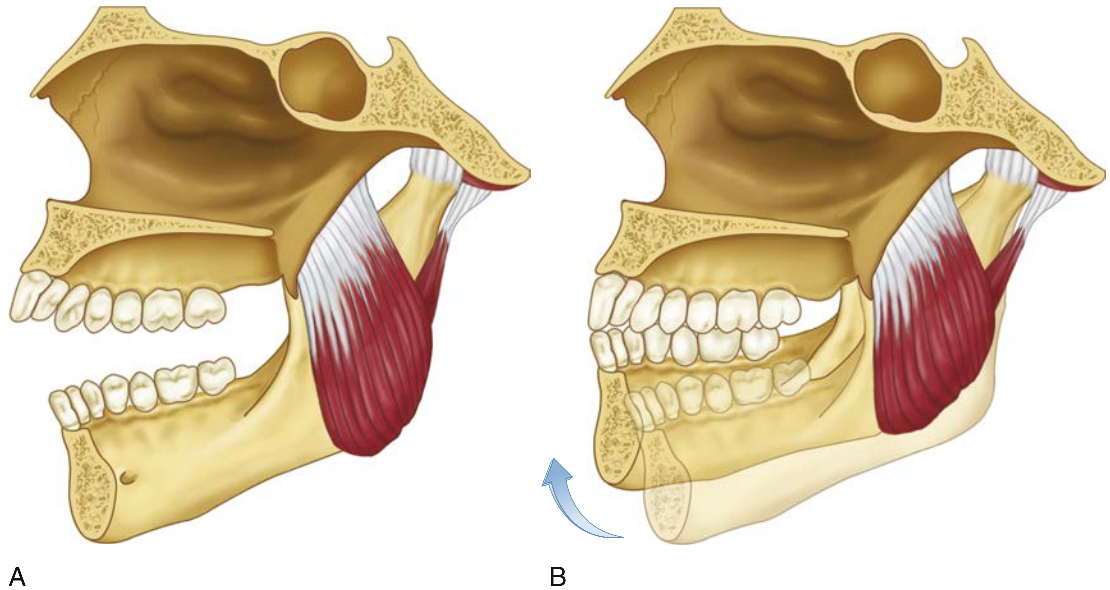
As fibers of the masseter contract, the mandible is elevated and the teeth are brought into contact. The masseter is a powerful muscle that provides the force necessary to chew efficiently. Its superficial portion may also aid in protruding the mandible. When the mandible is protruded and biting force is applied, the fibers of the deep portion stabilize the condyle against the articular eminence.

The Temporalis

The temporalis is a large, fan-shaped muscle that originates from the temporal fossa and the lateral surface of the skull. Its fibers come together as they extend downward between the zygomatic arch and the lateral surface of the skull to form a tendon that inserts on the coronoid process and anterior border of the ascending ramus. It can be divided into three distinct areas according to fiber direction and ultimate function (Fig. 1.24). The anterior portion consists of fibers that are directed almost vertically. The middle portion contains fibers that run obliquely across the lateral aspect of the skull (slightly forward as they pass downward). The posterior portion consists of fibers that are aligned almost



• **Fig. 1.24.** **A.** Temporal muscle. Note the following: *AP,* anterior portion; *MP,* middle portion; *PP,* posterior portion. **B.** Function: elevation of the mandible. The exact movement by the location of the fibers or portion being activated.



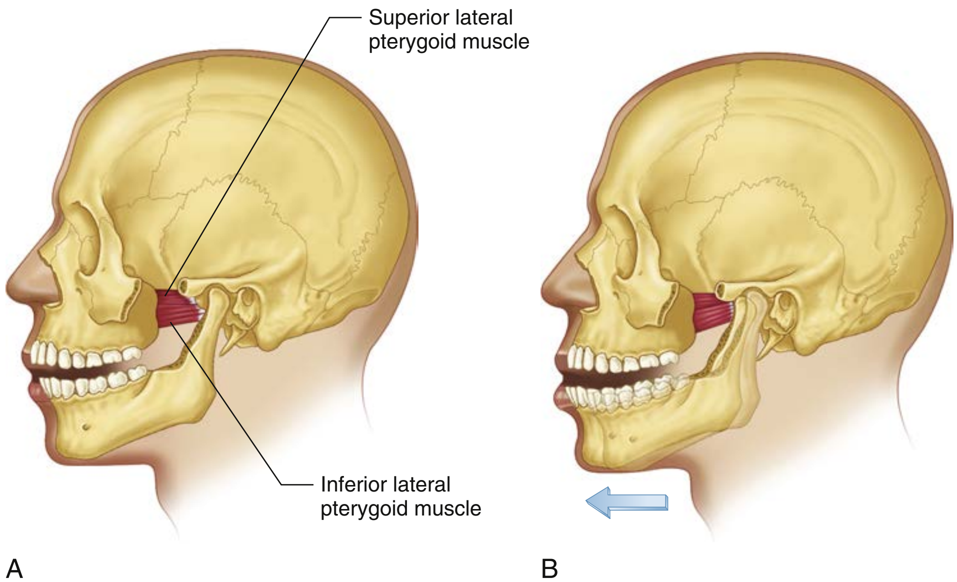
• **Fig. 1.25.** **A.** Medial pterygoid muscle. **B.** Function: elevation of the mandible.

horizontally, coming forward above the ear to join other temporalis fibers as they pass under the zygomatic arch.

