TEMPOROMANDIBULAR JOINT IMAGING

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With 472 illustrations

Mosby
Year Book

St. Louis Baltimore Boston Chicago London Philadelphia Sydney Toronto

Mosby
Year Book

Dedicated to Publishing Excellence

Editor: Anne S. Patterson
Assistant Editor: Michelle Hey
Project Manager: Peggy Fagen
Design: Laura E. Steube
Production: Barbara Merritt, Teresa Breckwoldt

Printed in the United States of America

Mosby–Year Book, Inc.
11830 Westline Industrial Drive
St. Louis, Missouri 63146

International Standard Book Number 0-8016-0999-2

CL/WA/WA/WA 9 8 7 6 5 4 3 2 1

CROW AND THE BIRDS

When the eagle soared through a dawn distilling of
emerald
When the curlew trawled in seadusk through a chime of
wine glasses
When the swallow swooped through a woman's song in a
cavern
And the swift flicked through the breath of a violet

When the owl sailed clear of tomorrow's conscience
And the sparrow preened himself of yesterday's promise
And the heron laboured clear of the Bessemer upglare
And the bluetit zipped clear of lace panties
And the woodpecker drummed clear of the rotovator and
the rose-farm
And the peewit tumbled clear of the laundromat

While the bullfinch plumped in the apple bud
And the goldfinch bulbed in the sun
And the wryneck crooked in the moon
And the dipper peered from the dewball

Crow spraddled head-down in the beach-garbage, guzzling
a dropped ice-cream.
Ted Hughes

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Foreword

Since 1983 Dr. Edwin Christiansen and Dr. Joseph Thompson have collaborated in clinical and basic research regarding temporomandibular joint imaging. Dr. Christiansen is Professor of Dentistry, Department of Endodontics, at the School of Dentistry, Loma Linda University. He graduated from Loma Linda University School of Dentistry in 1975 and has experience as a practicing dentist as well as special postgraduate training in the Department of Radiology at Loma Linda. He received a doctorate in Odontology at Karolinska Institute in Stockholm, Sweden. He defended his thesis in May, 1988.

Dr. Joseph Thompson is Chief of Pediatric Neuroradiology and Director of Pediatric Radiology in the Loma Linda School of Medicine. As a Professor of Radiology he has broad experience in CT, MR, and other fields of body sectioning imaging. He received his M.D. degree from Loma Linda in 1964 and radiology training at White Memorial Medical Center, Los Angeles, California. After a tour of military duty he returned to Loma Linda where he has been active in neuroradiology and research since 1970. He had special training at the Hospital for Sick Children in Toronto, Ontario, Canada in 1972.

In reviewing this manuscript I found it obvious that these two investigators set out with a goal to write the "definitive book" on temporomandibular joint imaging. Each chapter is meticulously and extensively documented with references. Over 400 illustrations are present in the book.

One of the most delightful things about the style of the authors is their willingness to enter headlong into controversial areas. This is commendable in a subject like the temporomandibular joint, which has multiple obscure causes for pain that defy effective treatment. The authors seem to take particular pride in presenting both sides of a controversy. If one did not believe that imaging should be performed in the temporomandibular joint pain syndrome, there would be ample evidence in the quoted references to justify such a stand. At the opposite extreme, the enthusiasts for temporomandibular joint imaging would consider their position quite secure after reading this book. For example, they quote the work of Goodman, Green, and Laskin, who reported that nontherapeutic grinding of the teeth relieves 64% of the patients with TMJ pain syndromes. This percentage was actually better than placebos, which were quoted at approximately 38% relief of pain.

A chapter is devoted to the technique and uses of arthroscopy and other therapeutic procedures that can be used to relieve the pain of temporomandibular joint dysfunction. Unfortunately these techniques are sufficiently new that no long-term follow-up statistics are available.

The clinician or radiologist dealing with temporomandibular joint problems should not be discouraged by some of the pitfalls and fallacies pointed out by the authors. It is their opinion that imaging provides much more information than can be utilized by clinicians to treat temporomandibular joint disorders. At first glance this would seem to discourage the use of imaging modalities in the very obscure pain syndromes. On the other hand, diagnosis has always outpaced therapeutic regimes in all areas of the body. This is why Drs. Christiansen and Thompson emphasize that the imaging techniques, although expensive, are justified to lay a sound scientific foundation to the research therapeutic regimes being tested in well-thought-out clinical trials.

