The Third Scientific Meeting of the TMJ Association

Advancing Diagnostic Approaches for TMJ Diseases and Disorders

Hyatt Regency Bethesda
Bethesda, MD
May 6 and 7, 2004

Meeting Abstracts

Support for this research was provided from grant 1 R13 DE 015850-01 from the National Institute of Dental and Craniofacial Research to Dr. Allen W. Cowley, Jr., Ph.D., The TMJ Association
Advancing Diagnostic Approaches for TMJ Diseases and Disorders

TMJ DISEASES AND DISORDERS:
DIFFICULT BUT NOT IMPOSSIBLE TO SOLVE

Christian S. Stohler, D.M.D., Dr. Med. Dent., University of Maryland Dental School, Baltimore, MD

Over the past 70 years, temporomandibular joint (TMJ) diseases have been subject to shifts in conceptual understanding. Unable to account for disease patterns, the mismatch between case assignment and treatment need, and different interventions producing similar treatment outcomes (although at varying levels of risks to patients), emerging theories make persuasive arguments in support of alternative explanations that conceptualize TMJ diseases as complex conditions influenced by genetic susceptibility, environmental factors and risk-conferring behaviors.

Individuals are not equally susceptible to TMJ disease. Women in their reproductive years represent the majority of those seeking care and the extent to which genetic and epigenetic factors contribute to TMJ symptoms has given new directions to TMJ research. Different genotypes are believed to increase the susceptibility to a particular disease, course of the disease and/or treatment response, including the development of complications. Unique molecular individuality seems to cause amplified or attenuated stress-response traits in TMJ disease, including the launch of titrated sensory, affective, neuroendocrine and autonomic body messages. Hormonal milieus, interacting with the respective genotype, influence the subject-specific response trait and seem to explain the increased TMJ symptomology in the reproductive years of women.

However, limitations of current taxonomies, assessment protocols and technologies are an obstacle to scientific progress. TMJ diseases are often not limited to a single anatomical domain (e.g., face) and neither is the case assignment to a particular TMJ subset (e.g., muscle, disk, joint) stable over the time course of TMJ disease. In fact, painful involvement outside the topographical boundaries of the masticatory system occurs with greater frequency among those patients for whom therapeutic interventions are more likely unsuccessful than not. Furthermore, ill-defined symptoms, suggesting dysregulation of autonomic, endocrine, antinociceptive and immune systems, are not depicted as critical taxonomic features of TMJ disease. This raises the concern that the narrow scope of patients’ assessment, centering on the orofacial complex, paired with the inadequately captured individuality of the systemic pain-stress response, may miss attributes of TMJ disease that are critical for understanding of the pathogenesis and causation of this complex condition.

Clearly, we need to find better ways to capture patients’ states using validated biotechnologies, notably functional imaging of central and peripheral processes, that offer mechanistic insight into the pathogenesis of disease and/or provide understanding of regulatory processes at the systems’ level, including the unique genetic make-ups that amplify symptoms of TMJ disease. Functional imaging should also enable investigations of the under-researched topic of plasticity of central neural circuits and the extent to which altered signal channeling contribute to discrete aspects of TMJ symptoms and/or disease progression. Peripheral imaging should allow the distinction between normal variation and progressive TMJ disease, which not only provides improved case characterization but will protect patients from the many tests that lack validity due to insufficient specificity. Most of all, we need comprehensive investigations that no longer isolate peripheral from central processes because both the disease and the response to disease cannot be studied in isolation. In sum, there is no question that technological advances in functional imaging will broaden and deepen our understanding of TMJ disease.
CURRENT RADIOGRAPHIC APPROACHES FOR ASSESSMENT OF TMJ DISEASE PROGRESSION

Sigvard Kopp, D.D.S., Ph.D., Institute of Odontology at Karolinska Institutet, Sweden

Tissue destruction of the temporomandibular joint (TMJ) is an essential aspect of temporomandibular disorders. It is frequently of inflammatory origin. Inflammatory processes of local and systemic nature cause neural and connective tissue responses, which results in joint destruction. Repeated assessments of radiographic changes provide a measure of the rate of progression of bone tissue destruction. The radiographic signs used for diagnostic purpose or for follow-up should be related to the pathophysiology and activity of the disease. Involvement of the TMJ by systemic joint disease such as rheumatoid arthritis has been used to study radiographic signs of tissue destruction in relation to the inflammatory disease process. TMJ synovial fluid and blood have been analyzed for inflammatory markers/mediators.

Among the radiographic signs tested, erosion (a local area with decreased density of the cortical joint surface including or not including adjacent subcortical bone) and flattening (a flat bony contour deviating from the convex form due to bone tissue loss) of the articular components, as detected by tomography (conventional or computerized), can be correlated to the local inflammatory disease process. Erosion/bone loss is associated with anterior open bite and presence of IL-1 in the synovial fluid and plasma. High plasma level of TNF, which activates macrophages to release IL-1, is also associated with this radiographic sign. Activation of thrombocytes is an important part of joint inflammation and erosion of the TMJ is associated with high numbers of circulating thrombocytes. Progression of TMJ erosions/bone loss is correlated to raised blood levels of CRP, IL-1 and free 5-HT in plasma, while regression of erosions is associated with high levels of IL-1sRII. The correlation between pain and these radiographic changes is not significant.

The presence and progression/regression of the radiographic signs of erosion and flattening (bone tissue loss) that occur in the TMJ with systemic joint inflammation are related to the underlying disease process and are therefore suitable for assessment of progression of bone tissue destruction. However, radiography has to be combined with blood and synovial fluid analyses to estimate the current disease activity and to predict future destruction. The latter methods are also relevant to explain pain mechanisms.