When the temporal muscle contracts, it elevates the mandible, and the teeth are brought into contact. If only portions contract, the mandible is moved according to the direction of those fibers that are activated. When the anterior portion contracts, the mandible is raised vertically. Contraction of the middle portion will elevate and retrude the mandible. Function of the posterior portion is somewhat controversial. Although it would appear that contraction of this portion will retrude the mandible, DuBrul[16] suggests that the fibers below the root of the zygomatic process are the only significant ones and therefore contraction will cause elevation and only slight retrusion. Because the angulation of its muscle fibers varies, the temporalis is capable of coordinating closing movements. It thus is a significant positioning muscle of the mandible.

The Medial Pterygoid

The medial (internal) pterygoid originates from the pterygoid fossa and extends downward, backward, and outward to insert along the medial surface of the mandibular angle (Fig. 1.25). Along with the masseter, it forms a muscular sling that supports the mandible at the mandibular angle. When its fibers contract, the mandible is elevated and the teeth are brought into contact. This muscle is also active in protruding the mandible. Unilateral contraction will bring about a mediotrusive movement of the mandible.



• **Fig. 1.26.** **A.** Inferior and superior lateral pterygoid muscles. **B.** Function of the inferior lateral pterygoid: protrusion of the mandible.

The Lateral Pterygoid

For many years the lateral (external) pterygoid was described as having two distinct portions or bellies: an inferior and a superior. Since the muscle appeared anatomically to be as one in structure and function, this description was acceptable until studies proved differently.[17,18] It is now appreciated that the two bellies of the lateral pterygoid function quite differently. Therefore in this text the lateral pterygoid will be divided and identified as two distinct and different muscles, which is appropriate since their functions are nearly opposite. The muscles will be described as (1) the inferior lateral pterygoid and (2) the superior lateral pterygoid.

Inferior Lateral Pterygoid. The inferior lateral pterygoid originates at the outer surface of the lateral pterygoid plate and extends backward, upward, and outward to its insertion primarily on the neck of the condyle (Fig. 1.26). When the right and left inferior lateral pterygoids contract simultaneously, the condyles are pulled forward down the articular eminences and the mandible is protruded. Unilateral contraction creates a mediotrusive movement of that condyle and causes a lateral movement of the mandible to the opposite side. When this muscle functions with the mandibular depressors, the mandible is lowered and the condyles glide forward and downward on the articular eminences.

Superior Lateral Pterygoid. The superior lateral pterygoid is considerably smaller than the inferior and originates at the infratemporal surface of the greater sphenoid wing, extending almost horizontally, backward, and outward to insert on the articular capsule, the disc, and the neck of the condyle (Figs. 1.15 and 1.26). The exact attachment of the superior lateral pterygoid to the disc is somewhat debated. Although some authors[19] suggest no attachment, most studies reveal the presence of a muscle-disc attachment.[14,20-23,24] The majority of the fibers of the superior lateral pterygoid (60% to 70%) attach to the neck of the condyle with only 30% to 40% attaching to the disc. It is also important to note that the attachments are more predominant on the medial aspect than on the lateral. Approaching the joint structures from the lateral aspect would reveal little or no muscle attachment. This may explain the different findings in these studies.

While the inferior lateral pterygoid is active during opening, the superior remains inactive, becoming active only in conjunction with the elevator muscles. The superior lateral pterygoid is especially active during the power stroke and when the teeth are held together. The *power stroke* refers to movements that involve closure of the mandible against resistance, such as in chewing or clenching the teeth together. The functional significance of the superior lateral pterygoid is discussed in more detail in the next section, which deals with the biomechanics of the TMJ.