Other contributors to their book have again emphasized some of the research aspects of imaging, such as signal levels coming from MR studies and pulsing sequences that need to be explored. The critical angle that collagen fibers make with the main magnetic field causes a 300% change in signal level. The authors term this angle, which is somewhere between 40 and 70 degrees, the "magic angle range." The angle that collagen fibers make to the main magnetic field affects the signal level found within the disk. Based on some of the work of Fullerton and others, the authors performed tests on multiple readers to determine where the disk margins lay within the temporomandibular joint based on signal levels. There was wide discrepancy in what was called the posterior margin of the disk; signals would vary depending on the angle the long fibers made with the main magnetic field. Hence, considerable confusion can occur between observers and even by the same observer when reviewing two different pulsing sequences.

Temporomandibular joint pain syndromes continue to plague the practicing clinician due to their elusiveness and almost ubiquitous penetration of our young adult population. Should imaging be performed on every patient when we have full knowledge that this is generally a self-limiting disease? The position of the authors is excellent. They believe that such studies should only be carried out in controlled circumstances where research is being conducted on a significant number of patients to provide meaningful, statistical results.

Drs. Christiansen and Thompson are to be congratulated on their fine work.

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Preface

Temporomandibular Joint Imaging is directed to dental and medical practitioners involved with the diagnosis and treatment of TMJ disorders and who are concerned with the practical applications of plain films, tomograms, arthrograms, computed tomograms, and magnetic resonance scans performed for what appears to be a growing number of patients.

Critics of TMJ imaging contributed to the inception of this book by arguing, often convincingly, that much of what passes as TMJ imaging is often inadequate, unnecessary, and expensive and neither immediately nor ultimately influences the clinical management of the patient. Unfortunately, the critics have been given much to criticize: disagreement between "experts" as to the cause of TMJ disorders and controversial and sometimes bizarre treatments, to name but two.

We sincerely hope that we have fulfilled the purpose of this book: to provide a critical, rational basis for the art and science of temporomandibular joint imaging in order to assist practitioners who must decide how to best serve the needs of their patients.

We are grateful for the opportunity to present our perspective.

Edwin L. Christiansen
Joseph R. Thompson

Ackowledgments

We are grateful to the following for their contributions, critiques, and assistance that helped to bring this opus to realization.

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Jennifer Shieck, TMJ Clinic Coordinator

Jim Simmons, R.T., Systems Photographer

Penny Thomas, Administrative Secretary, Section of Neuroradiology

Tissue Donors of the willed body program through the department of Anatomy, Loma Linda University; used to advance the art and science of TMJ imaging

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Chapter One

Historical Perspective

Physicians were the pioneers of temporomandibular joint (TMJ) roentgenography. In the early 1900s surgeons intending to operate on severely hypomobile jaws would use the new imaging modality to try to determine whether the hypomobility was caused by soft tissue or bony ankylosis. The earliest skiagrams *(from the Greek word for shadows), while not as useful as anticipated, sometimes proved helpful. Until TMJ tomography was introduced in 1939, investigations in TMJ imaging principally involved searching for the most effective transcranial projection. From 1939 through 1950 investigations into the use of conventional TMJ radiography declined, but several important papers dealing with transcranial projections were published. In the early to mid 1940s arthrography was shown to be effective for soft tissue disorders, but the technique did not flourish until medical and dental radiologists rediscovered its usefulness in the 1960s and 1970s. The first TMJ study using computed tomography (CT) in the United States was published in 1980, and interest in CT was sustained until 1985, after which it declined. The emergence of TMJ magnetic resonance imaging (MRI) paralleled the decline of CT. The first published reports of MRI studies of the temporomandibular joint appeared in 1984, although work in this area had begun as early as 1975. Direct arthroscopic examination of the TMJ, an alternative to indirect imaging, was developed in Japan in the mid to late 1970s.*

EARLY TMJ SURGERY (1856-1912)

Jaw ankylosis, a common occurrence before antibiotics were discovered, stimulated the development of TMJ surgery. The most frequent causes of ankylosis were trauma (50%) and scarlet fever (20%). Twenty-five percent of the patients were under 10 years of age.[4]

Nineteenth century Europeans were leaders in developing surgical techniques for restoring jaw function.[12,35] Baer[1] reasoned that the temporomandibular joint was the first joint in which arthroplasty was attempted because of the serious personal and clinical consequences of mandibular ankylosis.

