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**APLICAÇÕES DAS IMAGENS DE RESSONÂNCIA
MAGNÉTICA NO ESTUDO DAS DESORDENS
TEMPOROMANDIBULARES**

2019

SÉRGIO LUCIO PEREIRA DE CASTRO LOPES

**APLICAÇÕES DAS IMAGENS DE RESSONÂNCIA MAGNÉTICA NO
ESTUDO DESORDENS TEMPOROMANDIBULARES**

Tese apresentada ao Instituto de Ciência e Tecnologia, Universidade Estadual Paulista (Unesp), Campus de São José dos Campos, como parte dos requisitos para obtenção de título de LIVRE DOCENTE na disciplina de Radiologia, junto ao Departamento de Diagnóstico e Cirurgia.

São José dos Campos

2019

“ matéria é energia em estado de condensação e energia é matéria em estado radiante.”

Albert Einstein

DEDICATÓRIA

Aos meus queridos pais, Dirceu e Maria Luiza, pelo amor, exemplos de vida, ensinamentos. Sou infinitamente grato a vocês e imensamente feliz por tê-los como meus pais.

Aos meus irmãos Lino e Luis pela amizade e incentivo.

AGRADECIMENTOS

Agradeço a **Deus** pela saúde para desempenhar meu papel de docente e lutar sempre para melhorar meus conhecimentos e desta forma poder exercer minha profissão da melhor forma.

Agradeço à minha família de forma geral, meus avôs, meus tios, primos e sobrinhos.

Ao **Instituto de Ciência e Tecnologia da Universidade Estadual Paulista** no nome do Profa. Rebeca de Nicoló, atual diretora e a toda comunidade do ICT-UNESP.

Aos **Membros dessa banca examinadora (titulares e suplentes)** deste concurso, que tão prontamente aceitaram o convite.

À **Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas (FOP-UNICAMP)** pela oportunidade de realizar os cursos de **Mestrado e Doutorado** em Radiologia Odontológica, sem os quais não seria possível me tornar docente.

Agradeço à **Faculdade de Ciências Médicas da Universidade Estadual de Campinas (FCM-UNICAMP)**, em especial ao Prof. Li Li Min, meu supervisor no Programa de Pós-Doutorado.

Agradeço imensamente os docentes da área de Radiologia Odontológica do FOP-UNICAMP, **Prof Frab Norberto Bóscoli e, em especial e com muito carinho à minha orientadora nos Cursos de Mestrado e Doutorado, Profa**

Solange Maria de Almeida, por me incentivar, acreditar em minha capacidade e sonho de me tornar docente, com certeza sem a sua força não teria conseguido.
Muito obrigado Profa!

Aos órgãos de fomento, **CAPES, CNPq e FAPESP**, que na forma de bolsa de estudo ou auxílio financeiro à pesquisa, suportaram grande parte da minha formação como aluno e das minhas atividades como docentes.

Ao **Programa de Biopatologia Bucal**, em nome da Profa. Luciane Dias de Oliveira, atual coordenadora, que me concedeu a oportunidade de orientar e participar deste programa.

À **Disciplina de Radiologia** do ICT-UNESP e aos docentes, **Prof Luiz César de Moraes, Profa Mari Eli Leonelli de Moraes e Prof Luiz Roberto Coutinho Manhães-Júnior**, que me receberam tão bem na ocasião de meu ingresso nesta Universidade, confiando em meu trabalho e me dando total liberdade.

Aos colegas de trabalho, Técnicos em Radiologia, **Maria da Conceição, Alex Marques e Selma Leme**, que, além da dedicação no desempenho de suas funções, sempre me recebem com atenção e carinho, ajudando imensamente no bom funcionamento da Clínica de Radiologia desta instituição.

Além disso à funcionária **Eliana** pelo seu capricho e esmero, sempre deixando nosso ambiente de trabalho com aquele aspecto agradável e zeloso, muito obrigado!

Agradeço à **Profa Ucha** pela amizade e incentivos de sempre e por batalhar a meu lado para que eu pudesse me tornar Prof RDIDP, na ocasião como chefe do Departamento, muito Obrigado Ucha!

Agradeço ao **Prof Mauro Santamaria**, pela sua amizade, por me abrir as portas da pesquisa, pelas inúmeras ajudas nos projetos e incentivo, sou e serei sempre muito grato a você Mauro!

Agradeço à funcionária **Jacqueline**, secretária de nosso Departamento, pela sua notável competência no desempenho de suas funções, transcendendo suas obrigações de trabalho e de forma tão dedicada e carinhosa. Além disso às demais funcionárias do Departamento, **Márcia e Valéria**, que mesmo, com pouco contato, sempre me atendem nos momentos de necessidade de forma tão amigável.

Aos meus amigos, **André Costa, Afonso, Jucenir**, pelo companheirismo e força nos momentos mais difíceis! Tenho muito carinho por vocês e gratidão!

Aos meus colegas, professores do ICT-UNESP, em especial: **Profa Estela Kaminagakura, Porfa Jenete Dias, Profa Andréa Demarco, Prof Amorim, Profa Ana Sueli**, pelo acolhimento.

Em especial, à funcionária **Lilian Braga**, da Seção Técnica Acadêmica, por toda a orientação durante o processo de elaboração deste concurso de Livre-docência, muito obrigado!

Agradeço à funcionária **Fernanda Maria de Brito Cunha** pelo impecável e admirável trabalho na elaboração de meu Memorial.

A todos os **alunos de graduação** com os quais tive a oportunidade de exercer o ofício do ensino. Feliz é aquele que aprende com quem ensina.

A todos os meus **alunos de iniciação científica** e aos meus alunos de pós-graduação **Bianca Gonçalves, Karolina Fardim, Elaine Beda, Rafael de Paula, Débora Maria, Eurico Cândido e Fernanda Herrera**, agradeço pela confiança, paciência e sobretudo amizade.

Agradeço à **Sir. Wilhelm Conrad Rontgen**, descobridor dos raios X, pela sua dedicação à pesquisa, que culminou nesta fantástica revolução que abrangeu todas as áreas da ciência e que se tornou minha paixão profissional.

Aos **pacientes** que são atendidos em nossa Clínica de Radiologia, pela confiança em nosso serviço, pela possibilidade de aprendizagem a nossos alunos.

As outras Instituições que lecionei previamente à UNESP: à então Faculdades Federais Integradas de Diamantina (FAFEID), à Faculdade de Tecnólogo em Radiologia Novo Rumo, ao Colégio Técnico em Radiologia Enfermap, à Universidade de Lavras (UNILAVRAS) e à Universidade Federal de Pelotas (UFPel), por me fornecerem subsídios e várias experiências na docência, que com certeza engrandeceram meu conhecimento e aprendizado, que fortaleceram ainda mais meu amor à docência e à Radiologia.

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Lopes SLPC. Aplicações das imagens de ressonância magnética no estudo das desordens temporomandibulares [tese de livre-docência]. São José dos Campos (SP): Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia; 2019.

RESUMO

As articulações temporomandibulares (ATM) consistem numa articulação diartrodial, com notável complexidade anatômica, podendo sofrer a influência de diferentes fatores dentre os quais, os anatômicos, psíquicos, além de alterações sistêmicas. As desordens temporomandibulares (DTM) consistem em um conjunto de sinais e sintomas que caracterizam a presença de alterações que acometem as ATM, bem como estruturas anexas a elas relacionadas, como por exemplo, os músculos da mastigação. Dentre os exames por imagens que auxiliam no diagnóstico das DTM, as imagens por ressonância magnética (RM) constituem no padrão-ouro para esta finalidade. Esta modalidade de imagem apresenta, dentre outras vantagens, a não utilização de energia ionizante, sendo um exame não invasivo, além da possibilidade de fornecer alta definição dos tecidos moles, como o disco articular e músculos da mastigação, sendo assim a única técnica imaginológica que possibilita um estudo de alta precisão destas estruturas, além dos componentes anatômicos ósseos das ATM. Esta tese realizou a compilação de 06 estudos, publicados em periódicos de impacto, que analisaram, a relação entre: variações anatômicas das estrutura das ATM, presença de achados psicológicos e sistêmicos e a utilização de tecnologias computacionais de imagens, com o intuito de estudar as ATM e possíveis achados que suscitasse em DTM, utilizando imagens de RM. Dois desses estudos realizaram a abordagem por RM dos componentes das ATM em indivíduos portadores de Depressão Maior (DM) e de Cefaléia do tipo migrânea (CM), com intuito de se investigar o papel de alterações psíquicas e sistêmicas na presença das DTM, observando-se que a DM parece não estar relacionada com fatores que indicariam a presença de DTM, mas que a CM indicaria uma hipertrofia do músculo pterigóideo lateral e portanto poderia estar associada com fatores ligados à DTM. Sobre a abordagem de variações anatômicas, relacionadas com as DTM, um dos estudos aqui relatado investigou a relação entre a anatomia da eminência articular das ATM e a presença do deslocamento de disco articular, encontrando resultado que reforçou esta hipótese, outro trabalho objetivou-se em correlacionar a variação dos padrões anatômicos de inserções e volumetria do músculo pterigóideo lateral e alterações relacionadas com DTM, concluindo que a variação da volumetria deste grupo muscular e o tipo de sua inserção pode estar associado aos graus de abertura alterados dos

indivíduos. Ainda dentro do estudo anatômico e sua relação com as DTM, outro estudo procurou entender a variação anatômica entre as inclinações dos eixos condilares, com a possível presença de deslocamentos de disco e sinais de DTM, suscitando em um achado que não comprovou esta hipótese. Finalmente, no que tange a tecnologia computacional, para estudo das ATM, além daqueles estudos já citados em que foi investigado o volume dos músculos pterigoideos, e que, para tal, valeram-se de técnicas de computação gráfica para reconstruções tridimensionais, outro estudo componente desta tese elucidou o papel dos filtros de pós-processamento de imagens por RM como ferramentas que melhorassem as análises das estruturas das ATM e, portanto, possibilitassem melhores condições de identificação de alterações nas mesmas relacionadas com as DTM, concluindo que, de fato, estas ferramentas melhoram o desempenho dos avaliadores para estas finalidade. Desta forma, após a revisão dos artigos, pode-se concluir que, além do já denotado valor das imagens de RM no estudo das ATM e das DTM, novas possibilidades do uso das mesmas por meio de crescentes recursos computacionais valorizam ainda mais sua indicação para este fim.

Palavras-chaves: Articulação Temporomandibular. Ressonância Magnética. Radiologia. Artropatias.

Lopes SLPC. Applications of magnetic resonance imaging in the study of temporomandibular disorders [thesis]. São José dos Campos (SP): São Paulo State University (Unesp), Institute of Science and Technology; 2019.