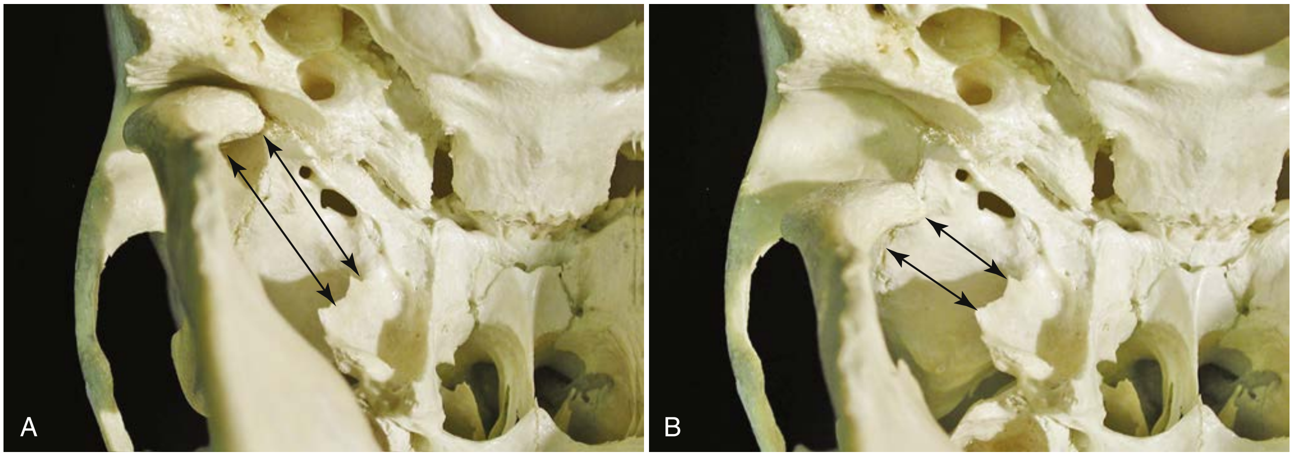
Note that the pull of the lateral pterygoid on the disc and condyle is predominantly in an anterior direction; however, it also has a significantly medial component (Fig. 1.27). As the condyle moves more forward, the medial angulation of the pull of these muscles becomes even greater. In the wide-open mouth position, the direction of the muscle pull is more medial than anterior.

It is interesting to note that approximately 80% of the fibers that make up both lateral pterygoid muscles are slow muscle fibers (Type I).[25,26] This suggests that these muscles are relatively resistant to fatigue and may serve to brace the condyle for long periods of time without difficulty.

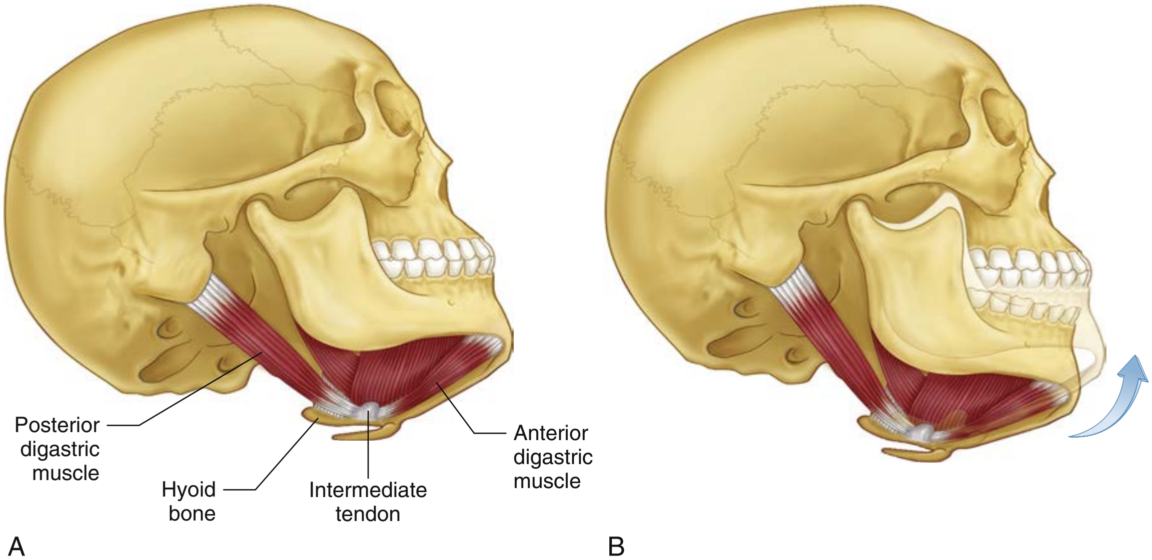
The Digastric

Although the digastric is not generally considered a muscle of mastication, it does have an important influence on the function of the mandible. It is divided into two portions or bellies (Fig. 1.28). The posterior belly originates from the mastoid notch, just medial to the mastoid process; its fibers run forward, downward, and inward to the intermediate tendon attached to the hyoid bone. The anterior belly originates at a fossa on the lingual surface of the mandible, just above the lower border and close to the midline; and its fibers extend downward and backward to insert at the same intermediate tendon as does the posterior belly.