From the perspective of modern dentistry and medicine, procedures currently thought to be new and unique actually are neither. Murphy[25] credits Verneuil[43] with being the first to resect ankylosed temporomandibular joints and place a portion of the capsule between the mandibular and temporal bones. According to Murphy, late in the nineteenth century Helferich pioneered the surgical technique of placing a flap of temporal muscle and fibrous tissue between the separated ends of ankylosed mandibular joints. Animal tissues, such as pig bladder, were used in TMJ arthroplasty.[1] Many TMJ surgical procedures of the late 1800s and early 1900s, including autogenous tissue repairs, were similar to those used today.[21,22]

Konrad Roentgen's discovery of x-rays in 1895 opened the door to unprecedented exploitation of a new technology for medical diagnosis. Roentgenographs of the temporomandibular joint began appearing in the early 1900s. Blair[1] makes the earliest reference to TMJ radiograms in discussing a case that was reported to the St. Louis Medical Society in 1910.

Roentgenographs weren't always helpful in demonstrating ankylosis or the side or sides of injury. Usually one joint was disordered, but occasionally both were involved, and making a correct diagnosis was complicated by inadequate radiographs. Murphy[26] complained that "the skiagrams of the temporomandibular joint do not shed much light upon the nature and extent of an injury to the joint." Clearly, advances in TMJ surgery demanded the advancement of TMJ radiographic techniques.[24-27]

RADIOLOGIC REFINEMENTS

Phase 1 (1910-1938): Transcranial Plain Film Projections

A review of the literature shows that TMJ radiography evolved in a cyclical fashion. Three distinct phases can be identified over a period of more than 70 years. The first phase, lasting approximately 30 years, was characterized by relatively intense activity in transcranial (including stereoscopic) TMJ radiography, principally by medical radiologists.

Just as it had been the stimulus for TMJ surgery, condylar ankylosis was also the catalyst that motivated medical radiologists to improve their previously unimpressive and inadequate techniques.[4,8] Kern[15a] developed a technique for making stereoscopic views of the head. He recommended that dental surgeons use such views for "impacted molars and arthritic changes in the mandibular joints."

Bishop[3] provided an important perspective on early TMJ radiography: "(TMJ radiograms) are . . . uncomplimentary to the roentgenologist (because) . . . they are conspicuous by their absence or unconvincing by their presence." The technique Bishop described involved stereoscopic lateral transcranial projections. The first exposure was made +30 degrees to the transverse plane. Bishop closed his paper by calling for improved image quality. Convinced that few possessed a simple, satisfactory technique for mandibular roentgenography, Sproull[39] used a +20-degree angled sinus board to project TMJ images, a technique that he said required no "great exercise of memory."

As the techniques of TMJ radiography were refined and the quality of TMJ radiographs improved, a broader interest in TMJ radiography developed, particularly on the part of dentists. Lindblom devised a technique for registering the position of the mandibular condyle within the glenoid fossa to obtain accurate transcranial radiographs.[16] Essentially this was the beginning of what are called corrected TMJ radiographs; the technique of directing the central x-ray beam along a path consistent with the morphology of certain joint structures, usually the condylar long axis. Lindblom preferred the path of the condylar axis, but Higley[11] used the summit of the articular eminence and Maves[20] the glenoid fossa for their respective anatomic landmarks for *corrected* TMJ radiographs. Although these radiographic techniques were corrected, they were not individualized because the settings were based on averages obtained from the study of large numbers of human skulls. Reisner, McQueen, and Gillis[7,18,33] carried out conceptually similar investigations.