ABSTRACT

The temporomandibular joint (TMJ) consist of a diarthrodial joint, with remarkable anatomical complexity, and may be influenced by different factors, including anatomical, psychic, and systemic changes. Temporomandibular disorders (TMD) consist of a set of signs and symptoms that characterize the presence of alterations that affect the TMJ, as well as related structures, such as mastigatory muscles. Among the imaging exams that help in the diagnosis of TMD, magnetic resonance imaging (MRI) is the gold standard for this purpose. This imaging modality has, among other advantages being a noninvasive examination, besides the possibility of providing high definition of soft tissues, such as the articular disc and mastigatory muscles, thus being the only imaging technique that enables a high precision study of these structures, besides the anatomical bone components of the TMJ. This thesis compiled 06 studies, published in impact journals, which analyzed the relationship between: anatomical variations of the TMJ structure, the presence of psychological and systemic findings and the use of computational imaging technologies, in order to study the TMJ and possible findings in TMD, using MRI. Two of these studies performed the MRI approach of the TMJ components in individuals with Major Depression (MD) and Migraine (M), in order to investigate the role of psychic and systemic changes in the presence of TMD, observing appears that MD does not appear to be related to factors that would indicate the presence of TMD, but that M would indicate lateral pterygoid muscle hypertrophy and, therefore, could be associated with factors linked to TMD. Regarding the approach of TMD-related anatomical variations, one of the studies reported here investigated the relationship between the articular eminence anatomy of the TMJ and the presence of articular disc displacement, finding a result that reinforced this hypothesis. To correlate the variation in the anatomical patterns of insertions and volumetry of the lateral pterygoid muscle and TMD-related alterations, concluding that the variation of the volumetry of this muscle group and the type of its insertion may be associated with the individuals' altered degrees of mount opening. Still within the anatomical study and its relationship with TMD, another study sought to understand the anatomical variation between the inclinations of the condylar axis, with the possible presence of disc dislocations

and TMD signals, leading to a finding that did not prove this hypothesis. Finally, with regard to computational technology, for the study of TMJ, in addition to those studies already cited in which the volume of the pterygoid muscles was investigated, and for that, they used computer graphics techniques for three-dimensional reconstructions, another component study. Another study elucidated the role of MRI preprocessing filters as tools that improve the analysis of TMJ structures and, therefore, enable better conditions for identifying TMD-related changes, thus concluding that these tools improve the performance of evaluators for these purposes. Thus, after reviewing the articles, it can be concluded that, besides the already denoted value of MRI in the study of TMJ and TMD, new possibilities of their use through increasing computational resources further value their indication for this aim.

Keywords: Temporomandibular joint. Magnetic Resonance Spectroscopy Radiology. Joint Diseases.

1 INTRODUÇÃO

A complexidade das articulações temporomandibulares (ATM), juntamente com outras estruturas que, associadas a elas, compõem o sistema estomatognático, aumenta suas susceptibilidades a alterações patológicas. A literatura que aborda este tema é ampla e rica e o fascínio pela fisiologia e patofisiologia das ATM sus i i extrema valia nas aplicações clínicas em várias áreas de saúde, como medicina, odontologia, fisioterapia e psicologia.

As desordens temporomandibulares (DTM) constituem uma síndrome que envolve as ATM e/ou os músculos da mastigação. Os sinais e sintomas dessas desordens incluem ruídos articulares, movimentos anormais da mandíbula, dor articular e/ou muscular e a presença do deslocamento do disco articular (DD). Além do DD, várias alterações podem envolver a cabeça da mandíbula e/ou o próprio disco. O diagnóstico dessas desordens é um dos importantes focos na clínica odontológica (Yang et al., 2002). A etiologia das DTM, apesar de atualmente ser considerada multifatorial, continua possuindo pontos obscuros, não somente no que diz respeito aos fatores responsáveis pelo seu desenvolvimento, mas também quanto à importância que cada um destes representa para desencadeá-la.

Kaplan et al, em 1991, relataram que o início dos estudos das DTM não possuem uma origem recente, sendo a primeira descrição dos desarranjos internos nas ATM publicada em fins do século XIX, correlacionado-se os sintomas clínicos às disfunções estruturais. Esses autores descrevem a observação de sintomas cínicos, nas regiões dos seios da face, ou i

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sobremordida. Concluiu-se que o trauma no disco articular era devido a seu constante movimento para trás e para frente levando a sua perfuração e a compressão da tuba auditiva, causando a injúria de diversos nervos na área. Entretanto, esta teoria não era capaz de explicar aqueles casos nos quais os sintomas eram inicialmente nos músculos da mastigação.

Estes diferentes sintomas, foram reunidos em uma Síndrome denominada “Síndrome de Ehlers-Danlos” que é uma doença hereditária neuromuscular que afeta a própria estrutura da ATM e oclusão. Várias investigações continuaram sendo realizadas a respeito da presença de deslocamento de disco e de estalidos, e, através do advento da artrografia, possibilitou-se a visualização dos contornos do disco articular deslocado, por meio da concentração das substâncias de contraste em imagens radiográficas convencionais. Nos Anos 80, porém, por meio da tomografia computadorizada (TC) e, posteriormente, dos exames por ressonância magnética (RM), houve um progresso considerável tanto no diagnóstico, como plano de tratamento dos desarranjos internos nas ATM.

Os desarranjos internos nas ATM (DI) podem ser definidos como relações anatômicas anômalas entre disco articular, cabeça da mandíbula, fossa da mandíbula e tubérculo articular, bem como alterações em suas formas e estruturas. O deslocamento anterior do disco apresenta duas fases progressivas e estágios clínicos, resultando em deformações das estruturas ósseas componentes da articulação temporomandibular. Estes estágios podem ser visualizados unicamente em imagens por ressonância magnética (RM), sendo o exame padrão ouro para seu estudo. (Held et al., 1996)

A American Academy of Orofacial Pain (Geshi et al., 2004) determinou os critérios para o diagnóstico de indivíduos como portadores de DTM: presença

de sensibilidade dolorosa na articulação temporomandibular e/ou nos músculos da mastigação; presença de limitação de movimentos mandibulares e finalmente a presença de ruídos articulares. Nassif et al. em 2001 afirmaram em seu trabalho, que estes sinais devem ser considerados como parâmetros clássicos para o diagnóstico de desordem temporomandibular em um indivíduo. Lopes et al. (2012) avaliando a presença das DTM em indivíduos com depressão maior, acrescentaram além destes sinais e sintomas previamente citados, a presença do deslocamento do disco articular, como um fator a ser considerado no diagnóstico das DTM, além das alterações musculares/articulares, ruídos e limitações de movimento.

Nas últimas décadas, o diagnóstico por imagens da ATM tem se desenvolvido com extrema rapidez. Estes avanços incluíram a artrografia, a tomografia computadorizada e, mais recentemente, as imagens por ressonância magnética (RM). Dentre estes métodos, é notável que a RM fornece informações mais apuradas da ATM, como deslocamento de disco, presença de osteoartrite, deformidades do disco e outras condições patológicas envolvendo os tecidos moles que formam ou se relacionam com esta articulação. Os achados através da RM quando comparados com achados cirúrgicos, observações histológicas e anatômicas decorrentes de necrópsia mostram-se fidedignos. Desta forma, a RM tem sido preconizada como o melhor método de diagnóstico por imagens para a ATM. Além da excelente qualidade de imagem, desde que seja estabelecido um protocolo ideal, esta modalidade não faz uso de radiações ionizantes que levam a efeitos deletérios aos organismos vivos (Yang et al., 2002).

O princípio de formação de imagens por RM, baseia-se na interação entre ondas eletromagnéticas de radiofrequência (RF), e portanto de baixa energia, e os prótons dos átomos dos tecidos da região contida no exame. Para tal, são

utilizadas bobinas de RF que envolvem a região de interesse e que são responsáveis tanto pela emissão da energia de RF, quanto pela sua captação, oriunda dos átomos dos tecidos. Por ser um método fundamentado na interação da energia de RF com os prótons, além de não invasivo (não ionizante), possibilita que os tecidos moles como músculos, tecido fibroso, gordura, água, dentre outros, sejam também visualizados com alta resolução nas imagens. Desta forma, para o estudo das ATM, a RM é o único método por imagem que fornece a visualização do disco articular fibrocartilaginoso, permitindo o estudo de sua posição, forma, possíveis alterações de sinal e sua função. Além disso, a ponderação das imagens, durante sua aquisição, seja em T1, T2 ou densidade protônica (DP), possibilita que sejam realizados estudos comparativos do comportamento dos tecidos, possibilitando a identificação por exemplo de alterações como necroses avasculares, edemas medulares e efusões articulares, característica inerente da RM (Lopes, 2018, p. 248).

São inúmeros os estudos relacionados à utilização de imagens por RM para o diagnóstico complementar das DTM, alguns dos quais avaliando o papel
 i i (L h i 2005; Ak ğ
 2018; Larhein et al., 2018; Bedran & Dos Santos, 2019), concluindo que de fato os exames de RM possuem grande valia para este objetivo. Outros estudos foram realizados valendo-se das imagens de RM para investigação de alterações ósseas nos componentes das ATM, como erosões, formações de osteófitos, alterações medulares indicativas de edemas e necroses avasculares

Neste contexto, baseado na alta frequência e importância do diagnóstico das DTM, bem como nas possibilidades inerentes aos exames por RM para a avaliação dos componentes das ATM, esta Tese apresenta a compilação de 06 trabalhos, que se valeram dos exames de imagens por RM como meio de estudo das ATM e, mais especificamente, de suas estruturas componentes, avaliadas,

para se determinar a presença de DTM, identificando-se desarranjos internos, alterações nos músculos da mastigação, além de ferramentas que possibilitem aprimorar a análise destas estruturas pela RM.

2 PROPOSIÇÃO

O objetivo da presente tese foi ressaltar a gama de possibilidades que os exames por imagens de ressonância magnética (RM) fornecem como meio de diagnóstico complementar no estudo das desordens temporomandibulares.

Para tal, sua estrutura foi dividida em capítulos, que correspondem aos artigos publicados abordando este tema, seguindo a seguinte sequência:

1.Lopes SL, Costa AL, Cruz AD, Li LM, de Almeida SM. Clinical and MRI investigation of temporomandibular joint in major depressed patients. *Dentomaxillofac Radiol.* 2012 May;41(4):316-22. doi: 10.1259/dmfr/27328352.

2.Lopes SL, Costa AL, Gamba Tde O, Flores IL, Cruz AD, Min LL. Lateral pterygoid muscle volume and migraine in patients with temporomandibular disorders. *Imaging Sci Dent.* 2015 Mar;45(1):1-5. doi: 10.5624/isd.2015.45.1.1. Epub 2015 Mar 13.

3.Melke GSF, Costa ALF, Lopes SLPC, Fuziy A, Ferreira-Santos RI. Three-dimensional lateral pterygoid muscle volume: MRI analyses with insertion patterns correlation. *Ann Anat.* 2016 Nov; 208:9-18. doi: 10.1016/j.aanat.2016.05.007. Epub 2016 Jun 7.

4.Nascimento Falcão I, Cal Alonso MBC, da Silva LH, Lopes SLPC, Comar LP, Costa ALF. 3D Morphology Analysis of TMJ Articular Eminence in Magnetic Resonance Imaging. *Int J Dent.* 2017;2017:5130241. doi: 10.1155/2017/5130241. Epub 2017 Jun 21.

5. Montesinos GA, de Castro Lopes SLP, Trivino T, Sánchez JA, Maeda FA, de Freitas CF, Costa ALF. Subjective analysis of the application of enhancement filters on magnetic resonance imaging of the temporomandibular joint. ***Oral Surg Oral Med Oral Pathol Oral Radiol***. 2019 Jun;127(6):552-559. doi: 10.1016/j.oooo.2018.11.015. Epub 2018 Dec 2.

6. Amorim MY, Alves MGO, Almeida JD, Montesinos GAP, Costa ALF, Lopes SLPC. Inclination of the condylar long axis is not related to temporomandibular disc displacement. ***J Investig Clin Dent***. 2019 Feb;10(1):e12375. doi: 10.1111/jicd.12375. Epub 2018 Nov 26.

3 ARTIGOS

3.1. Artigo 1

Lopes SL, Costa AL, Cruz AD, Li LM, de Almeida SM. Clinical and MRI investigation of temporomandibular joint in major depressed patients. *Dentomaxillofac Radiol.* 2012 May;41(4):316-22. doi: 10.1259/dmfr/27328352.

Este trabalho originou-se da minha pesquisa desenvolvida para a tese de Doutorado em Radiologia Odontológica.