When the right and left digastrics contract and the hyoid bone is fixed by the suprahyoid and infrahyoid muscles, the mandible is depressed and pulled backward and the teeth are brought out of contact. When the mandible is stabilized the digastric muscles with the suprahyoid and infrahyoid muscles elevate the hyoid bone, which is a necessary function for swallowing.



• **Fig. 1.27.** **A.** When the condyle is in a normal relationship in the fossa, the attachments of the superior and inferior lateral pterygoid muscles create a medial and anterior pull on the condyle and disc *(arrows)*. **B.** As the condyle moves anteriorly from the fossa, the pull becomes more medially directed *(arrows)*.

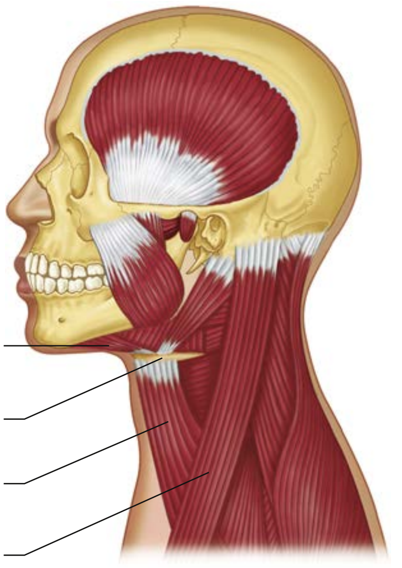


• **Fig. 1.28.** **A.** Digastric muscle. **B.** Function: depression of the mandible.

The digastrics are one of many muscles that depress the mandible and raise the hyoid bone (Fig. 1.29). Generally, muscles that are attached from the mandible to the hyoid bone are called *suprahyoid* and those attached from the hyoid bone to the clavicle and sternum are called *infrahyoid***.** The suprahyoid and infrahyoid muscles play a major role in coordinating mandibular function. So also do many of the other numerous muscles of the head and neck. It can be quickly observed that a study of mandibular function is not limited to the muscles of mastication. Other major muscles, such as the sternocleidomastoid and the posterior cervical muscles, play major roles in stabilizing the skull and enabling controlled movements of the mandible to be performed. A finely tuned dynamic balance exists among all of the head and neck muscles, and this must be appreciated for an understanding of the physiology of mandibular movement to occur. As a person yawns, the head is brought back by contraction of the posterior cervical muscles, which raises the maxillary teeth. This simple example demonstrates that even normal functioning of the masticatory system utilizes many more muscles than just those of mastication. With an understanding of this relationship, one can see that any effect on the function of the muscles of mastication also has an effect on other head and neck muscles. A more detailed review of the physiology of the entire masticatory system will be presented in Chapter 2. A summary of the anatomic features of the muscles of mastication is listed in Table 1.1.

Biomechanics of the Temporomandibular Joint

The TMJ is an extremely complex joint system. The fact that there are two TMJs connected to the same bone (the mandible) further complicates the function of the entire masticatory system. Although each joint can simultaneously carry out a different function, they cannot act without influencing the other. A sound understanding of the biomechanics of the TMJ is essential and basic to the study of function and dysfunction in the masticatory system.



• **Fig. 1.29.** Movement of the head and neck is a result of the finely coordinated efforts of many muscles. The muscles of mastication represent only part of this complex system.