REFERENCES

Five ways in which my research can be applied to the TMJ:
1. For determination of active TMJ inflammation and ongoing joint destruction.
2. To predict future destruction or progression of destruction.
3. Assessment of the development and extent of destruction.
4. To disclose the mechanisms behind pain in the TMJ.
5. To identify specific targets for treatment of TMJ pain and destruction.
Advancing Diagnostic Approaches for TMJ Diseases and Disorders

fMRI DURING JAW MOTION

James S. Hyde, Ph.D., David A. Soltsysik, Ph.D., and Vinai Roopchansingh, Ph.D.
Department of Biophysics, Medical College of Wisconsin, Milwaukee, WI

Few functional magnetic resonance imaging (fMRI) studies that involve muscles of the head, including jaw, tongue, face, and eye, have been carried out because of technical difficulties that include i) movement of the brain in laboratory coordinates that is correlated with muscle movement and ii) changes in the homogeneity of the static magnetic field in the brain because of modulation of tissue-susceptibility effects when muscle contraction occurs. Two adverse effects can arise from time-dependent susceptibility effects: anatomic distortion in the images and decrease of fMRI signal intensity. Recent progress, much of it from our laboratory, is providing solutions to these problems. These technical advances include half k-space echo-planar imaging (EPI) (1), pulse-sequence embedded acquisition of field homogeneity for every EPI image (2), and improved shimming of the static magnetic field. FMRI during speech has been demonstrated (3). Here, we present fMRI results in normal controls during the chewing of gum. We intend to extend this study to subjects with temporomandibular jaw disorder (TMD).

TMD may result from chronic pain caused by a disorder of the central pain regulatory system (4). Several studies have suggested that TMD subjects are more sensitive to experimental pain than pain-free individuals (5). A recent fMRI study has shown that subjects with high sensitivity to pain show greater magnitudes of activation in the anterior cingulate cortex, the primary somatosensory cortex, and the prefrontal cortex (6). We hypothesize that our recent technical advances can be used to examine the hemodynamic activation of TMD subjects, in both motor and pain areas, undergoing mastication. Even if such tasks result in no perceived pain, it is possible that areas of the brain known to activate during painful stimuli will still show activation, indicating subconscious presence of pain.

Use of a galvanic skin response (GSR) reference waveform was shown by the Helmstetter group (7) to reveal activation in the amygdala involving a painful stimulus whereas a generic stimulus-based waveform failed to show any such activation. A PET study applying a sustained pain stimulus to the masseter muscles in the jaw found activations of the μ-opioid receptor system in several areas of the brain, including the ipsilateral amygdala (8). Such pain is likely to be related to that experienced by TMD subjects. Both GSR and stimulus-based reference waveforms will be used in future studies.

REFERENCES

3D X-RAY/PET IMAGING APPROACHES AND USES IN NEUROVASCULAR DISEASES

Kieran Murphy, M.D., Johns Hopkins Hospital, Baltimore, MD

Static and fluoroscopic imaging of the temporomandibular joint can be performed with conventional ultrasound, conventional X-ray, fluoroscopy X-ray, CT, CT-fluoroscopy, MRI, MRI fluoroscopy. All of these have pluses and minuses. Of particular interest at the present time is the rapid development of multi-detected CT. Unlike traditional CT scanners which have one beam detected by one series of x-ray detections, the latest generation has between four and 32 detectors. These rotate at between .5 and .4 seconds per rotation and thus can give us between 32 and 80 slices a second. High-speed fluoroscopic imaging is possible up to 39 frames a second using CT fluoroscopy. Larger arrays of detectors have been designed. Currently, the largest is 256. This enables us to get wonderful 3D fluoroscopy definition of the entire temporomandibular joint, mandible and skull base. When it is stationary it functions as a flat panel detector. It does not, however, allow us currently to visualize the meniscus or the cartilaginous structures of ligaments of the temporomandibular joint. Clearly these machines will provide us with new diagnostic and therapeutic opportunities. 3D rotational DSA at 1024x 1024 matrix is now capable of a hybrid form of tomography and bone definition. Flat panel detector rotational DSA will further improve this and may give us imaging comparable to old-fashioned X-ray tomography.

1. This work will be applied to the study of neurovascular disease.
2. This work will improve volumetric TMJ imaging.
3. This work will focus on the development of techniques that are available in all hospitals in all economic environments.

Disclosure: Research support from Toshiba for 3D X-ray imaging.
Advancing Diagnostic Approaches for TMJ Diseases and Disorders

**Evolving Techniques for the Investigation of Muscle Bioenergetics and Oxygenation**

Russell S. Richardson, Ph.D., University of California San Diego, La Jolla, CA

Magnetic resonance imaging (MRI) and spectroscopy (MRS) are both powerful non-invasive methodologies and, as such, offer great potential to investigate both human biochemistry, human physiology and ultimately contribute significantly to the field of muscle physiology, medicine and potentially TMJ. Consequently there has been much effort devoted to fostering the evolution of these methodologies into distinct and applicable techniques. Here we will highlight several MRI and MRS techniques to assess human biochemistry and physiology that ultimately may provide useful clinical assessments and diagnoses of various muscular and cardiovascular pathologies. Specifically, the evolving techniques that will be discussed are: 1) \(^1\)H MRS of myoglobin to assess intracellular PO\(_2\), 2) \(^31\)P MRS to assess metabolic capacity, and 3) the combination of \(^31\)P chemical shift imaging (CSI) to assess local metabolic demand (VO\(_2\)) with arterial spin labeling (ASL) to assess local perfusion (Q) in an effort to characterize the elusive spatial matching of skeletal muscle (Q/VO\(_2\)).