Abstract:

Objective: The aim of the present study was to describe the clinical and MRI findings of the temporomandibular joint (TMJ) in patients with major depressive disorders (MDDs) of the non-psychotic type. Methods: 40 patients (80 TMJs) who were diagnosed as having MDDs were selected for this study. The clinical examination of the TMJs was conducted according to the research diagnostic criteria and temporomandibular disorders (TMDs). The MRIs were obtained bilaterally in each patient with axial, parasagittal and paracoronal sections within a real-time dynamic sequence. Two trained oral radiologists assessed all images. Fisher's exact test and χ^2 test were applied ($\alpha=0.05$). Results: Migraine was reported in 52.5% of subjects. Considering disc position, statistically significant differences between opening patterns with and without alteration ($p=0.00$) and between present and absent joint noises ($p=0.00$) were found. Regarding muscular pain, patients with and without abnormalities in disc function and patients with and without abnormalities in disc position were not statistically significant ($p=0.42$ and $p=0.40$, respectively). Significant differences between mandibular pathway with and without abnormalities ($p=0.00$) and between present and absent joint noises ($p=0.00$) were observed. Conclusion: Based on the preliminary results observed by clinical and MRI examination of the TMJ, no direct relationship could be determined between MDDs and TMDs.

RESEARCH

Clinical and MRI investigation of temporomandibular joint in major depressed patients

SLPC Lopes¹, ALF Costa^{*,2}, AD Cruz³, LM Li⁴ and SM de Almeida⁵

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Objective: The aim of the present study was to describe the clinical and MRI findings of the temporomandibular joint (TMJ) in patients with major depressive disorders (MDDs) of the non-psychotic type.

Methods: 40 patients (80 TMJs) who were diagnosed as having MDDs were selected for this study. The clinical examination of the TMJs was conducted according to the research diagnostic criteria and temporomandibular disorders (TMDs). The MRIs were obtained bilaterally in each patient with axial, parasagittal and paracoronal sections within a real-time dynamic sequence. Two trained oral radiologists assessed all images. For statistical analyses, Fisher's exact test and χ^2 test were applied ($\alpha = 0.05$).

Results: Migraine was reported in 52.5% of subjects. Considering disc position, statistically significant differences between opening patterns with and without alteration ($p = 0.00$) and between present and absent joint noises ($p = 0.00$) were found. Regarding muscular pain, patients with and without abnormalities in disc function and patients with and without abnormalities in disc position were not statistically significant ($p = 0.42$ and $p = 0.40$, respectively). Significant differences between mandibular pathway with and without abnormalities ($p = 0.00$) and between present and absent joint noises ($p = 0.00$) were observed.

Conclusion: Based on the preliminary results observed by clinical and MRI examination of the TMJ, no direct relationship could be determined between MDDs and TMDs.

Dentomaxillofacial Radiology (2012) **41**, 316–322. doi: 10.1259/dmfr/27328352

Keywords: major depression disorder; temporomandibular disorders; magnetic resonance imaging; orofacial pain

Introduction

The complexity of the temporomandibular joint (TMJ) and its structure increases the susceptibility to pathological changes. Temporomandibular disorders (TMDs) are a multifactorial syndrome involving the TMJ and/or the masticatory muscles (MMs),^{1,2} and the most common symptoms are joint noises, articular disc displacement, abnormal movements of the mandible and pain. It has been suggested that chronic pain conditions and depressive disorders share common pathophysiological characteristics³ and could cause major stress to the patient, thus precipitating a chronic pain condition.

A high degree of comorbidity was found between chronic facial pain, depression and anxiety.^{4–6} There is evidence that some TMD patients experience more anxiety than healthy control groups.⁷ According to some studies, depression and anxiety play an important role in the aetiopathogenesis of TMDs,^{7,8} while others found a weak association.⁹

Among the different types of depression, major depressive disorder (MDD) of the non-psychotic type is a category characterized by a severely depressed mood and is prevalent in 17.1% of the general population.¹⁰

There are multiple reports of subjects with MDDs and symptoms in their TMJs and MMs, such as limited jaw opening, joint noises and orofacial pain,^{3,11} but there is a lack of information about the relationship

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between TMDs and MDDs, although several studies have asserted the importance of the psychological factors in the aetiology of TMD.

Imaging of the TMJ is a helpful tool in the diagnosis of TMD in addition to its clinical findings. MRI allows analysis of disc position in both sagittal and coronal planes as well as dynamic assessment of condylar translation and disc movement during opening and closing, disc morphology and requires no ionizing radiation.^{12,13}

The aim of this study was to verify any correlation between the pathological clinical parameters of the TMJ and MRI diagnoses in MDD patients.

Materials and methods

This study was approved by the School of Dentistry, UNICAMP ethical committee, and informed consent was given by all patients. We evaluated 40 patients (26 females and 14 males; mean age 40.2 years), all of whom were diagnosed with an MDD of the non-psychotic type by a trained psychiatrist according to Diagnostic and Statistical Manual of Mental Disorders-Fourth Edition (Text Revision) criteria.¹⁴ The patients had received only an initial treatment of MDD and still showed the symptoms of this disease.

Clinical examination

Patients were asked about TMD symptoms and were evaluated by a qualified dentist according to the research diagnostic criteria for TMD (RDC/TMD axis I)¹⁵ in order to assess the presence of TMD symptoms. The RDC/TMD examinations allowed the diagnoses of the following: muscle disorders, disc displacement, arthralgia, osteoarthritis and osteoarthrosis. Joint sounds, *i.e.* click and crepitus, were recorded separately for each joint. The mouth opening and jaw excursions were measured (mm) and the presence of pain during these movements was recorded. During the procedure, the patients were asked whether or not they felt any pain. Symptoms such as headaches, bruxism and jaw protrusion were classified as always present, occasionally present, not present and uncertain.

Magnetic resonance imaging

Patients were examined using a 1.5 T scanner (Signa; GE Medical Systems, Milwaukee, WI) with 8.5 cm diameter surface coils.

MRI protocol was:

1. Axial images in maximum intercuspation position using spin echo sequence (SE), T_1 weighted (T1W), repetition time (TR) 850 ms, echo time (TE) 1.6 ms, section thickness (ST) 5.0 mm, field of view (FOV) 180×180 mm and a matrix of 256×256, number of excitations (NEX) 2, echo train length = 180°, radio frequency 4, flip angle 20°. Among these images, we

selected the side that showed the best view of the condyle. These images were called “localizer sections” and were used to determine the parasagittal and paracoronal sections (perpendicular and parallel, respectively, to the condyle).

2. Parasagittal images in SE in proton-density weighted (DP) (TR = 1200.0 ms, TE = 13.7 ms, ST = 3.0 mm, FOV = 150 × 150 mm and a matrix of 512 × 512). Six images from each side were obtained from lateral to medial positions. These images were first obtained with the patient in maximum intercuspation position and then with maximum opening.
3. Paracoronal images in SE in DP (TR = 1200.0 ms, TE = 13.7 ms, ST = 2.0 mm, FOV = 150 × 150 mm and a matrix of 512 × 512). Six images from each side were obtained from anterior to posterior. These images were obtained with the patient in maximum intercuspation position.
4. A real-time dynamic study in *fiesta fat* in a parasagittal plane (TR = 9.4 ms, TE = 4.2 ms, ST = 10.0 mm, FOV = 211 × 211 mm and a matrix of 256 × 256). The patients were instructed to slowly open their mouths to maximal opening and then to slowly close to maximum intercuspation in a repetitive sequence. This was rehearsed with patients before imaging. Each dynamic recording (duration 18 s) covered a full sequence.

The MRIs were studied separately by two radiologists (SLPCL and ALFC) with 10 years of experience in maxillofacial radiology. The examiners were evaluated previously during a calibration session at which inter-observer reliability assessment revealed acceptable agreement ($\kappa = 0.9$) for evaluation of the dichotomous variables. During the interpretation of the images of the study, any disagreements were discussed until a consensus was reached.

Protocol for MRI interpretation

(a) The disc position, which was assessed through the parasagittal and the paracoronal images. Normal disc position was defined by the location of the posterior band of the disc at the superior, or 12 o'clock, position relative to the condyle, whereas disc displacement was defined as the posterior band of the disc being in an anterior, anteromedial, anterolateral, medial or lateral position relative to the superior part of the condyle.¹⁶

(b) The disc function, which was assessed through parasagittal images and the real-time dynamic study.¹⁶

(c) The condyle position in the mandibular fossa was assessed using parasagittal closed-mouth images first and then parasagittal maximum opening mouth images. We used the e-Film workstation program (e-Film Medical Inc., Toronto, Canada) and its measurement tool to trace the condyle position in the fossa. The condylar position determined the narrowest anterior and posterior interarticular distances on mid-sagittal MR images of the condyle. When the anterior distance was greater than the posterior distance, the condylar

position was considered to be posterior within the fossa. When the difference was zero, the condylar position was considered to be centric within the fossa and when the posterior distance was greater, the condylar position was considered to be anterior within the fossa. When the articular space was reduced and the condyle occupied most of the area, it was considered intrusion. When the articular space was increased and the condyle was inferiorly displaced, it was considered extrusion.^{17,18}

Statistical methods and analyses of the results

A statistical analysis was performed to evaluate the association of:

1. TMJ functional pain, disc function and disc position
2. muscular pain, disc function and disc position
3. disc position, condyle position, opening patterns and joint noises.

A statistical analysis was performed separately with variables using Fisher's exact test and χ^2 test with a significance level of 5% ($\alpha=0.05$).

Results

Four scans in the TMJ dynamic presented a motion artefact with image blurring owing to an abrupt jaw movement. These four patients were invited to come back for a new scan session and underwent a second sequence, all of which were performed correctly without generating artefacts.

The most frequent alteration was the presence of migraines: 52.5% of the patients reported they always had them and 47.5% had them occasionally. Bruxism was the second most frequent complaint: 35.0% of the MDD patients stated that it was always present and 47.5% said it was occasionally present. Mandibular protrusion was reported in 7.5% of the patients as always present and 30.0% had it occasionally, but 40.0% of patients were certain they did not have it.

The normal values of maximum mouth opening are more than 40 mm, while the normal values of the laterotrusion and protrusion are more than 6 mm. The mean maximum mouth opening in our study was 46 mm and laterotrusion and protrusion movements were normal, with means of 7.5 mm and 7.4 mm, respectively. An abnormal mandibular pathway was observed in 34 patients (85.0%), 62.5% had deviation and 22.5% had deflection; 70% of the patients with TMDs had joint noises, while 55 (69.0%) had clicking and only 1 had crepitation.

When the TMD patients were examined by palpation in the rest position, 15 (18.75%) complained of pain. However, when they were examined while opening and closing their mouth, this number increased to 49

(61.2%). It was observed that the MM group reported pain during palpation in the sternocleidomastoid muscle followed by pain in the masseter (both sides were examined).

As to the disc positions in the closed mouth position in the MRIs, 26 (32.5%) of the articular discs were in their normal position and 54 (67.5%) were displaced. The most frequent type of disc displacement was the partial anterolateral displacement, present in 26 TMJs (32.5%), followed by anterior displacement in 17 TMJs (21.2%) and partial anteromedial displacement in 5 TMJs (6.2%), while medial displacements and lateral displacements were observed in 3 TMJs (3.75%). Rotational, anterolateral displacement, anteromedial displacement and posterior displacements were not observed in our study.