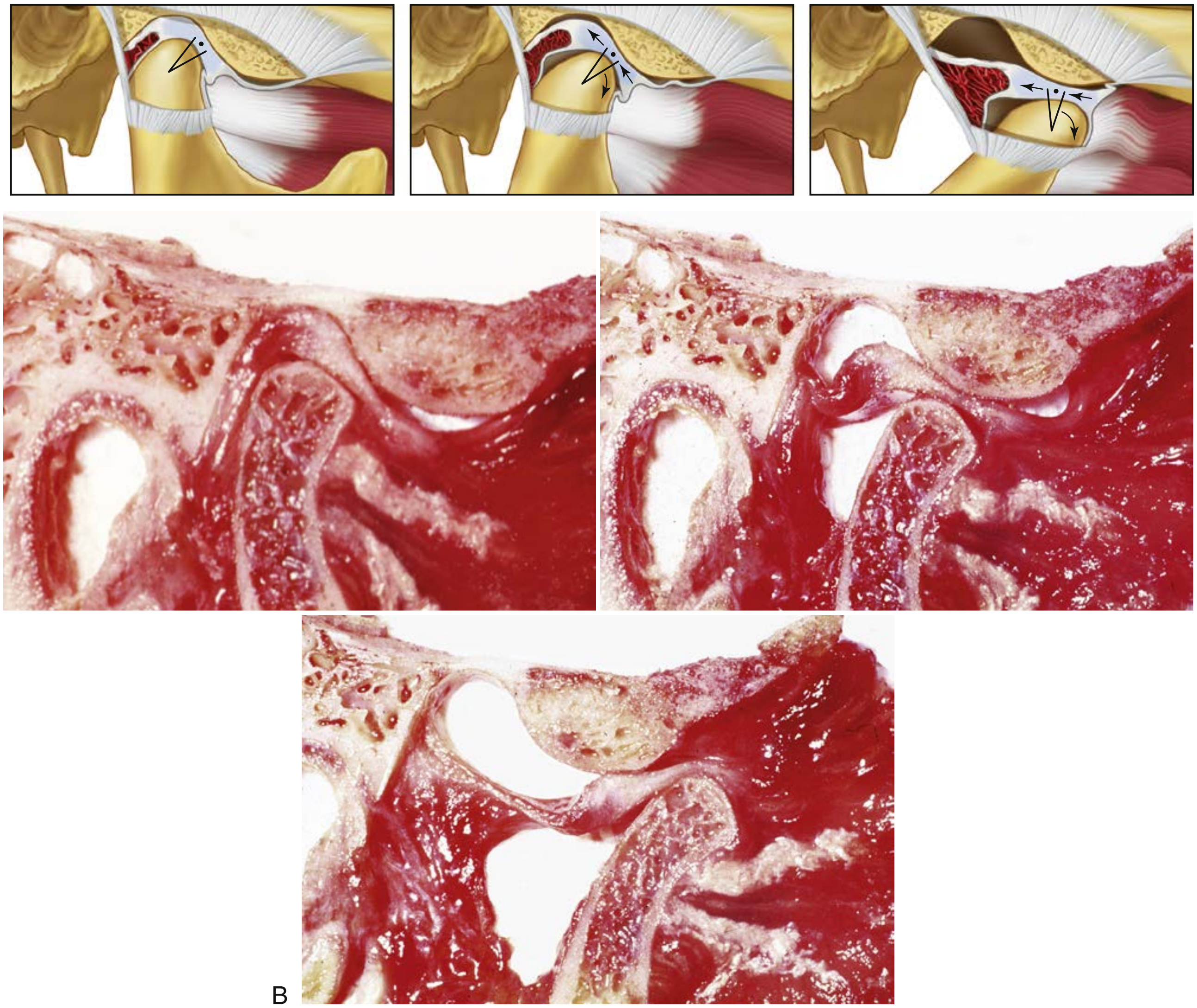
The TMJ is a compound joint. Its structure and function can be divided into two distinct systems:

1. One joint system is the tissues that surround the inferior synovial cavity (i.e., the condyle and the articular disc). Since the disc is tightly bound to the condyle by the lateral and medial discal ligaments, the only physiologic movement that can occur between these surfaces is rotation of the disc on the articular surface of the condyle. The disc and its attachment to the condyle are called the condyle-disc complex and is the joint system responsible for rotational movement in the TMJ.
2. The second system is made up of the condyle-disc complex functioning against the surface of the mandibular fossa. Since the disc is not tightly attached to the articular fossa, free sliding movement is possible between these surfaces in the superior cavity. This movement occurs when the mandible is moved forward (referred to as translation). Translation occurs in this superior joint cavity between the superior surface of the articular disc and the mandibular fossa. Thus the articular disc acts as a nonossified bone contributing to both joint systems, and hence the function of the disc justifies classifying the TMJ as a true compound joint (Fig. 1.30).

The articular disc has been referred to as a meniscus. However, it is not a meniscus at all. By definition, a meniscus is a