Higley designed a rather precise cephalostat that held the head in a 20-degree rotation with 8 degrees of lateral tipping.[11] Maves apparently had a cephalostat that he intended to market to dentists, and he gave notice of intent.[20] In his paper Maves also makes an interesting reference to the radiographic documentation of condylar position before and after placing dental occlusal splints. After nearly 50 years this concept is still applied to TMJ therapy.[41]

Phase 2 (1939-1970): Tomography, Arthrography, Videofluoroscopy

Phase two in the development of TMJ radiography also lasted approximately 30 years. In terms of publications it was characterized by diminished general interest in the temporomandibular joint. Nonetheless, several important studies appeared during this time. Petrilli, a radiologist, and Gurley, a dentist, were the first to make tomograms of the temporomandibular joint.[32] The quality of these linear tomograms seemed remarkable compared to plain films. Many of these early papers were laced with personal opinions and not-so-timid declarations of superiority. Petrilli and Gurley spoiled Maves' announcement of his precise radiographic device by declaring, "Perhaps Dr. Maves does not know it, but we have it here."

World War II did not halt the investigation and advancement in TMJ imaging. Zimmer[44] made the earliest attempts at TMJ arthrography, but these were largely unsuccessful because he found the procedure too difficult. The pioneering arthrographic research of Norgaard[30] in Copenhagen was advanced for its time, and it proved for the first time that the position and general condition of the articular disk could be determined from the shadow of the disk within the envelope of contrast medium.

Unfortunately, Norgaard's work attracted little attention outside of Scandinavia, and more than 20 years passed before TMJ arthrography was rediscovered.[5,6,19,40] Norgaard waited a long time before the significance of his work was recognized. The Farrar-Norgaard Society, an organization of dentists and physicians from many countries representing a fusion of clinical and radiologic expertise, is conamed to honor his pioneering work.

At the 1948 meeting of the American Dental Association, Updegrave outlined his improved technique for transcranial TMJ projections[42] and made specific recommendations for advancing the quality, safety, and reproducibility of TMJ transcranial radiograms. One of his chief purposes was to introduce a technique that could be easily adopted by dentists using ordinary dental x-ray equipment.

This was an important step toward greater involvement of dentists in joint imaging, since up to this time TMJ radiography was chiefly the domain of medical radiologists. However, Updegrave's technique (using a +15-degree angled board) did not differ markedly from those of Kern, Bishop, or Sproull.[3,15a,39]

Over the next 20 years laminagraphic,[34] fluoroscopic,[2] and cineradiographic[17] TMJ studies were published, but radiographic research did not increase significantly until the 1970s.

Phase 3 (1971-1990): Revival, Research (CT, MRI, Arthroscopy)

Almost simultaneously in many parts of the world there developed a resurgence of interest and activity in radiographic modalities that could be applied to the temporomandibular joint, most particularly in arthrography. Judging from the literature, this third phase of growth has been the most intense and geographically diverse in the history of TMJ imaging. The 1970s were especially important, because during this time the groundwork was laid for the application and eventual acceptance of computed tomography and magnetic resonance imaging.

This exploration did not follow a direct route. Many modalities were explored, including cineradiography,[38] magnification radiography,[28] xeroradiography,[13,29] ultrasound,[14] bone scanning,[9] and three-dimensional CT reconstructions of the temporomandibular joint.[36] However, these techniques were not widely accepted.

The first reported study of TMJ computed tomography in the United States was done by Suarez and others in 1980. This work gave examples of different joint conditions and presented correlated autopsy tissue sections to support the radiographic findings. Beginning in 1981 the number of TMJ CT papers nearly doubled each year through 1985, after which they declined sharply because of the emergence of magnetic resonance imaging.

Although most of the clinical TMJ CT studies originated in the United States, investigations were underway in Italy, West Germany, the Netherlands, Egypt, Israel, Scandinavia, and the People's Republic of China. With few exceptions CT studies of the temporomandibular joint focused on the articular disk. Radiologists seemed preoccupied with discovering and rediscovering the articular disk, which did little to advance the overall knowledge of joint disorders, in our opinion. As research progressed, it became apparent that computed tomography had some limitations in visualizing the disk. As is often the case with new techniques and modalities, imaging applications had surged ahead of clinical practice.