Table 1 Association between position/function of the temporomandibular joint (TMJ) disc and TMJ functional pain, masticatory muscles pain, joint noise, mandibular pathway and condyle position

Disc position	TMJ functional pain		
	Absent	Present	Total
Normal	12 (15%)	14 (17.5%)	26
Abnormal	19 (23.7%)	35 (43.7%)	54
Total $p=0.34$ (χ^2 test)	31	49	80

Disc function	TMJ functional pain		
	Absent	Present	Total
Normal	30 (37.5%)	45 (56.2%)	75
Abnormal	1 (1.2%)	4 (5%)	5
Total $p=0.32$ (Fisher's exact test)	31	49	80

Disc position	Muscle pain		
	Absent	Present	Total
Normal	3 (3.7%)	24 (30%)	27
Abnormal	3 (3.7%)	50 (62.5%)	53
Total $p=0.4$ (Fisher's exact test)	6	74	80

Disc function	Muscle pain		
	Absent	Present	Total
Normal	6 (7.5%)	68 (85%)	74
Abnormal	1 (1.2%)	5 (6.2%)	6
Total $p=0.42$ (Fisher's exact test)	7	73	80

Disc position	Joint noise		
	Absent	Present	Total
Normal	19 (23.7%)	7 (8.7%)	26
Abnormal	5 (6.2%)	49 (61.2%)	54
Total $p=0.00$ (χ^2 test)	24	56	80

Disc position	Mandibular pathway		
	Normal	Abnormal	Total
Without disc displacement	6 (15%)	2 (5%)	8
With disc displacement	0 (0%)	32 (80%)	32
Total $p=0.00$ (Fisher's exact test)	6	34	40

Disc position	Condyle position		
	Normal	Abnormal	Total
Normal	4 (5%)	6 (7.5%)	10
Abnormal	19 (23.7%)	51 (63.7%)	70
Total $p=0.30$ (Fisher's exact test)	23	57	80

Considering the functional disc categories, the exams revealed that 75 (93.75%) of the discs had reduction when the patients were in maximum opening mouth activity, while 5 (6.25%) of them did not assume a normal position and remained displaced while in the maximum opening mouth activity and had displacement without reduction.

We found the central condyle position in the mandibular fossa in 23 (28.75%) TMJs and the non-central positions in 57 TMJs (71.25%), divided into the following groups: 43 (53.78%) in the posterior position, 7 (8.75%) in the anterior position, 4 (5.0%) in the intrusion position and 3 (3.75 %) in the extrusion position.

The frequency of the different kinds of condyle mobility in the images showed that 22 (27.5%) of the condyles had a normal motion position and 58 (72.5%) had hyper- or hypomobility: 32 (40.0%) with hypermobility and 6 (7.5%) with hypomobility.

There was no relationship between the disc function and joint functional pain ($p=0.32$) and MM pain ($p=0.42$) as well as between disc position and joint functional pain ($p=0.34$) and MM pain ($p=0.40$). We found no relationship between disc position and condyle position in the mandibular fossa ($p=0.30$). When disc position was related to joint noise, we observed a relationship between both of them ($p=0.00$) as

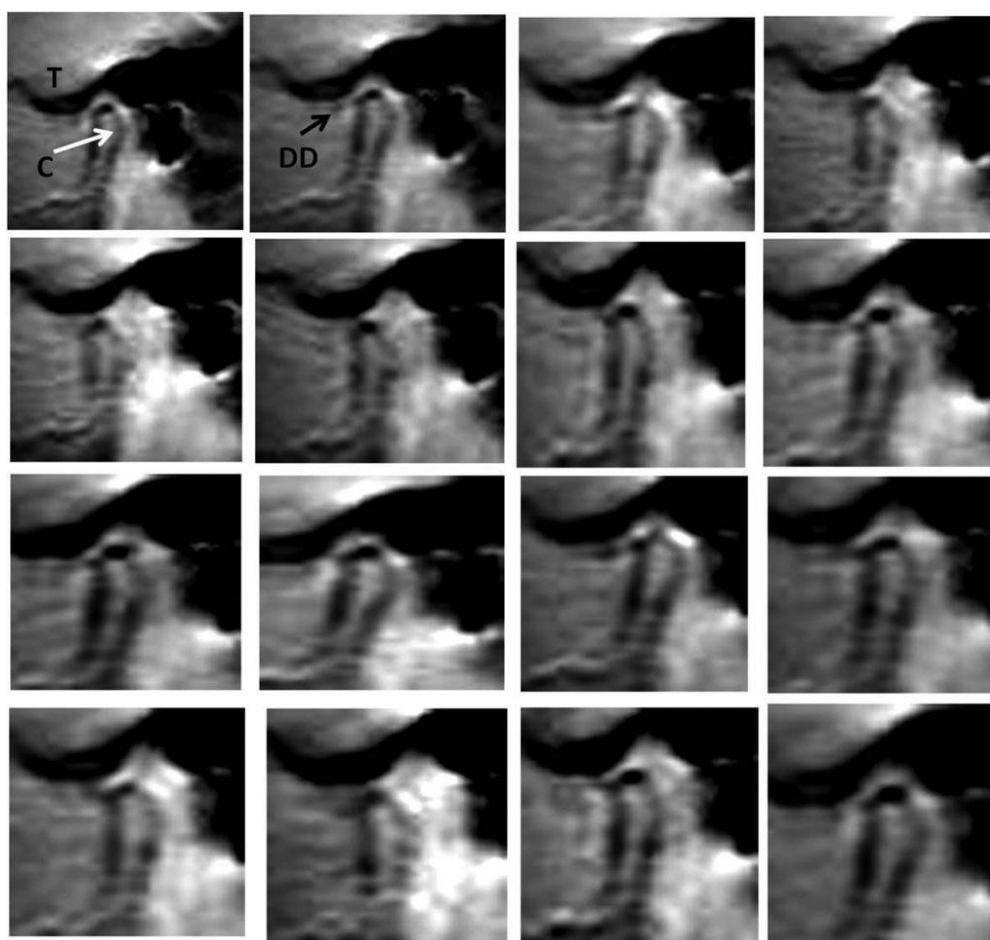


Figure 1 Real-time dynamic MRI of a temporomandibular joint movement with anterior disc displacement without reduction and discontinuous condyle movement. C, condyle; T, temporal bone; DD, disc displacement

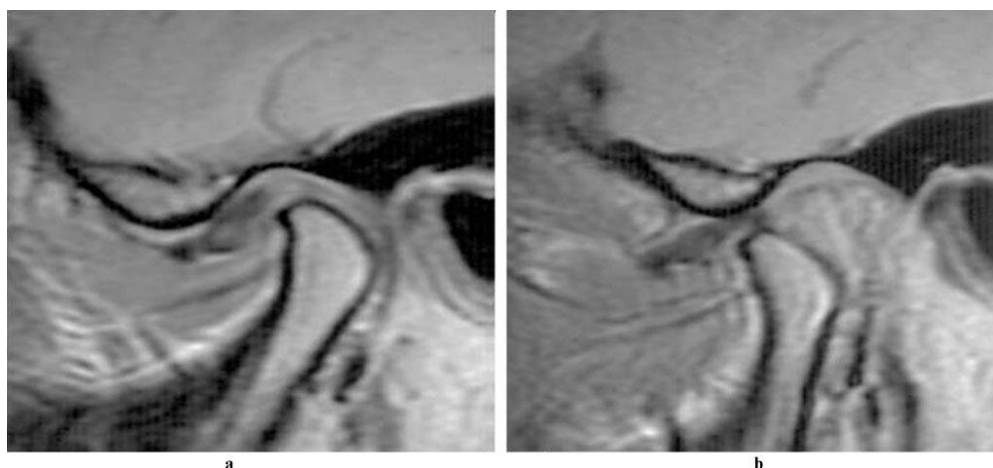


Figure 2 Static sagittal MRI slices showing disc displacement without reduction in (a) closed mouth and (b) open mouth

well as between disc position and mandibular pathway ($p=0.00$) (Table 1). Table 2 demonstrates the relationship between the signs and symptoms of TMD and disc displacement.

Figure 1 shows a series of images from real-time dynamic study in *fiesta fat* in a parasagittal plane of a subject with disc displacement without reduction and Figure 2 shows disc displacement without reduction during mouth closing and opening.

Discussion

A recurrent migraine was the most common symptom reported. Migraines are normal among TMD patients, suggesting that they may be correlated with TMDs.^{2,19} Conversely, migraines are frequently associated with MDD patients and are an important additional finding in MDD diagnosis.²⁰ Approximately 75.0% of MDD patients complained about migraines in their first MDD episode and the highest index was among the women;²¹ in our study, 65.0% were women. This explains the high presence of recurrent migraines. Besides the high levels of recurrent migraines, bruxism was the second most common complaint observed during the exams. Some of the patients in our study answered negatively when asked about it, but when the clinical exam was performed, we noted the occurrence of abrasion in the dental elements which suggested the presence of bruxism. There is evidence suggesting the psychological alterations is an important aetiological factor in bruxism.²²

In the present study, the association between disc position and pain (TMJ and MM) was not observed, but the literature shows a correlation between these findings.^{23–26} In addition, pain as an isolated symptom

was frequently observed. This can be explained by the MDD patients used in this sample. The MM pain was mainly observed in MDD subjects as a characteristic symptom. Besides this finding, we must remember that TMD patients have acute and chronic phases, with different signs and symptoms that can be responsible for the lack of relationship between pain and TMDs.

We did find a relationship between disc position and joint noise. According to some authors, there is a higher incidence of TMJ noise in the female gender.²⁷ Our findings confirm other works²⁸ which concluded that clicking occurs frequently in patients with disc displacement with reduction. In our study, 67.5% of those with TMD had disc displacement and, among these, 75% TMJs had disc reduction. The most prevalent disc noise found was clicking, except for one patient with crepitation. This suggests an association between joint sounds (clicking/crepitation) and disc displacement. Crepitation is frequently associated with disc displacement without reduction and, although there were five TMJs with disc displacement without reduction, just one presented crepitation. This emphasizes the non-specific noise presence as a TMD indicator since joint noise can be caused by different alterations, such as disc displacement, irregularities of surface of joint bone and hypermobility of the condyle.²⁹ We found a high percentage (52%) of TMJ patients who presented hypermobility.

There was no relationship between disc position and condyle position, even though in the present study 53.7% of the TMJ patients had the condyle in a posterior position and the proportion of disc displacement was high (67.5%). Some authors^{30,31} have associated the posterior position of the condyle with the anterior displacement of the disc. However, they did not make clear if the posterior

Table 2 The relationship between the signs and symptoms of temporomandibular disorder (TMD) and disc displacement

Disc position	Sign/symptom								Total
	Abs	Pain	LM	Noise	Pain + LM	LM + noise	Pain + noise	Pain + noise + LM	
Normal	3 (3.75%)	16 (20%)	0	0	0	0	8 (10%)	0	27
Displaced	0	1 (1.2%)	0	2 (2.5%)	3 (3.75%)	0	46 (57.5%)	1 (1.2%)	53
Total	3	17	0	2	3	0	54	1	80

Abs, no sign and symptom; LM, limited mandibular movements; noise, joint noise present (clicking/crepitation); pain, pain in the temporomandibular joint and/or masticatory muscles.

position of the condyle could be the cause or is the consequence of the anterior disc displacement. Other authors^{32,33} have questioned the real significance of the condyle position affecting disc displacement.

Dynamic assessments of TMJ function remain a great challenge. The diagnostic provided by dynamic MRI includes disc deformation and movement under loading and an evaluation of dynamic condylar translation.³⁴ The use of techniques that offer dynamic studies of the TMJ with short examination time requires avoidance of the artefact and may reduce the quality of examinations.^{34–36} The real-time dynamic study in fiesta fat was chosen for the reduced time for scan and quality of images acquired. Fiesta fat sequences are relatively insensitive to motion artefacts.³⁷ However, in our study this sequence generated 10% of artefacts in the exams, degrading the image quality and hampering the diagnostic accuracy.