TABLE 1.1 Anatomic Features of the Muscles of Mastication

Muscle	Origin	Insertion	Function	Innervation	Blood Supply
Masseter	The zygomatic process of the maxilla and the anterior two-thirds of the lower border of the zygomatic arch	The angle and lower half of the lateral surface of the ramus of the mandible	Elevates the mandible, contributes to protrusion	Masseteric branch of the mandibular nerve of the trigeminal nerve	Masseteric artery
Temporalis	The lateral aspect of the skull to the full extent of the superior temporal line	The anterior border of the coronoid process and the anterior border of the ramus of the mandible as far forward as the last molar tooth	Elevates the mandible, contributes to retrusion	Deep temporal nerve from the mandibular branch of the trigeminal nerve	Anterior, posterior, and superficial temporal arteries
Medial Pterygoid	The medial surface of the lateral pterygoid plate and the grooved surface of the pyramidal process of the palatine bone	The inferior and posterior portion of the medial surface of the ramus and angle of the mandible, as high as the mandibular foramen	Elevates the mandible, contributes to protrusion	Mandibular branch of the trigeminal nerve	Pterygoid branch of maxillary artery
Superior Lateral Pterygoid	The lower part of the lateral surface of the great wing of the sphenoid and from the infratemporal crest	The neck of the mandibular condyle and into the front margin of the articular disc	Stabilizes the condyle and disc during mandible loading (i.e., unilateral chewing)	Pterygoid branch of the trigeminal nerve	Pterygoid branch of the maxillary artery
Inferior Lateral Pterygoid	The lateral surface of the lateral pterygoid plate	The neck of the mandibular condyle	Protrudes the mandible, contributes to lateral movements and mouth opening	Pterygoid branch of the trigeminal nerve	Pterygoid branch of the maxillary artery
Anterior Digastric	A depression on the inner side of the lower border of the mandible, close to the symphysis	A tendon which passes through a tendinous pulley attached to the hyoid bone. The anterior digastric attaches to the tendon of the posterior digastric muscle	Depresses the mandible and elevates the hyoid bone	Mandibular branch of the trigeminal nerve and the mylohyoid nerve	The submental artery
Posterior Digastric	The inferior surface of the skull, from the mastoid notch on the medial surface of the mastoid process of the temporal bone and a deep groove between the mastoid process and the styloid process	A tendon that passes through a tendinous pulley attached to the hyoid bone. The posterior digastric attaches to the tendon of the anterior digastric muscle	Depresses the mandible and elevates the hyoid bone	Digastric branch of facial nerve	Lingual artery and facial artery



• **Fig. 1.30. A.** Normal movement of the condyle and disc during mouth opening. Note that as the condyle moves out of the fossa the disc rotates posteriorly on the condyle. Rotational movement predominately occurs in the lower joint space while translation predominately occurs in the superior joint space. **B.** Note the same movements in the cadaver specimen. (Courtesy Dr. Terry Tanaka, San Diego, CA.)

wedge-shaped crescent piece of fibrocartilage attached on one side to the articular capsule and unattached on the other side, extending freely into the joint spaces. A meniscus does not divide a joint cavity, isolating the synovial fluid, nor does it serve as a determinant of joint movement. Instead, it functions passively to facilitate movement between the bony parts. Typical menisci are found in the knee joint. In the TMJ the disc functions as a true articular surface in both joint systems and is therefore more accurately termed an articular disc.

Now that the two individual joint systems have been described, we can consider once again the entire TMJ. The articular surfaces of the joint have no structural attachment or union, yet contact must be maintained constantly for joint stability. Stability of the joint is maintained by constant activity of the muscles that pull across the joint, primarily the elevators. Even in the resting state, these muscles are in a mild state of contraction called *tonus*. This feature will be discussed in Chapter 2. As muscle activity increases, the condyle is increasingly forced against the disc and the disc against the fossa, resulting in an increase in the interarticular pressure* of these joint structures.[27–29] In the absence of interarticular pressure, the articular surfaces will separate and the joint will technically dislocate.

The width of the articular disc space varies with interarticular pressure. When the pressure is low, as in the closed rest position, the disc space widens slightly. When the pressure is high, as during clenching of the teeth, the disc space narrows. The contour and movement of the disc permit constant contact of the articular surfaces of the joint, which is necessary for joint stability. As the interarticular pressure increases, the condyle seats itself on the thinner intermediate zone of the disc. When the pressure is decreased and the disc space is widened, a thicker portion of the disc is rotated to fill the space. Since the anterior and posterior bands of the disc are wider than the intermediate zone, technically the disc could be rotated either anteriorly or posteriorly to accomplish this task. The

*Interarticular pressure is the pressure *between* the articular surfaces of the joint.

direction of the disc rotation is determined not by chance but by the structures attached to the anterior and posterior borders of the disc.

Attached to the posterior border of the articular disc are the retrodiscal tissues, sometimes referred to as the posterior attachment. As previously mentioned, the superior retrodiscal lamina is composed of varying amounts of elastic connective tissue. Since this tissue has elastic properties and because in the closed mouth position it is somewhat folded over itself, the condyle can easy move out of the fossa without creating any damage to the superior retrodiscal lamina. When the mouth is closed (the closed joint position), the elastic traction on the disc is minimal to none. However, during mandibular opening, when the condyle is pulled forward down the articular eminence, the superior retrodiscal lamina becomes increasingly stretched, creating increased forces to retract the disc. In the full forward position, the posterior retractive force on the disc created by the tension of the stretched superior retrodiscal lamina is at a maximum. The interarticular pressure and the morphology of the disc prevent the disc from being over retracted posteriorly. In other words, as the mandible moves into a full forward position and during its return, the retraction force of the superior retrodiscal lamina holds the disc rotated as far posteriorly on the condyle as the width of the articular disc space will permit. This is an important principle in understanding joint function. Likewise, it is important to remember that the superior retrodiscal lamina is the only structure capable of retracting the disc posteriorly on the condyle, although this retractive force is only present during wide opening movements.