**Applications of this work to TMJ:**

The muscles that control the function of the jaw are skeletal muscles and their function is much like more commonly studied locomotor muscles, therefore the following would be useful in relation to TMJ:

1. As O\(_2\) is essential for life and normal physiological function, the noninvasive MRS assessment of intracellular PO\(_2\) offers a unique view of muscle function and this can easily be applied to muscles that control jaw function.
2. Muscle metabolism noninvasively studied by \(^31\)P MRS provides insight into normal function in muscles both at rest and during work and can easily be applied to the muscles that control the jaw.
3. Muscle blood flow assessed noninvasively by ASL provides extremely high resolution mapping of perfusion in muscle, when at work or at rest, and can provide useful insight into normal and abnormal perfusion in human jaw muscles.
4. The accurate combination or matching of blood flow and metabolism in muscle during work is essential for human function. The noninvasive assessment of this process with ASL and \(^31\)P CSI affords the opportunity to examine this process and can easily be applied to the muscles that control the jaw.
HIGH-RESOLUTION ULTRASONOGRAPHY OF THE TMJ JOINT-SONOGRAPHY VERSUS MAGNETIC RESONANCE IMAGING

Rudiger Emshoff, M.D., D.M.D., University of Innsbruck, Austria

Sonography enables dynamic visualization of the soft-tissue structures of the temporomandibular joint (TMJ). Although some reports about the use of sonography in the diagnosis of disc displacements have been published [1-4], little attention has been directed at differences that occur when disc positions are evaluated separately at closed- and maximum-mouth opening position. The purpose of this study was to describe the technique of high-resolution ultrasonography (HR-US) evaluation of an internal derangement and to discuss the reliability of the sonographic findings.

The sonographic reports of 166 patients aged 13-78 years who had a prospective clinical diagnosis of TMJ internal derangement were correlated with magnetic resonance imaging results. Among TMJ positions diagnosed with high-resolution ultrasonography (HR-US) as disc displacement, MR imaging showed 133 disc displacements at closed-mouth position (PPV, 89%) and 70 disc displacements at maximum-mouth opening position (PPV, 84%). Of the TMJ positions with a HR-US diagnosis of normal disc position, 41 had disc displacement at closed-mouth position (NPV, 66%), and 37 at maximum-mouth opening position (NPV, 80%). Disc position of the TMJ was correctly diagnosed at HR-US interpretations in 214 (79%) of the 271 closed-mouth positions, and in 221 (82%) of the 271 maximum-mouth opening positions.

Sonography, despite its limitations, may provide valuable information about disc displacement of the TMJ.

REFERENCES

Ways in which research in TMJ ultrasonography could be applied to the management of TMJ disorders:

1. Diagnosis of soft tissue lesions in TMJ trauma patients
2. Diagnoses of internal derangement and effusion in TMJ pain and dysfunction patients
3. Evaluating TMJ-related effects of specific therapeutic interventions
4. Monitoring of TMJ disorder patients
5. Screening for TMJ internal derangements
WHY LOOK IN THE BRAIN FOR ANSWERS TO TMJ PAIN?

Joel D. Greenspan, Ph.D., University of Maryland, Baltimore, MD

TMD pain is typically considered a consequence of tissue injury of the TMJ or surrounding tissues. While this is certainly a factor, there is increasing evidence that a component of TMD pain, and several other chronic pain syndromes, can be ascribed to abnormal function of the nociceptive processing regions within the central nervous system (CNS).

This presentation will review the scientific evidence that abnormal CNS processing of nociceptive input can contribute to chronic pain conditions, including that of TMD. The fact that TMD sufferers exhibit other chronic pain conditions in greater proportion than the general population suggests more is involved than just a tissue-specific pathology. Animal neurophysiological studies have documented mechanisms of altered nociceptive processing in the spinal cord and brain stem, as a consequence of tissue injury and sustained nociceptive input. Such altered nociceptive processing can extend beyond the CNS representation of the injured body region, thus providing a substrate for abnormal pain sensitivity for body regions without peripheral pathology.

Recent work in our Research Center for Neuroendocrine Influences on Pain has demonstrated that TMD patients with principally masticatory myofascial pain demonstrate upregulated temporal integration of nociceptive input centrally, even outside of symptomatic regions of the body. This enhanced “temporal summation of pain” suggests changes in the CNS processing of nociceptive signals, potentially at the level of the spinal cord, brain stem, thalamus, or cerebral cortex. Also, TMD patients demonstrate more intense and longer lasting aftereffects following painful stimulation, suggesting an enhanced temporal perseveration of nociceptive signals centrally. Potentially related to this phenomenon is the fact that healthy women show significantly greater temporal summation of pain than healthy men. Thus, women would need less of a change in their CNS processing of nociceptive signals to reach a level that could sustain a chronic pain condition. This sex difference could explain the greater prevalence of TMD among women, and in particular, the greater pain complaint associated with TMD.

REFERENCES

Applicability to the study of TMD:
1. Pain assessment protocol that can identify “central sensitization” state.
2. Such assessment has implications for underlying mechanisms of chronic pain.
3. Such assessment has implications for choice of treatment options.
4. Could be a useful tool to predict specific treatment outcomes.
NEURAL CORRELATES OF THE
SUBJECTIVE EXPERIENCE OF PAIN

Robert C. Coghill, Ph.D., Wake Forest University School of Medicine, Winston-Salem, NC

The conscious experience of a sensory event is derived from a complex convolution of afferent information arising from peripheral sensory transducers with cognitive information about the present context, past history, and future implications of the stimulus. Accordingly, the experience of a specific stimulus is unique to a given individual. In the case of pain, interindividual differences in subjective reports arising from similar stimuli are pronounced, and have significant clinical implications. In order to better understand the relationship between interindividual differences in pain sensitivity and psychophysical responses, 17 healthy volunteers (8 women, 9 men) participated in a combined psychophysical and functional MRI (fMRI) investigation of thermal pain. Subjects' visual analog scale (VAS) ratings of pain intensity arising from the same 49°C stimulus varied widely (range 1.05/10 to 8.90/10) across individuals. Highly sensitive individuals exhibited more frequent and more robust pain-induced activation of the primary somatosensory cortex, anterior cingulate cortex, and prefrontal cortex than did insensitive individuals. All three of these brain regions play important roles in the processing of pain. Taken together, these results provide a compelling neurophysiological substrate for the differing subjective experiences of pain produced by an identical sensory stimulus. Furthermore, by identifying objective neural correlates of subjective differences, these findings validate the utility of introspection and subjective reporting as a means of communicating a first-person experience.