The early published reports of MRI investigations of the temporomandibular joint appeared in 1984 and 1985.[10,15,37] Magnetic resonance imaging has shown great potential as a noninvasive imaging alternative, and medical and dental radiologists are generally optimistic about future applications. Caution is needed, however, because basic research must be conducted into the MRI signal characteristics of normal and abnormal joint tissues and the imaging accuracies of various systems and pulsing sequences must be established. Research projects in progress should more clearly define the role of MRI in the continuum of imaging choices that face medical and dental radiologists.

The development of TMJ arthroscopy paralleled that of computed tomography and magnetic resonance imaging.[23,31] For arthroscopy the question awaiting an answer is, what will it contribute to TMJ diagnosis compared to conventional and advanced imaging modalities?

Judging by the number of publications, a fourth phase of TMJ imaging is beginning: one of diminishing general interest. We believe this is the result of the gap that has developed between the ability to image, describe, and diagnose TMJ disorders and the ability to treat them.

The roles of clinical management and TMJ radiology now appear to be reversed from what they were 70 years ago. Diagnostic imaging technology is developing rapidly and is ahead (hopefully only temporarily) not only of surgery but also of dentistry's ability to effectively manage many TMJ disorders. Consequently, the widespread enthusiasm for TMJ imaging appears to be waning. Judging from the heated arguments expressed at recent national dental meetings, dentistry is in an unfortunate and uncomfortable credibility morass as regards the temporomandibular joint. But the future presents a challenge to those committed to the scientific unraveling of the complexities of this joint.

Currently the greatest research and clinical opportunities lie in the coherent application of advanced imaging modalities to the basic investigation of TMJ disorders. Regrettably, because of the present confusion about TMJ pathology and patient management, skeptics within dentistry may pose the greatest obstruction to such efforts.

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Chapter Two

Temporomandibular Joint Anatomy

Embryologic development of the temporomandibular joint usually begins at 8 or 9 weeks of gestation. Formation of the joint elements is essentially completed between 21 weeks of gestation and term. Ossification of the condyle lags behind that of the articular eminence and may not be completed until 20 years of age. Incomplete ossification may give the false radiographic impression of degenerative change. The mandible is suspended from the skull base by the sphenomandibular and stylomandibular ligaments. The ginglymoarthrodial temporomandibular joint is unlike any other joint in the body, moving by rotation and gliding. The principal mandibular elevator muscles are the temporalis, the masseter, and the medial pterygoid. The inferior and superior bellies of the lateral pterygoid muscles function independently; the superior belly is active during jaw closing, and the inferior belly assists jaw opening. The digastric, mylohyoid, and geniohyoid muscles are accessory masticatory muscles that aid early jaw opening. There are independent superior and inferior joint spaces that are completely separated by the articular disk. The temporomandibular ligament makes up the lateral wall of the joint capsule, which is well organized, in contrast to the medial capsular wall. In the normal adult joint the transverse condylar dimension is greater for men (19.6 mm) than for women (17.7 mm). The anteroposterior condylar dimension is approximately half that of the transverse dimension. Transverse condylar shapes are ellipsoid (40%), concavoconvex (40%), or ovoid (20%). The articular disk attaches firmly to the condylar poles by collateral ligaments. The disk is thickest in its posterior band (3 mm) and thinnest in its intermediate zone (1.5 mm); it is 2.5 mm thick in the anterior band. Posterior to the disk the diskal fibrocartilage merges with the bilaminar zone, the superior lamina of which contains elastin. Normal joints function silently. The joint space anterosuperior to the condyle averages 1.5 to 2 mm and is consistent across the breadth of the condyle. Medial to the condyle the joint space is slightly more variable, ranging from 2.7 to 3.4 mm. At birth the slope of the articular eminence is nearly flat, but it increases with age, averaging approximately 60 degrees in adults. Innervation of the joint is provided by branches of the masseteric, auriculotemporal, temporal, and posterior deep temporal nerves. Vascularization is provided by the superficial and deep temporal branches of the external carotid artery.

EMBRYOLOGY

The independent condylar and glenoid blastemata appear in the eighth or ninth week of gestation.[3,4] Development of the condyle leads to development of the glenoid fossa and articular eminence (Figure 2-1). The joint cavities, articular disk, synovial tissues, and secondary cartilage develop between the tenth and seventeenth weeks of gestation (Figure 2-2).