References

- Dworkin SF, Huggins KH, LeResche L, Von Korff M, Howard J, Truelove E, et al. Epidemiology of signs and symptoms in temporomandibular disorders: clinical signs in cases and controls. *J Am Dent Assoc* 1990; **120**: 273–281.
- Costa AL, D'Abreu A, Cendes F. Temporomandibular joint internal derangement: association with headache, joint effusion, bruxism and joint pain. *J Contemp Dent Pract* 2008; **9**: 9–16.
- Korszun A, Hinderstein B, Wong M. Comorbidity of depression with chronic facial pain and temporomandibular disorders. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1996; **82**: 496–500.
- Vimpari SS, Knuuttila ML, Sakki TK, Kivela SL. Depressive symptoms associated with symptoms of the temporomandibular joint pain and dysfunction syndrome. *Psychosom Med* 1995; **57**: 439–444.
- Feinmann C. Psychogenic facial pain: presentation and treatment. *J Psychosom Res* 1983; **27**: 403–410.
- Mongini F, Ciccone G, Ceccarelli M, Baldi I, Ferrero L. Muscle tenderness in different types of facial pain and its relation to anxiety and depression: a cross-sectional study on 649 patients. *Pain* 2007; **131**: 106–111.
- Yap AU, Tan KB, Chua EK, Tan HH. Depression and somatization in patients with temporomandibular disorders. *J Prosthet Dent* 2002; **88**: 479–484.
- Celić R, Pandurić J, Dulčić N. Psychologic status in patients with temporomandibular disorders. *Int J Prosthodont* 2006; **19**: 28–29.
- Manfredini D, Borella L, Favero L, Ferronato G, Guarda-Nardini L. Chronic pain severity and depression/somatization levels in TMD patients. *Int J Prosthodont* 2010; **23**: 529–534.
- Kessler RC, McGonagle KA, Zhao S, Nelson CB, Hughes M, Eshleman S, et al. Lifetime and 12-month prevalence of DSM-III-R psychiatric disorders in the United States. Results from the National Comorbidity Survey. *Arch Gen Psychiatry* 1994; **51**: 8–19.
- Korszun A, Papadopoulos E, Demitrack M, Engleberg C, Crofford L. The relationship between temporomandibular disorders and stress-associated syndromes. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1998; **86**: 416–420.
- Limchaichana N, Petersson A, Rohlin M. The efficacy of magnetic resonance imaging in the diagnosis of degenerative and inflammatory temporomandibular joint disorders: a systematic literature review. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006; **102**: 521–536.
- Costa AL, Yasuda CL, Appenzeller S, Lopes SL, Cendes F. Comparison of conventional MRI and 3D reconstruction model for evaluation of temporomandibular joint. *Surg Radiol Anat* 2008; **30**: 663–667.
- American Psychiatric Association. Practice guideline for major depressive disorder in adults. *Suppl Am J Psychiatry* 1993; **150**: 1–26.
- Dworkin SF, LeResche L. Research diagnostic criteria in temporomandibular disorders: review, criteria, examinations and specifications, critique. *J Craniomandib Disord* 1992; **6**: 301–355.
- Tasaki MM, Westesson PL, Isberg AM, Ren YF, Tallents RH. Classification and prevalence of temporomandibular joint disc displacement in patients and symptom-free volunteers. *Am J Orthod Dentofacial Orthop* 1996; **109**: 249–262.
- Robinson de Senna B, Marques LS, França JP, Ramos-Jorge ML, Pereira LJ. Condyle-disc-fossa position and relationship to clinical signs and symptoms of temporomandibular disorders in women. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009; **108**: 117–124.
- Incesu L, Takaya-Yilmaz N, Ođütten-Toller M, Uzun E. Relationship of condylar position to disc position and morphology. *Eur J Radiol* 2004; **51**: 269–273.
- Ballegaard V, Thede-Schmidt-Hansen P, Svensson P, Jensen R. Are headache and temporomandibular disorders related? A blinded study. *Cephalgia* 2008; **28**: 832–841.

20. Gesztelyi G. Primary headache and depression. *Orv Hetil* 2004; **145**: 2419–2424.
21. Lepine JP, Briley M. The epidemiology of pain in depression. *Hum Psychopharmacol* 2004; **19**(Suppl. 1): S3–7.
22. Manfredini D, Landi N, Romagnoli M, Bosco M. Psychic and occlusal factors in bruxers. *Aust Dent J* 2004; **49**: 84–89.
23. Paesani D, Westesson PL, Hatala M, Tallents RH, Kurita K. Prevalence of temporomandibular joint internal derangement in patients with craniomandibular disorders. *Am J Orthod Dentofacial Orthop* 1992; **101**: 41–47.
24. Matsuda S, Yoshimura Y, Lin Y. Magnetic resonance imaging assessment of the temporomandibular joint in disc displacement. *Int J Oral Maxillofac Surg* 1994; **23**: 266–270.
25. Tallents RH, Katzberg RW, Murphy W, Proskin H. Magnetic resonance imaging findings in asymptomatic volunteers and symptomatic patients with temporomandibular disorders. *J Prosthet Dent* 1996; **75**: 529–533.
26. Emshoff R, Brandlmaier I, Bosch R, Gerhard S, Rudisch A, Bertram S. Validation of the clinical diagnostic criteria for temporomandibular disorders for the diagnostic subgroup – disc derangement with reduction. *J Oral Rehabil* 2002; **29**: 1139–1145.
27. Salonen L, Helldén L, Carlsson GE. Prevalence of signs and symptoms of dysfunction in the masticatory system: an epidemiologic study in an adult Swedish population. *J Craniomandibular Disord Facil Oral Pain* 1990; **4**: 241–250.
28. Güler N, Yatmaz PI, Ataoglu H, Emlik D, Uçkan S. Temporomandibular internal derangement: correlation of MRI findings with clinical symptoms of pain and joint sounds in patients with bruxing behaviour. *Dentomaxillofac Radiol* 2003; **32**: 304–310.
29. Kobs G, Bernhardt O, Kocher T, Meyer G. Critical assessment of temporomandibular joint clicking in diagnosing anterior disc displacement. *Stomatologija* 2005; **7**: 28–30.
30. Pullinger AG, Solberg WK, Hollender L, Petersson A. Relation of mandibular condylar position to dental occlusion factors in an asymptomatic population. *Am J Orthod Dentofacial Orthop* 1987; **91**: 200–206.
31. Fernandez Sanromán J, Gomez González JM, del Hoyo JA. Relationship between condylar position, dentofacial deformity and temporomandibular joint dysfunction: an MRI and CT prospective study. *J Cranio-Maxfac Surg* 1997; **26**: 35–42.
32. Hansson LG, Hansson T, Petersson A. A comparison between clinical and radiologic findings in 259 temporomandibular joint patients. *J Prosthet Dent* 1983; **50**: 89–94.
33. Kurita H, Ohtsuka A, Kobayashi H, Kurashina K. A study of the relationship between the position of the condylar head and displacement of the temporomandibular joint disc. *Dentomaxillofac Radiol* 2001; **30**: 162–165.
34. Wang EY, Mulholland TP, Pramanik BK, Nusbaum AO, Babb J, Pavone AG, et al. Dynamic sagittal half-fourier acquired single-shot turbo spin-echo MR imaging of the temporomandibular joint: initial experience and comparison with sagittal oblique proton-attenuation images. *AJNR Am J Neuroradiol* 2007; **28**: 1126–1132.
35. Chen YJ, Callo LM, Meier D, Palla S. Dynamic magnetic resonance imaging technique for the study of the temporomandibular joint. *J Orofac Pain* 2000; **14**: 65–73.
36. Shimazaki Y, Saito K, Matsukawa S, Onizawa R, Kotake F, Nishio R, et al. Image quality using dynamic MR imaging of the temporomandibular joint with true-FISP sequence. *Magn Reson Med Sci* 2007; **6**: 15–20.
37. Kayhan A, Oommen J, Dahi F, Oto A. Magnetic resonance enterography in Crohn's disease: standard and advanced techniques. *World J Radiol* 2010; **2**: 113–121.
38. Rantala MA, Ahlberg J, Suvinen TI, Savolainen A, Könönen M. Chronic myofascial pain, disc displacement with reduction and psychosocial factors in Finnish non-patients. *Acta Odontol Scand* 2004; **62**: 293–297.

3.2. Artigo 2

Lopes SL, Costa AL, Gamba Tde O, Flores IL, Cruz AD, Min LL. Lateral pterygoid muscle volume and migraine in patients with temporomandibular disorders. *Imaging Sci Dent.* 2015 Mar;45(1):1-5. doi: 10.5624/isd.2015.45.1.1. Epub 2015 Mar 13.

Este trabalho originou-se da minha pesquisa desenvolvida no período de Pós Doutorado na Faculdade de Ciências Médicas da Universidade Estadual de Campinas, FCM UNICAMP, no laboratório de Neuroimagem.

Abstract:

Purpose: Lateral pterygoid muscle (LPM) plays an important role in jaw movement and has been implicated in Temporomandibular disorders (TMDs). Migraine has been described as a common symptom in patients with TMDs and may be related to muscle hyperactivity. This study aimed to compare LPM volume in individuals with and without migraine, using segmentation of the LPM in magnetic resonance (MR) imaging of the TMJ. Materials and Methods: Twenty patients with migraine and 20 volunteers without migraine underwent a clinical examination of the TMJ, according to the Research Diagnostic Criteria for TMDs. MR imaging was performed and the LPM was segmented using the ITK-SNAP 1.4.1 software, which calculates the volume of each segmented structure in voxels per cubic millimeter. The chi-square and Fisher's exact test were used to relate the TMD variables obtained from the MR images and clinical examinations to the presence of migraine. Logistic binary regression was used to determine the importance of each factor for predicting the presence of a migraine headache. Results: Patients with TMDs and migraine tended to have hypertrophy of the LPM (58.7%). In addition, abnormal mandibular movements (61.2%) and disc displacement (70.0%) were found to be the most common signs in patients with TMDs and migraine. Conclusion: In patients with TMDs and simultaneous migraine, the LPM tends to be hypertrophic. LPM segmentation on MR imaging may be an alternative method to study this muscle in such patients because the hypertrophic LPM is not always palpable.

Lateral pterygoid muscle volume and migraine in patients with temporomandibular disorders

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ABSTRACT

Purpose: Lateral pterygoid muscle (LPM) plays an important role in jaw movement and has been implicated in Temporomandibular disorders (TMDs). Migraine has been described as a common symptom in patients with TMDs and may be related to muscle hyperactivity. This study aimed to compare LPM volume in individuals with and without migraine, using segmentation of the LPM in magnetic resonance (MR) imaging of the TMJ.

Materials and Methods: Twenty patients with migraine and 20 volunteers without migraine underwent a clinical examination of the TMJ, according to the Research Diagnostic Criteria for TMDs. MR imaging was performed and the LPM was segmented using the ITK-SNAP 1.4.1 software, which calculates the volume of each segmented structure in voxels per cubic millimeter. The chi-squared test and the Fisher's exact test were used to relate the TMD variables obtained from the MR images and clinical examinations to the presence of migraine. Logistic binary regression was used to determine the importance of each factor for predicting the presence of a migraine headache.

Results: Patients with TMDs and migraine tended to have hypertrophy of the LPM (58.7%). In addition, abnormal mandibular movements (61.2%) and disc displacement (70.0%) were found to be the most common signs in patients with TMDs and migraine.