REFERENCES

Applications to TMJ:
1. Provide the healthcare practitioner with increased confidence in subjective ratings of pain.
2. Provide the patient with increased confidence that normal people feel similar injuries very differently.
INTERINDIVIDUAL VARIATIONS IN THE NEUROCHEMICAL REGULATION OF TEMPOROMANDIBULAR PAIN

University of Michigan and University of Maryland

One of the challenges facing the rapidly evolving field of neurobiology is the systematic integration of typically reductionistic genetic, molecular and biochemical investigations with those afforded by the broader exploration of human brain functional responses. We have chosen a model of deep muscular mandibular pain as an example of a stimulus of critical significance to all organisms, with both physical and emotional valences, the study of which requires the dynamic interfacing of basic and clinical sciences. It is also a model of direct relevance to the study of the pathophysiology of TMD. The utilization of positron emission tomography (PET) allows for this interface by directly examining the response of specific neurochemical circuits in the response and regulation of the experience of pain.

Our studies have shown that a pain stressor engages neurotransmitters involved in the assessment of salience (e.g., dopaminergic), as well as inhibitory systems (e.g., opioid) that modulate these responses. The latter system suppresses sensory and affective qualities of pain, as well as the negative internal affective state induced by this stimulus, in distinct neuroanatomical circuits. Subsequent studies have also demonstrated that it is further influenced by gender, circulating levels of gonadal steroids, and common genetic polymorphisms. These examples demonstrate the complexity of the regulatory mechanisms engaged during sustained pain, as well as the factors that contribute to the interindividual variations in responses to temporomandibular pain. It also shows the effectiveness of neurochemical PET as a tool to integrate psychophysical, genetic, endocrine and neurochemical function to achieve a mechanistic, systems levels understanding of human physiological and pathophysiological processes such as TMD.

REFERENCES

Application of our research to TMJ:
1. Neurochemical systems and circuitry engaged during TM pain.
2. Brain regulatory factors involved in responses to TM pain.
3. Interindividual variations in the capacity to suppress TM pain.
5. Objective and subjective responses to TM pain.
TARGETED NANOPARTICLE EMULSIONS FOR MOLECULAR IMAGING AND DRUG DELIVERY

Samuel A. Wickline, M.D., Washington University School of Medicine, St. Louis, MO

Unlike blood pool imaging agents, site-targeted contrast agents are intended to enhance a specific pathological tissue that otherwise might be difficult to distinguish from surrounding normal tissue. Targeted liquid perfluorocarbon nanoparticles were developed initially as molecular imaging agents for ultrasound applications (1995). These nanoparticles also can be loaded with large payloads of other imaging agents such as paramagnetic or supraparamagnetic metals, fluorophores, or radionuclides to enable detection with standard imaging equipment. Indeed, liquid perfluorocarbon nanoparticles were the first example of molecular targeting agents useful for MRI of thrombus by incorporating antibody ligands directed against cross-linked fibrin, and have been shown recently to be useful for characterizing experimental thrombus in vivo and human unstable carotid plaques ex vivo. Liquid perfluorocarbon nanoparticle emulsions targeted to $\alpha_v\beta_3$ also permit robust tumor and atherosclerosis imaging after only 1 hour in the circulation, with specific uptake demonstrated by in vivo competition experiments. For paramagnetic perfluorocarbon nanoparticles, particle based relaxivities (or unit signal strength) are the highest reported to date in the literature, exceeding that of clinically available MRI paramagnetic contrast agents by nearly 1,000,000X or more. We have estimated that such agents will provide sufficient signal to be detectable at local concentrations in the picomolar range, which had been thought possible only with nuclear agents.

These agents also are useful for delivery drugs (e.g., doxorubicin, paclitaxel, fumagillin) after binding to cellular epitopes by a mechanism called “contact facilitated drug delivery.” This results in part from enhanced lipid exchange with the lipid membranes of the targeted cells, which is facilitated by the binding of the particle to the cell. We have shown recently that ultrasound energy applied at clinical frequencies and strengths also markedly augments content delivery to targeted cells, suggesting additional mechanisms for effecting highly specific and local pharmaceutical efficacy while limiting systemic toxicity. Such agents may ultimately serve as both imaging constructs and as depot drug delivery systems with prolonged release kinetics and long persistence at the site. The significance of these efforts for TMJ disease similarly relates to early diagnosis of specific molecular events causative for the disease process, site-targeted therapeutics, long term follow-up of disease evolution, and rational adjustments of therapy and dosing with image-based monitoring.

REFERENCES


Disclosure: Research support from Philips Medical Systems, Inc.; Kereos, Inc.: equity and board membership
POTENTIAL OF MRI AND PET IN EARLY AND PRESYMPTOMATIC CHARACTERIZATION OF TMJ DISEASE

Thomas F. Budinger, M.D., Ph.D., University of California, Berkeley, CA

Introduction
Non-invasive imaging methods for study of the etiology, disease progression and treatment efficacy in the temporomandibular joint (TMJ) disease include x-ray CT, MRI, PET and ultrasound. Of these, this paper will focus on MRI and PET because these methods have specific attributes relevant to TMJ pathology and surrounding muscle pathology, respectively. Though this paper is meant to show the potential of modern imaging methods, a specific focus on the study of the lateral pterygoid muscle is presented in this abstract.