Completion of the joint elements occurs between the twenty-first week and full term. The normal biconcave shape of the articular disk appears at the twelfth week and increases in size until birth[71] (Figure 2-3). Van der Linden and others[69] and Furstman[22] consider the seventh through twelfth weeks of gestation to be the most critical for the development of joint anomalies.[5]

Because symptoms associated with temporomandibular disorders include tinnitus, fullness, and subjective hearing loss,[9] some investigators believe that these otic symptoms

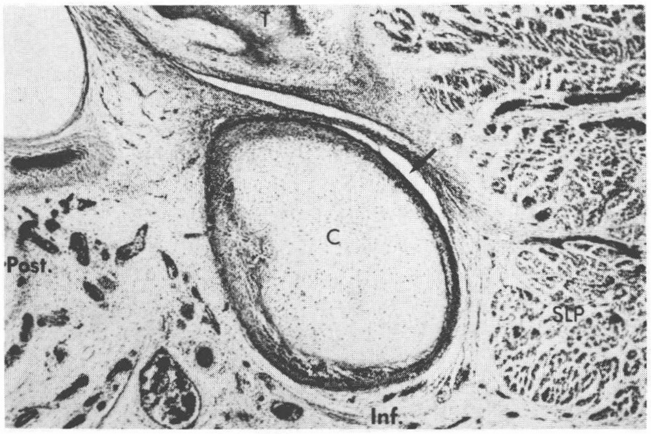

Figure 2-1. Sagittal section of embryonal TMJ of 67 mm crown to rump (CR) human fetus showing temporal (*T*) and more organized condylar (*C*) blastemata. Note inferior joint cavity (*arrow*) and superior belly of lateral pterygoid muscle (*SLP*).
(Photograph courtesy of Harold Perry, DDS, PhD, Northwestern University, Chicago, IL.)

Figure 2-2. Sagittal section of TMJ from 80 mm human fetus CR showing approximation of condylar (*C*) and temporal (*T*) joint portions. Presumptive disk tissue (*arrow*) is condensed and cellular. Connection between disk and malleus (*M*) (Pinto's ligament) (*arrowhead*) is more fibrous.
(Photograph courtesy of Harold Perry, DDS, PhD, Northwestern University, Chicago, IL.)

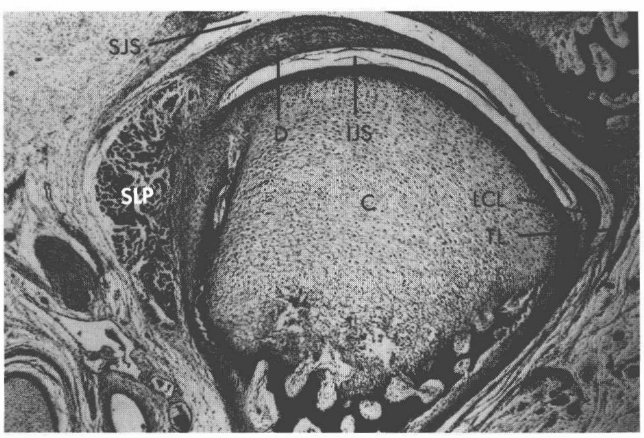

Figure 2-3. Coronal section of TMJ from 112 mm human fetus CR showing advancing differentiation of superior head of lateral pterygoid muscle (*SLP*), condyle (*C*), superior joint space (*SJS*), articular disk (*D*), inferior joint spaces (*IJS*), lateral collateral ligament (*LCL*), and temporomandibular ligament (*TL*).
(Photograph courtesy of Harold Perry, DDS, PhD, Northwestern University, Chicago, IL.)

may be related to a ligamentous connection between the disk, capsule, and the malleus.[32] Others dispute the extent of a ligamentous connection between the lateral pterygoid muscle, the articular disk, and the malleus, and what role such a ligament[57] might play in TMJ symptoms.[73]

Perry and his colleagues[56] traced Pinto's ligament in embryonal sections. They suggested that the lateral pterygoid muscle played a pivotal role in the histodifferentiation of the temporomandibular joint. Perry suggested that joint cavitation may depend on the mechanical interaction of the lateral pterygoid with the malleus by way of this ligamentous attachment.