Conclusion: In patients with TMDs and simultaneous migraine, the LPM tends to be hypertrophic. LPM segmentation on MR imaging may be an alternative method to study this muscle in such patients because the hypertrophic LPM is not always palpable. (*Imaging Sci Dent* 2015; 45: 1-5)

KEY WORDS: Pterygoid Muscles; Temporomandibular Joint Disorders; Migraine Disorders; Magnetic Resonance Imaging

Introduction

Temporomandibular disorders (TMDs) are characterized by pain around the temporomandibular joint (TMJ) and jaw muscles, limited jaw movement, and TMJ sounds.¹

Frequently, patients with TMDs also describe symptoms of headache, similar to those reported by patients diagnosed with tension-type or migraine headaches, according to the nosology developed by the International Headache Society.² The relationship between tension-type headache, which was formerly known as musculoskeletal headache, and myalgia of the masticatory muscles is well known and has been demonstrated in many patients with TMDs. However, only a few studies have shown a significant association between vascular headache or migraine and TMDs,

Received April 18, 2014; Revised January 1, 2015; Accepted January 3, 2015

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Imaging Science in Dentistry · pISSN 2233-7822 eISSN 2233-7830

with tenderness of the lateral pterygoid muscle (LPM) and the temporalis muscle commonly found in patients with migraine.³⁻⁶

The LPM makes a singular contribution to jaw movement control by virtue of its attachments to components of the TMJ, such as the capsule, disc, and condyle. The superior lateral pterygoid muscle is primarily attached directly to the disc and the TMJ capsule, contributing to disc stability and positioning, whereas the inferior lateral pterygoid muscle contributes primarily to jaw opening.⁷⁻⁹

No studies have yet been published relating the volume of the LPM to migraine in patients with TMDs. The purpose of this study was to compare the volume of the LPM in patients with migraine and a control group made up of volunteers without migraine, using the segmentation of the LPM in magnetic resonance (MR) images of the TMJ to determine the volume of the LPM. In addition, the most frequent signs and symptoms of TMDs were investigated in patients with migraine.

Materials and Methods

Research ethics committee approval was obtained for this study (protocol number 055/2005). The study sample comprised 20 patients with migraine (8 males and 12 females, age range 21-49 years, mean 39.3 years) and the control group comprised 20 volunteers without migraine or any signs or symptoms of TMDs (10 males and 10 females, age range 18-75 years, mean 42.4 years). Patients with migraine were diagnosed and selected by an expert neurologist according to the 2004 International Classification of Headache. Patients with no symptoms of migraine according to the international classification were excluded from the patient group.

Both the control and patient groups underwent a clinical examination of the TMJ conducted by an experienced orofacial pain specialist according to the Research Diagnostic Criteria for TMDs.¹⁰ The signs and symptoms of TMDs, such as mandibular range of motion (opening, laterotrusion, and protusion), joint noise, and muscle and/or TMJ pain on palpation, were evaluated and the resulting data were collected. All patients had some signs and symptoms of TMDs in both TMJs for at least five years and were referred by their dentists to the Orofacial Pain and Temporomandibular Disorders Center in the Department of Oral and Maxillofacial Surgery at the State University of Campinas (UNICAMP). Patients taking any type of medication for hypertension or heart disease, patients taking muscle relaxants, and patients who had undergone surgical treat-

ment of the TMJ, orthognathic surgery, or orthodontic treatment were excluded from the sample.

Image acquisition

MR imaging was performed on all patients and controls using a 1.5-T MR Imager (Sigma; General Electric, Milwaukee, WI, USA) with a bilateral and dedicated circular polarized 8.0-cm transmit-and-receive TMJ coil. Images were obtained in closed-mouth and open-mouth positions. Using the axial localizer image, parasagittal images (perpendicular to the condylar axis) were obtained and selected to analyze the disc-condyle relationship, using the following protocol.

In the closed-mouth images, the disc was considered to be in normal position when the posterior band of the disc was located at the most superior part of the condyle, as indicated by being in the 12 o'clock position relative to the condyle. The disc was considered displaced when the posterior band of the disc was located anterior to the superior part of the condyle.¹⁰ In the open-mouth images, the disc was considered reduced only if it was located between the condyle and the eminence.¹⁰

According to this protocol, if the disc was displaced - including anterior, anterolateral, and anterolateral displacements - in the closed-mouth images, and reduced in the corresponding open-mouth images, the disc was classified as experiencing disc displacement with reduction. In contrast, if the disc was displaced in the closed-mouth images and not reduced, but still displaced, in the corresponding open-mouth images, the disc was classified as experiencing disc displacement without reduction.

Condylar motion was considered normal in open-mouth images when the vertex of the condyle was situated beyond the articular eminence, and was considered abnormal when a bite block was necessary to maintain the open-mouth position and avoid motion artifacts.¹⁰

The same dentomaxillofacial radiologist evaluated all images, using Merge eFilm Workstation 1.5 (Merge Healthcare, Chicago, IL, USA). The images were interpreted on a 17-inch LCD monitor under appropriate conditions with suitable brightness.

Segmentation procedure: lateral pterygoid muscle volume

All the closed-mouth images were recorded in the Digital Imaging and Communications in Medicine format and then converted to the Analyze (Mayo Clinic, Rochester, USA) format using the MRIcro software (www.mccaus-

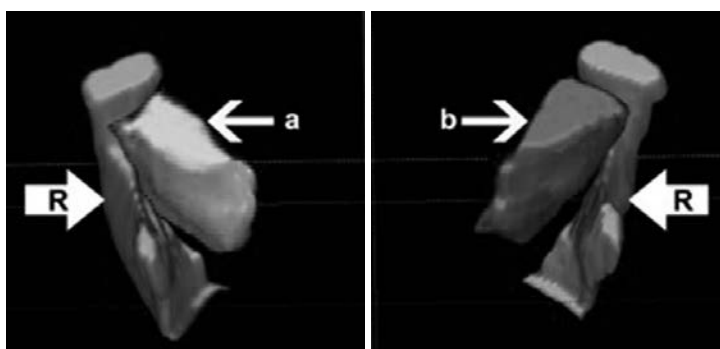


Fig. 1. Three-dimensional model of the segmented structures using the ITK-SNAP software in an anterior superior view shows the lateral pterygoid muscle (a, b), the condyle, the coronoid process of the mandible, and part of the mandibular ramus (R).

landcenter.sc.edu, MacCausland Center for Brain Imaging, Columbia, SC, USA). The Analyze format is required for processing and image fusion programs. The DICOM format contains text information about the patient, while the Analyze format only contains the raw image. All the Analyze images were exported into the ITK-SNAP 1.4.1 software (University of North Carolina, Chapel Hill, NC), which calculates the volume of each segmented structure in voxels per cubic millimeter.¹¹ In this study, the images of the muscles in each corresponding slice were segmented in the axial, sagittal, and coronal planes to obtain the LPM volume of each TMJ. The right and left LPMs were segmented individually, using different labels and colors (red for the right and dark pink for the left), in order to obtain the volume for each LPM. The condyle, coronoid process, and part of the ramus of the mandible (labeled in light blue) were also segmented, in order to provide orientation landmarks in the three-dimensional models (Fig. 1).

All the LPM volumes (right and left, separately) were recorded in tables and related to the clinical findings (signs and symptoms) that were obtained by clinical examinations following the Research Diagnostic Criteria for TMDs and by MR imaging of the TMJ. This was carried out in the same manner for all patients with migraine and the control group.

The chi-squared test and the Fisher's exact test, with p -values < 0.05 considered to indicate statistical significance, were performed to relate the TMD variables on the MR images to the variables obtained from clinical examinations (disc displacement, disc reduction, normal or abnormal condyle motion, articular and/or muscle pain, mandibular range of motion, and joint noise) for the control and migraine groups. The t -test was used to compare LPM volume values with different variances (P ($t=1$) one-tailed=

Table 1. Analysis of the factors from closed-mouth images involved in temporomandibular disorders in the control and migraine groups according to the chi-squared and Fisher's exact tests

TMD factors	Control group	Migraine group	P-value
No disc displacement	32	12	
Disc displacement	8	28	$< 0.0001^a$
Total	40	40	
Disc reduction	35	25	
No disc reduction	5	15	0.019 ^a
Total	40	40	
Normal condyle motion	34	14	
Abnormal condyle motion	6	26	$< 0.0001^a$
Total	40	40	
No joint noise	34	27	
Joint noise	6	13	0.0282 ^a
Total	40	40	
No pain	33	20	
Pain	7	20	$< 0.0001^a$
Total	40	40	
Normal mandibular motion	18	6	
Limited mandibular motion	2	14	0.0001 ^b
Total	20	20	

^achi-squared test, ^bFisher's exact test, TMD: temporomandibular disorders

0.000001). All tests were performed using the Minitab statistical software (Minitab Inc., State College, PA, USA).

Logistic binary regression was applied in order to study the importance of each factor for predicting the presence of migraine headache.

Results

Statistically significant differences between the two groups were found for all the variables analyzed. This was confirmed by the chi-squared and Fisher's exact tests, with p -values < 0.05 considered to indicate statistical significance.

Table 2. Analysis of the relevance percentage of each factor in the patients with migraine headache according to the logistic binary regression test

Factor	Migraine (% relevance)	LPM volume (% relevance)	Disc displacement (% relevance)	Disc reduction (% relevance)	Condyle motion (% relevance)	TMJ noise (% relevance)	Pain (% relevance)
LPM volume	58.7	—	—	—	—	—	—
Disc displacement	70.0	34.5	—	—	—	—	—
Disc reduction	28.9	17.3	58.0	—	—	—	—
Condyle motion	45.5	13.9	44.2	38.0	—	—	—
TMJ noise	20.6	16.8	44.0	32.2	0.4	—	—
Pain	34.4	11.7	57.6	68.7	45.6	8.8	—
Mandibular motion	61.2	25.5	54.4	35.4	69.2	14.4	61.2

LPM: lateral pterygoid muscle, TMJ: temporomandibular joint

cance. Disc displacement, absence of disc reduction, abnormal condyle motion, joint noise, articular and/or muscle pain, and limited mandibular range of motion were found more frequently in the migraine group than the control group (Table 1).

With regard to the volume of the LPM, the *t*-test showed a statistically significant relationship between migraine and increase of LPM volume. According to logistic binary regression, the relevant factors that predicted the presence of migraine headache were limited mandibular motion (relevance 61.2%), increased volume of the LPM (relevance 58.7%), and disc displacement (70.0%) (Table 2).

Discussion

Patients diagnosed with painful TMDs often report headaches and pain, typically located in the mastication muscles.³ Although it has been suggested that TMDs can be a trigger for migraine, the role of muscle hyperactivity in migraine has not been clearly established.¹² The main results of this study are that the LPM was hypertrophic in most of the patients with migraine and that these patients had signs and symptoms of TMDs (such as pain, joint noise, and disc displacement) when migraine was present. The human LPM plays an important role in the control of jaw movement and has been implicated in TMDs because it is very tender in patients with TMDs.^{11,13,14} Moreover, a widespread hypothesis exists that abnormal patterns of LPM activity in some patients with TMDs, associated with hyperactivity of the superior head of the LPM, could lead to degenerative arthritic changes in the TMJ.^{1,13,14} Our study was performed using a specific method that allowed a realistic evaluation of the structure of the LPM, using MR imaging and reliable software to calculate its volume, which was then related to the signs and symptoms of TMDs and the presence of migraine. Previous studies eval-

uating the functional properties of the LPM in patients with TMDs were based on palpation and electromyographic activity, which is widely known to be a challenging method to apply to this group of muscles.^{1,13}

Another important finding in this study was the relative importance of each factor (TMD signs and symptoms) and the volume of the LPM for predicting the presence or absence of migraine. The results showed that the three most important variables related to migraine in patients with migraine were abnormal mandibular motion, hypertrophic LPM volume, and the presence of disc displacement in the TMJ.¹⁰ Our study found a relationship between disc displacement/reduction and abnormal mandibular motion. Mandibular deviation was related to disc displacement with reduction, whereas mandibular deflection was related to disc displacement without reduction.