The importance of PET combined with MRI is based on reported findings that clinical pain in and of itself is not reliable for predicting the presence of TMJ osteoarthritis and joint effusion (Emshoff, et al. Int. J. Oral Maxillofac. Surg. 31, 2002). In addition, MRI has detected pathological changes in the lateral pterygoid muscle in 75% of patients with anterior disk displacement with non-reduction of the TMJ (Yang, et al. Cranio, 20, 2002). These and our own pilot studies have led to the hypothesis that the metabolic activity of the lateral pterygoid muscle as measured by transport of fluorodeoxyglucose using positron emission tomography might aid in understanding the etiology and give early evidence of abnormal stress on this muscle.

Methods
Bone blood flow is studied by F-18 PET, anatomy by x-ray CT, soft tissue characteristics and joint effusions by MRI and muscle metabolism by F-18 fluorodeoxyglucose PET or magnetic resonance spectroscopy. Before embarking on a study of TMJ disease using these four or five methods, we examined the scans of cancer patients with FDG to learn if there was increased uptake of FDG in the joint areas. FDG uptake can indicate inflammation or increased metabolism associated with increase in muscle work. Though many patients have been studied for heart and cancer with the incidental finding of lateral face uptake usually thought to be parotid or maxillary gland uptake, we searched our archives for suitable PET images to define the anatomical localization of the face uptake. Three cases of FDG-PET uptake in the face were analyzed for this presentation.

Results
In this pilot evaluation we noted an unusually high uptake in the region of the lateral pterygoid muscles bilaterally in one of the three subjects studied. We determined from other studies that an increase in muscle activity will result in an increase in FDG uptake even hours after the period of muscle stress.

Conclusion
Of four methods for evaluation of joint disease used by us, FDG-PET provides evidence of either inflammation of soft tissues or an increase in muscle activity at the time of the exam or even hours before the exam. The verification that the abnormally high uptake of FDG is related to TMJ disease symptoms is yet to be proved but PET might be an important modality in the characterization of TMJ disease and is potentially more sensitive to muscle stress and pathologies than MRI.
Advancing Diagnostic Approaches for TMJ Diseases and Disorders

ROLE OF MRI IN CLINICAL DIAGNOSIS OF THE TEMPOROMANDIBULAR JOINT

Tore A. Larheim D.D.S., Ph.D., University of Oslo, Oslo, Norway

MR imaging is today the most superior imaging modality for diagnosing TMJ disorders and diseases. With this diagnostic tool we may assess disc position and morphology, cortical bone and bone marrow condition, and joint fluid. The presentation will focus on disc disorders with normal bone and osteoarthritis. It is well known that disc displacement is rather common in asymptomatic volunteers, questioning the clinical implication of such displacement. However, recent research has demonstrated differences between asymptomatic volunteers and patients concerning type of TMJ disc displacement\(^1\). Differences between such groups concerning accompanying joint abnormalities such as joint effusion, have also been shown.\(^2,\,3\) Histological evidence of bone marrow abnormalities in the mandibular condyle is reported,\(^4\) and it is suggested that bone marrow alterations may occur either primarily or secondarily to osteoarthritis.\(^4,\,5\) Associations of TMJ pain with joint effusion and abnormal bone marrow in the condyle are published.\(^3,\,6,\,7\) Thus, research indicates that there may be subgroups of patients with more severe intra-articular pathology than those with disc displacement but no other abnormalities.

Surprisingly few longitudinal MRI studies of TMJ disc displacement have been reported. Preliminary results from an ongoing 10-15 year follow-up study of a Norwegian patient material will be discussed.

Inflammatory diseases of the TMJ such as rheumatoid arthritis, may have characteristic MRI manifestations, both without\(^8\) and with intravenous contrast enhancement.\(^9\) These manifestations will briefly be mentioned.

REFERENCES


Future MRI research:

- Further studies to confirm whether there are only certain types of disc displacement that can be associated with patient symptoms.
- Further research to elucidate the significance of accompanying joint abnormalities to disc displacement for patient symptoms.
- Longitudinal studies to follow the possible development of disc displacement into osteoarthritis and to elucidate whether accompanying joint abnormalities may be fluctuating in nature.
- Develop a classification system for joint severity, and study how such a grading system correlates with patient symptoms.
- Longitudinal studies of rheumatic TMJ disease.
TMD SYMPTOMS AND SPECIFICITY —
A LONGITUDINAL CLINICAL TMJ STUDY

Jos Dibbets, D.D.S., Ph.D., Philipps University, Marburg, Germany

Temporomandibular disorders or TMD’s are considered to be present when certain signs and or symptoms emerge. Diagnostic instruments for TMD are questionnaires, clinical examination and joint imaging. Attention has focused on improving screening procedures that lead to a correct diagnosis. Particularly, imaging techniques have experienced enormous improvement over the past years. For several diagnostic procedures, sensitivity and specificity criteria have been developed. The assumption underlying specificity tests is absence of TMD in absence of signs or symptoms. However, TMD is considered a chronic condition (Dworkin et al. 1991). The persistent character of TMD is further confirmed by our finding that a sagittal shorter midface in young adults was associated with TMD signs that had been registered some 14 years before (Dibbets and van der Weele 1996). Without further knowledge about past or future events of the TMJ it remains uncertain, therefore, if a person without signs and symptoms has TMD or not. The only possibility to test the validity of a negative diagnosis when no symptoms are present is a longitudinal database.