Komori and others[39] described two ligaments that converged in the petrotympanic fissure (Huguier's canal). The ligaments varied greatly in size among autopsy specimens, and a connection to the malleus was not found in all cases. No evidence of visible movement was found in response to a given strain on the ligaments. The persistence of the ligament in adults prompted Komori to dispute Perry's hypothesis about the ligament's role in joint cavitation; Komori maintained that the ligament should atrophy and disappear if its sole function were to facilitate cavitation.

It has been shown that cavitation does not occur without movement, which can occur as local muscle-driven joint movement or as whole-body movements of the embryo.[67] Research on avian embryos paralyzed in ovo showed that although initial joint formation proceeds as normal, without embryonal movement, cavitation either fails or is very limited.[52] Without a demonstrated mechanical interaction between the lateral pterygoid muscle and the malleolus, it seems unlikely to us that cavitation of the temporomandibular joint depends on the local effects of the diskomalleolar ligament.

MANDIBULAR SUSPENSION, ARTICULATION, AND MOVEMENT

Suspension

The mandible is suspended from the skull base by the stylomandibular and sphenomandibular ligaments (Figure 2-4). When the jaw is closed, the stylomandibular ligament is lax, increasingly lax when the jaw is opened, and tense when the jaw is protruded.[30] During mouth opening the sphenomandibular ligament is believed to protect the neurovascular structures that pass through the mandibular foramen, particularly during protrusion.

Symptoms of atypical facial pain associated with calcification of the stylohyoid ligament (such calcification can be seen on radiographs) occur in about 26% of all normal children between 18 months and 15 years of age.[16] Interestingly, the stylohyoid ligament has been found to be calcified in 88% of children with Hurler's syndrome.[53]

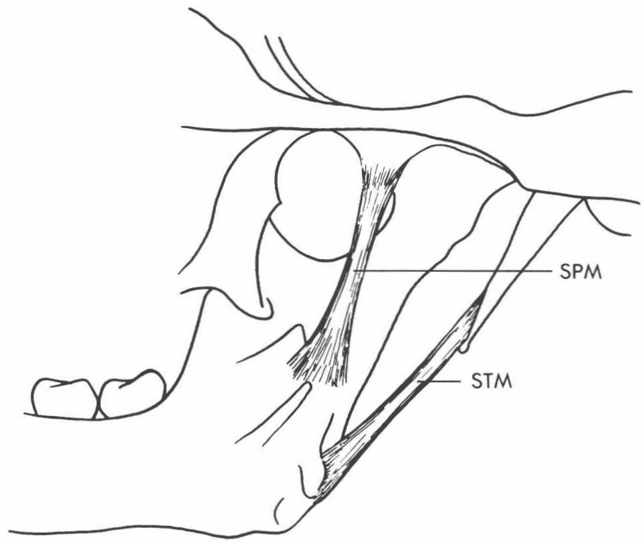

Figure 2-4. Artist's cutaway rendering of suspensory stylomandibular (*STM*) and sphenomandibular (*SPM*) ligaments viewed from medial aspect.

Mandibular Movement

The paired mandibular condyles articulate with the skull base by means of complex ginglymoarthrodial joints that move by hingelike rotation and/or sliding translation (Figure 2-5). Rotational condylar movements occur principally between the superior condylar surface and the inferior surface of the articular disk. Translational condylar movements normally occur between the superior surface of the disk and the articular eminence.

Mandibular movements in the sagittal and axial planes occur when the condyles rotate and translate during opening, protrusion, and laterotrusion. Lateral movement of the condyles is called Bennett movement.

Muscles of Mastication

During normal mandibular function, one or both condyles translate[19] (essentially silently) from their respective glenoid fossae to the summits of their articular eminentia. Translation beyond the summit of the articular eminence, a finding frequently seen on radiograms with maximum jaw opening, is not a function of mastication, but rather usually occurs when the mouth is opened more widely, as with yawning.

The principal muscles responsible for mandibular movements are the temporalis, masseter, and medial and lateral pterygoid muscles (Figure 2-6). The temporalis muscle, the chief mandibular elevator, originates from the whole of the temporal fossa and inserts broadly about the coronoid