Considering the high percentage of patients with migraine and disc displacement (70.0%), it is possible that the activity of the LPM can increase in order to stabilize the displaced disc during mandibular movements, which could lead to hypertrophic muscles, as have been observed in patients with TMDs and migraine. Previous studies in which the TMJ was dissected have shown that the superior surface of the upper head of the lateral pterygoid and the midmedial muscle bundle were attached to the disc.¹⁵ These findings could explain the hypertrophic LPM that is so common in patients with migraine who have one of the most prevalent signs of disc displacement; abnormal disc position could stimulate LPM activity in an attempt to preserve normal function and position.

D'Ippolito et al.¹⁶ studied the visibility of the LPM on MR imaging and concluded that alterations in the thickness of the LPM are more frequent in patients with TMDs.¹⁶ In our study, both groups (controls and patients with migraine) had TMDs, but the thickness of the LPM was only significant in the migraine group. Some studies have shown

no statistically significant correlations between LPM alterations and TMJ abnormalities; however, they only used visual analysis of the MR images instead of LPM segmentation. We consider the segmentation method to be more accurate than visual analysis, because it provides a numerical value for the volume of the LPM.¹⁷

Taskaya-Yılmaz et al.⁹ concluded that the LPM is atrophied and degenerated in TMJs with disc displacement and no reduction. This result differs from ours, which can probably be explained by their visual evaluation of atrophy and degeneration on MR images, compared to our use of specific software to accurately calculate the real segmented volume of the LPM. In addition, the duration of the symptoms may help to explain the difference between their findings and ours. In our study, the patients with migraine had acute symptoms, which can increase the volume of the LPM. However, Taskaya-Yılmaz et al.'s study contained no information about whether the symptoms were acute or chronic, and the decreased LPM volume they observed was probably related to the presence of chronic symptoms in their patients.

It may prove useful to consider the inferior and superior parts of the LPM separately. Some studies have examined the muscle architecture of the superior and inferior heads of the LPM using cadaveric specimens.¹⁸ We did not perform segmentation separately on the superior and inferior parts of the LPM in order to consider the distinct heads of the muscle, because it was difficult to determine the real limits of each head on the MR images. Moreover, this method could lead to misinterpretation and erroneous conclusions about the LPM.

In conclusion, this study showed that the LPM tends to be hypertrophic in patients with TMDs and simultaneous migraine. Furthermore, disc displacement and abnormal mandibular movements seem to be the most common signs in patients with migraine and TMDs. Although not all patients with TMDs and migraine showed LPM hypertrophy, our results suggest that TMDs can be a cause of LPM hypertrophy. Moreover, our results suggest that the known difficulties in using palpation alone to study the LPM may be circumvented by employing LPM segmentation on MR imaging as an alternative method for studying this muscle group.

References

1. Murray GM, Bhutada M, Peck CC, Phanachet I, Sae-Lee D, Whittle T. The human lateral pterygoid muscle. *Arch Oral Biol* 2007; 52: 377-80.
2. Lipton RB, Bigal ME, Steiner TJ. Classification of primary headaches. *Neurology* 2004; 63: 427-35.
3. Ballegaard V, Thede-Schmidt-Hansen P, Svensson P, Jensen R. Are headache and temporomandibular disorders related? A blinded study. *Cephalalgia* 2008; 28: 832-41.
4. DeRossi S, Stoopler E, Sollecito T. Temporomandibular disorders and migraine headaches: comorbid conditions? *Internet J Dent Sci* 2005; 2.
5. Svensson P. Muscle pain in the head: overlap between temporomandibular disorders and tension-type headaches. *Curr Opin Neurol* 2007; 20: 320-5.
6. Kreisberg MK. Headache as a symptom of craniomandibular disorders. I: Pathophysiology. *Cranio* 1986; 4: 135-42.
7. Murray GM, Phanachet I, Uchida S, Whittle T. The role of the human lateral pterygoid muscle in the control of horizontal jaw movements. *J Orofac Pain* 2001; 15: 279-92.
8. Murray GM, Phanachet I, Uchida S, Whittle T. The human lateral pterygoid muscle: a review of some experimental aspects and possible clinical relevance. *Aust Dent J* 2004; 49: 2-8.
9. Taskaya-Yılmaz N, Ceylan G, Incesu L, Muglali M. A possible etiology of the internal derangement of the temporomandibular joint based on the MRI observations of the lateral pterygoid muscle. *Surg Radiol Anat* 2005; 27: 19-24.
10. Tasaki MM, Westesson PL. Temporomandibular joint: diagnostic accuracy with sagittal and coronal MR imaging. *Radiology* 1993; 186: 723-9.
11. Wang MQ, Yan CY, Yuan YP. Is the superior belly of the lateral pterygoid primarily a stabilizer? An EMG study. *J Oral Rehabil* 2001; 28: 507-10.
12. Lamey PJ, Burnett CA, Fartash L, Clifford TJ, McGovern JM. Migraine and masticatory muscle volume, bite force, and craniofacial morphology. *Headache* 2001; 41: 49-56.
13. Türp JC, Minagi S. Palpation of the lateral pterygoid region in TMD - where is the evidence? *J Dent* 2001; 29: 475-83.
14. Yushkevich PA, Piven J, Hazlett HC, Smith RG, Ho S, Gee JC, et al. User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability. *Neuroimage* 2006; 31: 1116-28.
15. Headache Classification Subcommittee of the International Headache Society. The international classification of headache disorders. 2nd ed. Oxford; Blackwell Pub: 2004. p. 9-160.
16. D'Ippolito SM, Borri Wolosker AM, D'Ippolito G, Herbert de Souza B, Fenyó-Pereira M. Evaluation of the lateral pterygoid muscle using magnetic resonance imaging. *Dentomaxillofac Radiol* 2010; 39: 494-500.
17. Dergin G, Kilic C, Gozneli R, Yildirim D, Garip H, Moroglu S. Evaluating the correlation between the lateral pterygoid muscle attachment type and internal derangement of the temporomandibular joint with an emphasis on MR imaging findings. *J Craniomaxillofac Surg* 2012; 40: 459-63.
18. Davies JC, Charles M, Cantelmi D, Liebgott B, Ravichandiran M, Ravichandiran K, et al. Lateral pterygoid muscle: a three-dimensional analysis of neuromuscular partitioning. *Clin Anat* 2012; 25: 576-83.

3.3. Artigo 3

Melke GSF, Costa ALF, Lopes SLPC, Fuziy A, Ferreira-Santos RI. Three-dimensional lateral pterygoid muscle volume: MRI analyses with insertion patterns correlation. *Ann Anat.* 2016 Nov;208:9-18. doi: 10.1016/j.aanat.2016.05.007. Epub 2016 Jun 7.

Este trabalho foi realizado em parceria com pesquisadores da Universidade da Cidade de São Paulo, UNICIC.

Abstract:

We evaluated lateral pterygoid muscle volume in closed and open mouth positions in association with anterior disc displacement, effusion and abnormal articular disc shape from three-dimensional reformations of MRI. A total of 24 MRI of a sample (15 females, 9 males) aged 19–64 years (37.2 years $\pm$ 11.4) were assessed. Segmentation and volumetric assessment of the total, upper and lower heads of the lateral pterygoid muscle were performed using free software. The upper head of the lateral pterygoid muscle had a smaller volume than the lower head at both sides, in the closed- and open-mouth positions. In the open-mouth position, individuals with a subdivided upper head, where one component was inserted in the articular disc and another in the mandibular head, displayed a significantly larger volume of the upper head compared to individuals who had a single attachment to the articular disc ($p = 0.0130$). The lateral pterygoid muscle has different volumes in the closed- and open-mouth positions. Gender affected muscle volume, specifically the upper head component. Insertion type in the upper head also seemed to affect muscle volume.



Research article

Three-dimensional lateral pterygoid muscle volume: MRI analyses with insertion patterns correlation



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ARTICLE INFO

Article history:

Received 11 March 2016

Received in revised form 25 April 2016

Accepted 13 May 2016

Keywords:

Temporomandibular joint

Muscle, Skeletal

MRI, Diagnostic imaging

ABSTRACT

We evaluated lateral pterygoid muscle volume in closed and open mouth positions in association with anterior disc displacement, effusion and abnormal articular disc shape from three-dimensional reformations of MRI. A total of 24 MRI of a sample (15 females, 9 males) aged 19–64 years ($37.2 \text{ years} \pm 11.4$) were assessed. Segmentation and volumetric assessment of the total, upper and lower heads of the lateral pterygoid muscle were performed using free software. The upper head of the lateral pterygoid muscle had a smaller volume than the lower head at both sides, in the closed- and open-mouth positions. In the open-mouth position, individuals with a subdivided upper head, where one component was inserted in the articular disc and another in the mandibular head, displayed a significantly larger volume of the upper head compared to individuals who had a single attachment to the articular disc ($p = 0.0130$). The lateral pterygoid muscle has different volumes in the closed- and open-mouth positions. Gender affected muscle volume, specifically the upper head component. Insertion type in the upper head also seemed to affect muscle volume.

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1. Introduction

During the past decades, an increasing number of studies have focused on the temporomandibular joint (TMJ) because of its complex anatomy and relatively high susceptibility to pathological alterations (Costa et al., 2008a, 2008b, 2014; Dworkin, 2010; Dworkin and LeResche, 1992; Lopes et al., 2012). Such alterations often result in symptoms that characterize a temporomandibular disorder (TMD). The anterior articular disc displacement represents the most prevalent TMD (Costa et al., 2008a). Diagnosis in these cases requires precise location of the disc, usually via magnetic resonance imaging (MRI) (Costa et al., 2008b; Tomas et al., 2006).

This imaging technique also allows for the assessment of muscles of mastication and their possible involvement in TMD (Balcioglu et al., 2009; Barriere et al., 2009; D'Ippolito et al., 2010; Farrugia et al., 2007; Goto et al., 2002; Imanimoghaddam et al., 2013; Lamey et al., 2001; Mazza et al., 2009; Ng et al., 2009; Omami

and Lurie, 2012; Schellhas, 1989; Taskaya-Yilmaz et al., 2005). The lateral pterygoid muscle (LPM) represents one of the most important muscles in the physiology of mastication, and, inserted in the TMJ, it acts in mandibular opening, lateral movement and protrusion (D'Ippolito et al., 2010; Omami and Lurie, 2012). The LPM is a symmetric paired muscle, located in the interior of the infratemporal fossa, formed by an upper head (connected to the TMJ articular disc) and a lower head (Imanimoghaddam et al., 2013; Mazza et al., 2009; Omami and Lurie, 2012). Articular disc displacements without reduction or effusion may result from alterations in the physiology of muscles of mastication (Costa et al., 2008a; D'Ippolito et al., 2010).

Previous studies report increased LPM volume occurring in parallel to (and on the same side as) unilateral mastication (Goto et al., 2002), and greater thickness of this muscle is associated with anterior disc displacement and articular hypermobility (Benington et al., 1999). However, some authors suggest that anterior articular disc displacement without reduction may correlate with atrophy of the upper head of the lateral pterygoid muscle (Balcioglu et al., 2009).

In this study, we used MRI to evaluate associations between lateral pterygoid volume – total muscle, upper and lower head volumes – in open- and closed-mouth positions with TMDs, including

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<http://dx.doi.org/10.1016/j.aanat.2016.05.007>

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Table 1
Sample characteristics: gender, age and TMJ pain.