In 1970, a study was started in the Netherlands with the goal to document the development of TMD in a group of 172 children before, during, and after orthodontic treatment. The study was continued until 1990 and data of a standardized questionnaire, clinical examination and a variety of X-ray projections are available. This documentation allows the longitudinal analysis of signs and symptoms in individual persons over a period of 20 years.

It appears that in a single individual, absence of signs and symptoms, or even absence of roentgenographic criteria does not exclude the presence of these symptoms in an earlier or later part of life. Moreover, it seems that the majority of symptoms experienced in adulthood had a juvenile forerunner.

REFERENCES

Possible ways to improve research on TMJ:
1. Longitudinal studies on the presence and absence of TMD signs and symptoms, including imaging, are needed.
2. A longitudinal study in children, starting at age 8 years, could provide information as to when TMD emerges first. This information is vital to develop preventive TMD strategies.
3. The influence of TMD on facial growth deserves more attention.
Advancing Diagnostic Approaches for TMJ Diseases and Disorders

IMAGING TOOLS-LESSONS FROM THE KNEE JOINT

Carl S. Winalski, M.D., Brigham and Women’s Hospital, Boston, MA

The knee is an ideal joint for imaging investigations because of its size and ease of positioning. In fact, most clinical imaging research on joints has been performed on the knee. This presentation will review this research and the potential application of the techniques to the temporomandibular joint (TMJ).

A number of qualitative and quantitative methods have been devised for evaluation of bone, cartilage, menisci and ligaments. The introduction of technical advances in equipment, e.g. multidetector computed tomography (MDCT) and high field magnetic resonance (MR) systems (3 Tesla and greater) hold great potential for improved spatial resolution that may allow the knee MR techniques to be transferred to TMJ.

For the evaluation of bone, CT and MR imaging have complimentary roles. While CT visualizes the calcified structures (bone) with excellent detail, MR is very sensitive to changes in the bone marrow that reflect processes at the level of the overlying articular surface. Routine MR imaging protocols are able to reliably visualize focal cartilage defects within the knee and, following cartilage repair procedures, MR imaging is able to demonstrate the status of the repair tissue. Specialized MR techniques, in combination with image post-processing, have been devised to measure knee articular cartilage thickness and volumes as well as the glycosaminoglycan content of articular cartilage. With the addition of an intraarticular injection of contrast, MDCT can also be used to assess articular cartilage and the knee meniscus. Kinematic studies of knee motion with MR imaging is a relatively new field of research. Direct MR imaging of motion within an open magnet can be performed with active motion or with passive positioning of the joint with subsequent “motion” simulated by visualizing the series of images in a “cine loop”. While imaging with active motion is more physiologic, multiposition imaging can afford higher resolution images.

The new CT and MR methods have great potential in the investigation of TMJ disorders that is only limited by the ability to obtain images with adequate spatial resolution in a clinically useful time frame.

REFERENCES

2. Winalski CS, Gupta KB. Magnetic resonance imaging of focal articular cartilage lesions. Topics in Magnetic Resonance Imaging 2003;14:131-144

Continued on next page.
Five ways to apply the research to the TMJ:
1. Measurement of articular cartilage volume and thickness
2. MR assessment of glycosaminoglycan content of articular cartilage
3. Kinematic study of TMJ motion
4. Quantitative analysis of bone sclerosis
5. MDCT-arthrographic assessment of TMJ structures

Disclosure: Grant funding from Genzyme Biosurgery, Inc.
MECHANICAL ACTIONS OF DIFFERENT PARTITIONS OF MASTICORY MUSCLES

Arthur W. English, Ph.D., and Charles G. Widmer, Department of Cell Biology, Emory University School of Medicine, Atlanta, GA, and Department of Orthodontics, University of Florida, Gainesville, FL

The different muscles of mastication cooperate to produce movements about the temporomandibular joints. These movements are precisely regulated to control both the positions of the teeth in three dimensions and the forces applied to those teeth. They thus have significant components outside of the sagittal plane. Each of these muscles is highly partitioned and organized into multiple, anatomically distinct neuromuscular compartments. Using a six degrees of freedom force-moment sensor to study the mechanical actions produced by electrical activation of these compartments, we determined the torque vector that each produces about the ipsilateral temporomandibular joint. We found that different compartments produced torques whose directions were significantly different from one another. Activation of compartments together produced mechanical actions which were vector sums of the actions of the contributing compartments. By determining the mechanical characteristics of the compartments with the mandible placed at different positions, we were able to simulate the torque vectors produced by each compartment at different locations in the normal masticatory workspace. Based on these simulations, the nature of the mechanical actions of some compartments, especially their off-sagittal plane components, were found to be position-dependent. Using the same approach to study the mechanical actions produced during the elaboration of different cortically-evoked oral behaviors, we found convergence of torque fields toward zero at distinct parts of the workspace. We interpreted this point of convergence to be the equilibrium point in space that defines the behaviors. Using principal components analysis, we discovered that the timings of activation of different compartments are temporally grouped in different ways in different behaviors. These data are compatible with a model of masticatory muscle function that consists of multiple force-generating modules combined in different ways in the regulation of masticatory behaviors. Supported by DE11536 from the USPHS.
Advancing Diagnostic Approaches for TMJ Diseases and Disorders

TMJ MECHANICS (CONDYLE, CAPSULE, AND DISC)