Attached to the anterior border of the articular disc is the superior lateral pterygoid muscle. When this muscle is active, the fibers that are attached to the disc pull anteriorly and medially. Therefore the superior lateral pterygoid is technically a protractor of the disc. Remember, however, that this muscle is also attached to the neck of the condyle. This dual attachment does not allow the muscle to pull the disc through the discal space. Protraction of the disc, however, does not occur during jaw opening. When the inferior lateral pterygoid is protracting the condyle forward, the superior lateral pterygoid is inactive and therefore does not bring the disc forward with the condyle. The superior lateral pterygoid is activated only in conjunction with activity of the elevator muscles during mandibular closure or a power stroke.

It is important to understand the features that cause the disc to move forward with the condyle in the absence of superior lateral pterygoid activity. The anterior capsular ligament attaches the disc to the anterior margin of the articular surface of the condyle (Fig. 1.15). Also, the inferior retrodiscal lamina attaches the posterior edge of the disc to the posterior margin of the articular surface of the condyle. Both these ligaments are composed of collagenous fibers and will not stretch. Therefore a logical assumption is that they force the disc to translate forward with the condyle. Although logical, such an assumption is incorrect: these structures are not primarily responsible for movement of the disc with the condyle. Remember that ligaments do not actively participate in normal joint function but only passively restrict the extreme border movements. The mechanism by which the disc is maintained with the translating condyle is dependent on the morphology of the disc and the interarticular pressure. In the presence of a normally shaped articular disc, the articulating surface of the condyle rests on the intermediate zone, between the two thicker portions. As the interarticular pressure is increased, the discal space narrows, which more positively seats the condyle on the intermediate zone.

During translation, the combination of disc morphology and interarticular pressure maintains the condyle on the intermediate zone and the disc is forced to translate forward with the condyle. The morphology of the disc therefore is extremely important in maintaining proper position during function. Proper morphology plus interarticular pressure results in an important self-positioning feature of the disc. Only when the morphology of the disc has been greatly altered does the ligamentous attachment of the disc affect joint function. When this occurs the biomechanics of the joint is altered and dysfunctional signs begin. These conditions will be discussed in detail in later chapters.

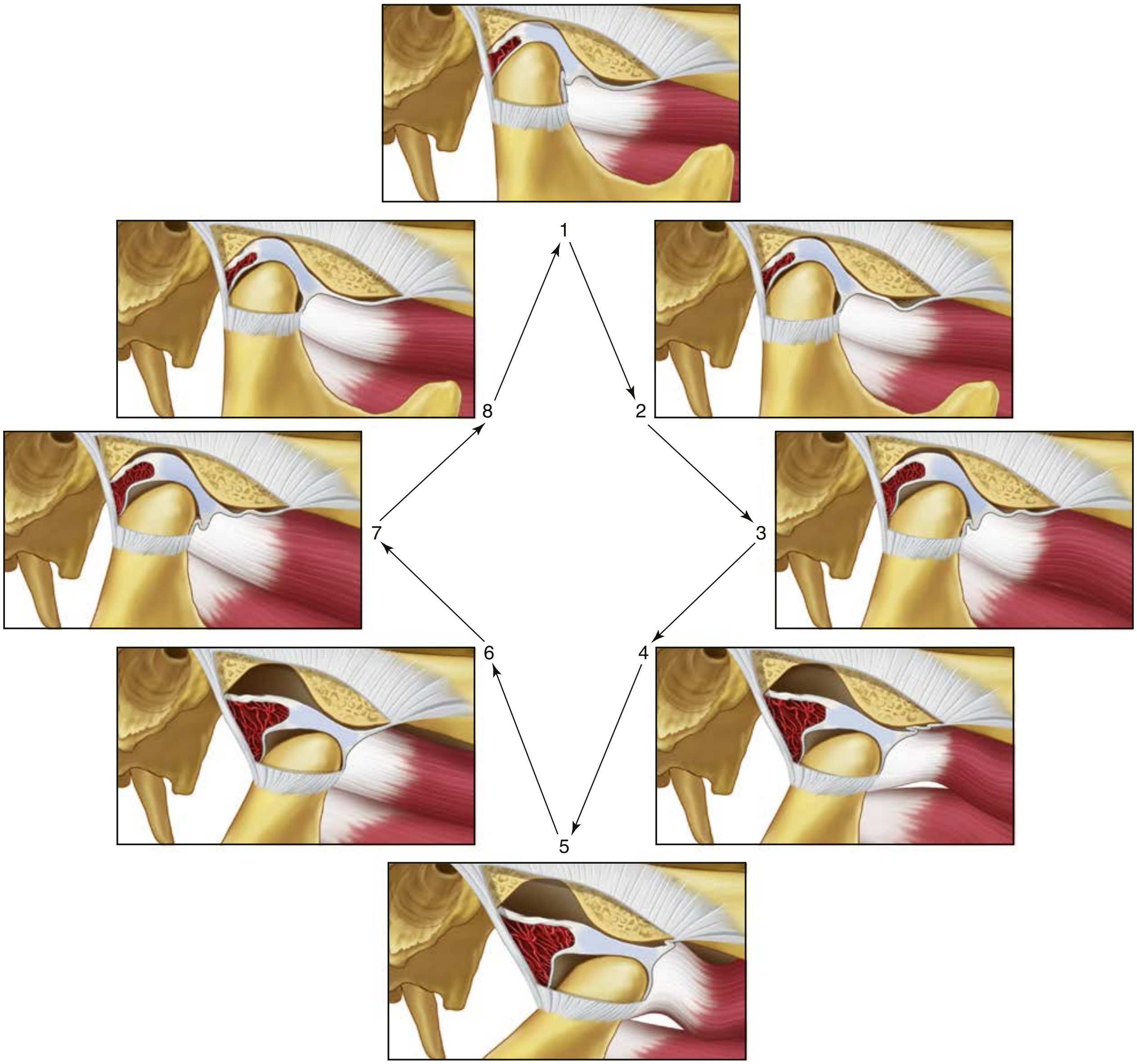
Like most muscles, the superior lateral pterygoid is constantly maintained in a mild state of contraction or tonus, which exerts a slight anterior and medial force on the disc. In the resting closed joint position, this anterior and medial force will normally exceed the posterior elastic retraction force provided by the nonstretched superior retrodiscal lamina. Therefore in the resting closed joint position, when the interarticular pressure is low and the disc space widened, the disc will occupy the most anterior rotary position on the condyle permitted by the width of the space. In other words, at rest with the mouth closed, the condyle will be positioned in contact with the intermediate and posterior zones of the disc.