Susan W. Herring, Ph.D., University of Washington, Seattle, WA

Direct measurements of TMJ tissue deformation still require animal experimentation. Most of the available data pertain to the mechanical strain on the bone surfaces around the joint. Both in primates and in pigs, such studies indicate that the joint is loaded in compression during chewing. However, bone is rarely the first joint tissue to show injury, instead being affected at later stages of degeneration, after damage to the collagenous tissues of the TMJ such as the disc or capsule. These soft tissues are fundamental for maintaining joint integrity during movement. Capsular ligaments guide or limit movement, while the intra-articular disc may also distribute joint loads. However, these tissues are difficult to visualize dynamically and not suitable for strain gage attachment, so in vivo deformations are unknown. Using pigs as the best nonprimate model for human TMJ function, we implanted differential variable reluctance transducers (DVRT, MicroStrain, VT) to measure linear strains of the lateral aspects of the jaw joint capsule (n=11) and disc (n=5). Devices were oriented roughly anteroposteriorly. In addition, radio-opaque markers were placed in the posterior capsular area and in the mandible and temporal bone (n=11). Cinefluorography was used to visualize the markers. During jaw movement the retrodiscal tissue echoed the movements of the mandible but on a smaller scale, indicating possible tethering to the temporal bone and deformation of the tissue rather than bodily movement. Passive manipulation in anesthetized animals indicated that opening, protrusion, and contralateral movements caused the lateral capsule to shorten and the disc to elongate. On the contrary, closing, retrusion and ipsilateral movements caused capsular lengthening and disc shortening. These findings are expected on anatomical grounds. During mastication, the capsule elongated during the power stroke, especially on the more retractive balancing side (15%±9) compared to the working side (9%±6). Surprisingly, disc strain during mastication was opposite to that expected. The disc elongated during jaw closure, more on the balancing (16%±1) than on the working side (8%±2). This anomalous behavior may reflect compressive loading, such that the disc elongates as a result of the Poisson effect rather than condylar movement. In summary, collagenous joint tissues undergo considerable strains, caused not only by movement but also by loading. Supported by PHS awards DE11236 and DE11962.

REFERENCES


Ways in which this research could be applied to TMJ:

1. Further data on TMJ function in the pig helps evaluate ways in which it is a good or not so good model for human function. For example, the pig TMJ was found to permit more posterior movement than does the human.
2. This work focuses attention on the fact that the disc is not an isolated element, but is attached to the joint capsule around its perimeter (including bony attachments). When the capsule is injured, the disc must inevitably be affected.
3. Collagenous tissues that deform 15% or more during normal function clearly are moving a lot and are probably liable to many traumas.
4. The deformations of the collagenous tissues raise questions about how the vasculature and nerve supply to the joint are maintained in a dynamic mechanical environment.
5. Perhaps more attention should be given to ways to strengthen or reinforce the capsule, since it is probably key to both bony movements and discal integrity.
MODELING OF TMJ FUNCTION USING MRI AND JAW TRACKING TECHNOLOGIES – MECHANICS

Luigi M. Gallo, P.D., University of Zurich, Switzerland

The study of jaw mechanics has evolved from the analysis of the traces of single condylar points to an accurate and compact description of mandibular motion relative to the skull, in which also forces and torques acting on the jaw are considered [1]. However, in order to further understand the biomechanical relationships within the TMJ and its biomechanics-related pathologies, the anatomical structures need to be coupled to mandibular kinematics and dynamics. This has been modeled in the past by either oversimplifying the structure of the TMJ or by applying idealized kinematics to anatomical data obtained from cadavers.

The development of osteoarthritis is likely to be related to the magnitude and frequency of stresses applied to joint cartilage. Animal models have shown that TMJ disc displacement or failure induce TMJ osteoarthritis, so that the in vivo dynamic analysis of disc deformation and loading appears to be of primary interest in the study of degenerative joint disease. For this purpose, we developed a combination of a software 3D-reconstruction of TMJ anatomy obtained by MRI with jaw motion tracked with 6 degrees-of-freedom [2]. This technique allows us to analyze dynamically the relationship between the articular surfaces, providing indirect insight into disc deformation during function and parafunction as well as TMJ loading.

Studies performed with this system on the variation of the joint space during mastication seem to indicate that both TMJs are loaded during chewing, the balancing joint more than the working one [3]. As a matter of fact, during chewing, the intraarticular distance was smaller for hard than for soft food, on closing than on opening, on the balancing than on the working side. This last finding was confirmed during static biting experiments, in which the condyle-fossa distance decreased more on the side contralateral to the bite force, depending on its magnitude.

Also studies on the dynamics of compression areas in the TMJ indicated that plowing forces can occur through the disc during functional movements (such as opening/closing, protrusion and laterotrusion), especially in mediolateral direction, due to stress-field translation [4]. These forces might contribute to cartilage wear and fatigue also because of the anisotropic material properties of the disc, which is weaker mediolaterally. Further data indicate that, in the majority of cases, the lateral area of the disc is more often exposed to a higher mechanical energy density than the medial one. This will be the object of a more intensive investigation using FEM analysis [5].

REFERENCES

This research a) provides a good didactical visualization of the movement of the TMJ condyles in the respective fossa; b) helps improve our understanding of the complexity of condylar and mandibular movements in general; c) gives detailed insight into TMJ biomechanics and can help in understanding the etiology of degenerative joint diseases, by yielding accurate data for laboratory experiments on cartilage; d) could also possibly provide clues on the origin of internal derangement; e) finally, it could help in identifying subjects prone to the development of craniomandibular disorders on the basis of their specific anatomies and kinem
ANATOMICALLY BASED MODELING OF THE HUMAN JAW AND FACE

van Essen, N.L.,1 Anderson, I.A.,1 Hunter, P.J,1 Clarke, R.D.,2 Pullan, A.J.1

1 Bioengineering Institute, The University of Auckland, Auckland, New Zealand
2 AgResearch, Hamilton, New Zealand

Introduction
The Bioengineering Institute, in conjunction with AgResearch [1] is developing a computational model of the human jaw, teeth and masticatory system. The initial purpose of this model is to simulate mastication and to calculate the forces on the teeth that are involved. Beyond this initial application, however, the model will be able to provide a basis for further research on jaw structure and function, with two particular areas of interest being the teeth and the temporomandibular joint.

Methods
An initial three dimensional finite element model of the masticatory system has been developed (fig. 1a). This model consists of anatomically realistic representations of the mandible, maxilla, zygomatic arch and temporal bones and the crowns of the teeth. All four pairs of muscles of mastication have been modeled (the masseter, temporalis, medial pterygoid and lateral pterygoid), as well as the suprahyoid muscles. This generic model was developed using a number of data sources including digitised drawings of an averaged skull and the visible human data [2].

Results
As a simple test of the model capabilities, the model’s mandible has been used in simple clenching simulations where the positions of the condyles and teeth were fixed, and forces were applied directly to regions of the mandible to simulate muscle forces (fig. 1b). Results from these simulations show realistic mandible deformation and reaction forces at the teeth [3]. Initial contraction simulations using two of the anatomical muscle models have also been undertaken, illustrating that the muscle models are capable of solving both passive and active contractions.

Discussion
To extend the simple clenching simulations to full mastication simulations, the anatomically realistic muscle models will be used and will be electrically activated to produce forces on the mandible. To improve accuracy in specific areas, separate more detailed models of the temporomandibular joint and some teeth will be created, which can be used in conjunction with the full jaw model. The model will ultimately allow the kinematics of the mandible to be studied and related to forces applied to the TMJ.

Fig 1. a) The full jaw model showing the bones, teeth and muscle geometry, b) the simple clenching simulation showing the initial and deformed mesh and the muscle force lines.

REFERENCES
1. AgResearch Ltd., www.agresearch.co.nz
MULTIFACTORIAL MODELING OF TEMPOROMANDIBULAR ANATOMY AND ORTHOPAEDIC RELATIONSHIPS IN NORMAL AND DISC DISPLACED JOINTS

Andrew Pullinger D.D.S. M.Sc., University of California Los Angeles, Los Angeles, CA

The UCLA multifactorial approach recognizes that both occlusion \textsuperscript{1,2} and TM joint organization \textsuperscript{3,4,5} can only be studied as a biological system using multifactorial models if meaningful prediction value is to be discerned. We assume that there has to be some relationship of structure to function, but that no variable in a system can operate in isolation. Hence the previous failure to generate useful prediction accuracy with mostly univariate testing, and thereby the clinical reaction and concerns \textsuperscript{6} about the conclusions of the 1996 NIH Conference.\textsuperscript{7} We believe that these multifactorial systems probably provide a protective mechanism whereby presence of an extreme range of a variable is absorbed without inducing abnormal adaptation demand on the system and hence the survival of the masticatory system. However this has a confounded study of isolated variables.

Differences in TM joint intracapsular osseous anatomic and orthopaedic organization (14 linear and angular measurements and 8 ratios in center section tomograms) were modeled using classification tree (validated with a 30% set aside sample) and stepwise logistic regression analyses in females with unilateral TMJ derangements and normals.

Normal TM joints were moderately well distinguished from pooled disc displacement (DD) joints with a specificity of 85.7% (sensitivity 67.9%) (32.6% likelihood, Cox and Snell $R^2$) with features and interactions that were not revealed in univariate analysis: typified by less extreme ranges of fossa size and shape, with a more centered condyle position. Normal joints that had non-concentric positions preserved an average fossa size and shape in contrast to the diseased joints that were more likely to combine non-concentric position with more extreme fossa shapes.

Tree analysis differentiated internal derangement joints from normals with sensitivity 70.2% and specificity 90.5% (37.0% $R^2$) for DD with reduction characterized by either a much wider and or shallow fossa, or by a moderately posterior condyle position in an average to deeper fossa; and sensitivity 66.7% and specificity 85.7% (28.8% $R^2$) for recent onset DD without reduction joints, characterized by either a very posterior condyle position or by a much deeper fossa when the condyle was concentric or anterior.

Direct comparison of DD with reduction vs. DD without reduction joints revealed differences with a 73% prediction accuracy (31.7% $R^2$) indicating that they are not necessarily part of a single disease progression continuum. DD without reduction joints had either deeper posterior fossa walls or average posterior wall length combined with a more open-wedge-shaped anterior joint space combined with a flatter articular eminence. In contrast, most disc displacement with reduction joints had shorter posterior fossa wall height combined with more equal or larger superior-to-anterior joint spaces.

REFERENCES


Continued on next page.
Advancing Diagnostic Approaches for TMJ Diseases and Disorders

1. Pullinger AG, Seligman DA, John MT, Harkins S. Multifactorial comparison of disk displacement with and without reduction to normals according to temporomandibular joint hard tissue anatomic relationships. *J Prosthet Dent* 2002; 87; 298-310.


Applications to TMD:

1. TM joint orthopaedic hard tissue organization can predict function with moderate accuracy, but more than one model is associated with each type of disc instability.

2. TMD has to be examined as dichotomous sub-diagnostic entities.

3. Although orthopaedic organization is significant, additional factors including articular and disc soft tissue and tissue typing qualities must be as or more important in the etiology of TMJ disc disorders.

4. It is conjectured that the orthopaedic organization may influence the degree of propagation of disc disorders.

5. The 9.5% to 14.3% false positive classification of normals with orthopaedic organization more characteristic of DD joints would be an interesting subgroup to follow for risk of future disc displacement.

6. Similarly, 35% of DD with reduction joints had the organization of the DD without reductions joints and should be followed for risk for symptom progression.