This disc relationship is maintained during minor passive rotational and translatory mandibular movements. As soon as the condyle is moved forward enough to cause the retractive force of the superior retrodiscal lamina to be greater than the muscle tonus force of the superior lateral pterygoid, the disc is rotated posteriorly to the extent permitted by the width of the articular disc space. When the condyle is returned to the resting closed joint position, once again the tonus of the superior lateral pterygoid becomes the predominant force and the disc is repositioned forward as far as the disc space will permit (Fig. 1.31).

The functional importance of the superior lateral pterygoid muscle becomes obvious when observing the effects of the power stroke during unilateral chewing. When one bites down on a hard substance on one side (e.g., a tough steak), the TMJs are not equally loaded. This occurs because the force of closure is not applied to the joint but is instead applied to the food. The jaw is fulcrumed around the hard food, causing an increase in interarticular pressure in the contralateral joint and a sudden decrease in interarticular pressure in the ipsilateral (same side) joint.[30,31] This can lead to separation of the articular surfaces, resulting in dislocation of the ipsilateral joint. To prevent this dislocation, the superior lateral pterygoid becomes active during the power stroke, rotating the disc forward on the condyle so the thicker posterior border of the disc maintains articular contact. Therefore joint stability is maintained during the power stroke of chewing. As the teeth pass through the food and approach intercuspation, the interarticular pressure is increased. As the interarticular pressure is increased in the joint, the disc space is decreased and the disc is mechanically rotated posteriorly so the thinner intermediate zone fills the space. When the force of closure is discontinued, the resting closed joint position is once again assumed.

Understanding these basic concepts in TMJ function is essential to the understanding of joint dysfunction. Normal biomechanical function of the TMJ must follow the orthopedic principles just presented. Remember:

1. Ligaments do not actively participate in normal function of the TMJ. They act as guide wires, restricting certain joint movements while permitting others. They restrict joint movements both mechanically and through neuromuscular reflex activity (see Chapter 2).
2. Ligaments do not stretch. If traction force is applied, they can become elongated, that is, increase in length. (Stretch implies the ability to return to the original length.) Once ligaments have been elongated, normal joint function is often compromised.



• Fig. 1.31. Normal functional movement of the condyle and disc during the full range of opening and closing. Note that the disc is rotated posteriorly on the condyle as the condyle is translated out of the fossa. The closing movement is the exact opposite of opening. This is pressure *between* the articular surfaces of the joint.

3. The articular surfaces of the TMJs must be maintained in constant contact. This contact is produced by the muscles that pull across the joints (the elevators: temporal, masseter, and medial pterygoid).

A sound understanding of these principles is necessary for the evaluation and treatment of the various disorders that will be presented throughout the remainder of this book.

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