Characteristics	Gender				Total	
	Female		Male			
	n	%	n	%	n	%
Age						
≤39	10	66.7	4	44.4	14	58.3
≥40	5	33.3	5	55.6	10	41.7
Pain						
No	10	66.7	5	55.6	15	62.5
Yes	5	33.3	4	44.4	9	37.5
Total	15	100.0	9	100.0	24	100.0

anterior articular disc displacements, effusion, and morphological alterations in the articular disc.

2. Materials and methods

2.1. Sample selection

The images were originally taken as part of previous research. After approval by the UNICID Research Ethics Committee (protocol number 13350813.1.0000.0064), MRI from 24 patients (15 women and 9 men) between 19 and 64 years of age ($37.2 \text{ years} \pm 11.4$) were selected for analysis, from an initial sample derived from 57 individuals. Discarded images were not clear enough, as per the exclusion criteria discussed below. Five of the 24 patients were diagnosed with anterior articular disc dislocation and effusion, 6 had only anterior articular disc dislocation, 3 had only effusion, and the remaining 10 were negative for both TMDs. Based on the physical exams performed prior to this study, 33.3% of women and 44.4% of men reported TMJ pain (Table 1).

Two dentomaxillofacial radiologists evaluated the MRIs in the open- and closed-mouth positions to describe disc morphology and diagnose dislocation and/or effusion. The position of articular discs was defined based on previously established criteria using parasagittal images (Lopes et al., 2012). Discs were considered normally positioned when, in a closed mouth, their posterior band aligned with the superior part of the mandible head, an anterior articular disc displacement was defined by the anterior positioning of the posterior band of the disc in relation to the mandible head. In MRIs of open mouths, the anterior dislocations were grouped as “with reduction” – when the posterior band of the disc realigned with the mandible head – or “without reduction” – when the disc maintained an anterior position in relation to the articular tubercle (Taskaya-Yilmaz et al., 2005). Articular effusion was identified as a hyperintense signal in the superior and/or inferior articular spaces

(Costa et al., 2008a). Articular disc morphology was analyzed in the open- and closed-mouth positions and classified as normal biconcave or abnormal with altered morphology (Fig. 1) (Amaral Rde et al., 2013).

The MRI files were selected according to the following inclusion criteria (Costa et al., 2008b): all patients should have received a positive or negative diagnosis of anterior articular disc displacement, through MRI analysis. However, patients could not have concurrent conditions such as rheumatoid arthritis, rheumatic psoriasis, and severe myasthenia (Schellhas, 1989). Exclusion criteria included: impaired visualization of the LPM; impaired visualization of details; images with low sharpness resulting from patient movements during scanning; signs of previous patient trauma; signs of other systemic conditions that might alter the TMJ and muscles of mastication; presence of metallic prosthetics and accessories and any history of TMJ-related therapy.

2.2. Image acquisition data

All patients were submitted to bilateral MRI of the TMJ in Signa 1.5T equipment (GE Medical systems, Milwaukee, WI, USA) with 8.5 cm surface coils. Initially, 24 axial T1-weighted slices were acquired in *spin echo* (SE) sequence (repetition time TR = 1400 ms, echo time TE = 1.6 ms, slice thickness ST = 5.0 mm field of vision FOV of 18.0 cm × 18.0 cm, in a 256 × 256 matrix). Among these slices, we selected the one allowing for better visualization of the mandible along its long axis. Based on this slice, we then established the orientation of the parasagittal planes. In this study, specifically, we utilized parasagittal proton-density images of the closed-mouth and open-mouth positions in SE sequence (TR = 1200 ms, TE = 13.7 ms, ST = 3.0 mm, FOV = 150 cm × 150 mm, image matrix = 512 × 512, excitation number NEX = 2, radiofrequency 4 and excitation angle of the radiofrequency pulse/flip angle = 20°). All parasagittal slices in the lateromedial direction were analyzed. To evaluate pathological states, including effusion, we utilized oblique sagittal T2-weighted images (TR = 1500.0 ms, TE = 100.2 ms, ST = 3.0 mm, FOV = 15 cm × 15 cm, and 512 × 512 matrix) with central cuts in three stages (closed-mouth, half-open mouth and open-mouth).

2.3. Image segmentation and volumetry

Selected MRI files were number-coded to protect patient identities and converted from DICOM (*Digital Imaging and Communications in Medicine*) to the ANALYZE format utilizing the MRICro software (www.mricro.com). After format conversion, the ITKSNAP® software (<http://www.itksnap.org/download/snap/>) was utilized to segment the entire right and left lateral pterygoid

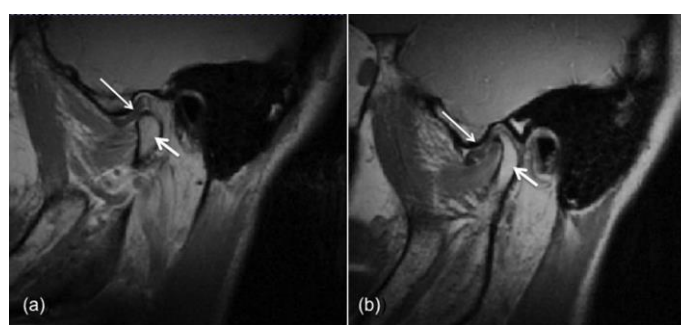


Fig. 1. Articular disc morphology in the closed-mouth position: (a) normal and (b) altered. Long arrow: articular disc; short arrow: condyle.

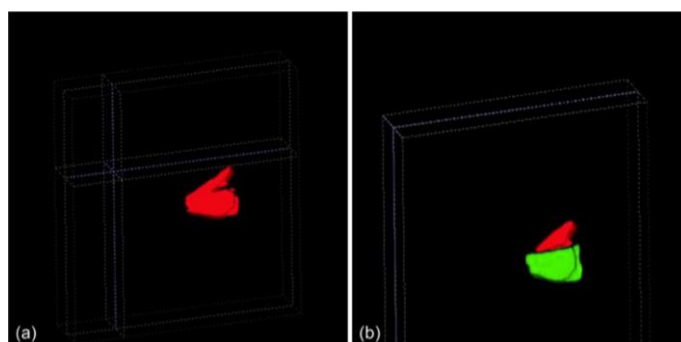


Fig. 2. Three-dimensional images of the lateral pterygoid muscle, obtained after segmentation: (a) total muscle and (b) upper head in red and lower head in green. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

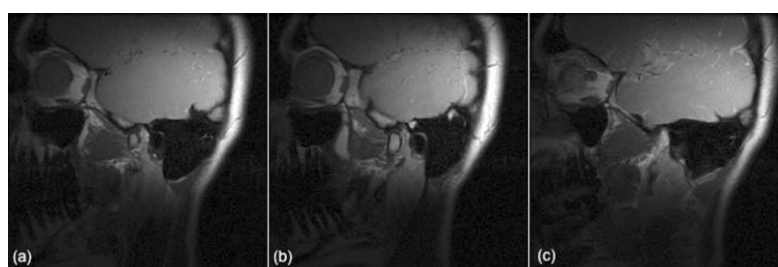


Fig. 3. Insertion type I: the upper head is subdivided into two components, one inserted in the articular disc and the other in the head of the mandible (open-mouth position): (a) lateral image, (b) central image and (c) medial image.

muscles, as well as their upper and lower heads (Fig. 2) (Yushkevich et al., 2006). This software allows for an active contour of anatomical structures and for the segmentation of regions delineated by the examiner (Costa et al., 2008b; Yushkevich et al., 2006). The process of segmentation correlates image points (voxels) to specific anatomical structures. In the current study, we selected the three consecutive slices with the most detail and sharpness for each TMJ (Fujita et al., 2001). Selected images had a 512×512 matrix with pixels and voxels measuring 0.29 mm (height) $\times$ 0.29 mm (width) $\times$ 3.00 mm (depth). The software generates volumetric data after 3D image reconstruction.

The closed- and open-mouth images were randomized, segmented and 3D reconstructed in a Sony Vaio i7[®] S 13" SVS notebook

(Sony Corporation, China). The examiner could manipulate brightness, contrast and zoom utilizing the software tools to improve diagnosis. Fifteen days after the first stage of evaluation, the examiner repeated the procedure for 14 randomly selected patients, utilizing closed- and open-mouth images.

In addition to volumetric data, the examiner also registered the insertion pattern of the upper head of the LPM, using closed- and open-mouth images (Dergin et al., 2012; Imanimoghaddam et al., 2013; Mazza et al., 2009). Three insertion types were defined: type I (Fig. 3) – the upper head is subdivided into two components, one inserted in the articular disc and the other in the mandible head; type II (Fig. 4) – there is no subdivision of the upper head, but the muscle is inserted in both the articular disc and the mandible head;

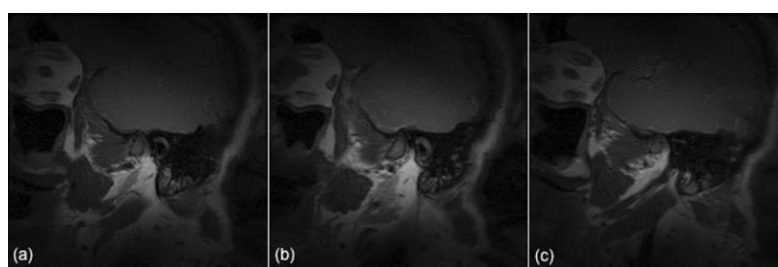


Fig. 4. Insertion type II: the upper head of the muscle has no subdivisions, but it is still inserted in both the articular disc and the head of the mandible (closed-mouth position): (a) lateral image, (b) central image and (c) medial image.

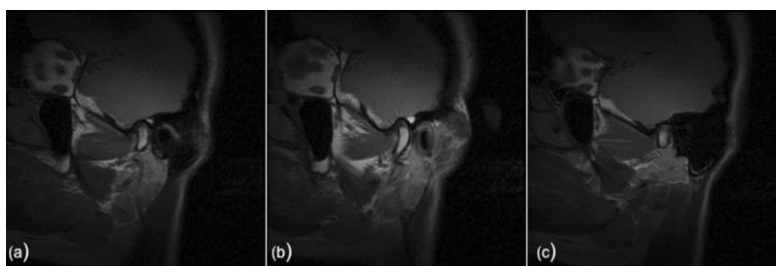


Fig. 5. Insertion type III: the upper head of the muscle has no subdivisions and is only connected to the articular disc (closed-mouth position): (a) lateral image, (b) central image and (c) medial image.

and type III, the muscle upper head, with no subdivisions, is inserted in the articular disc (Fig. 5). Three-dimensional images of all three different patterns were acquired as well (Fig. 6).

2.4. Statistical analyses

The reproducibility of volume estimates for the lateral pterygoid muscle was assessed through Lin's concordance correlation coefficient and Spearman's correlation. Comparisons of volumetric data from closed- and open-mouth images were performed using averages and the likelihood-ratio test. Co-variance effects such as side (right and left), gender, age group, type of insertion of the muscle upper head, articular disc morphology, presence/absence of effusion, and position of the articular disc (normal/anterior dislocation with or without reduction) were analyzed by linear regression

($\alpha = 5\%$). Analyses were performed utilizing the R software, version 3.0.2 (The R Foundation for Statistical Computing, Vienna, Austria).

3. Results

The most prevalent type of insertion was characterized by a single upper head of the LPM adhering both to the disc and the mandible head (type II), accounting for 50% of insertions on the right side and 75% on the left. Most patients presented some morphological alteration to the right (54.2%) and left (70.8%) articular discs. The effusion signal varied between 20.8% and 29.2%. The frequency of images compatible with disc dislocation, with or without reduction, was lower than 40% (Table 2).

Measurements were highly consistent and reproducible, as shown in Table 3: Spearman's coefficients ranged between 0.857

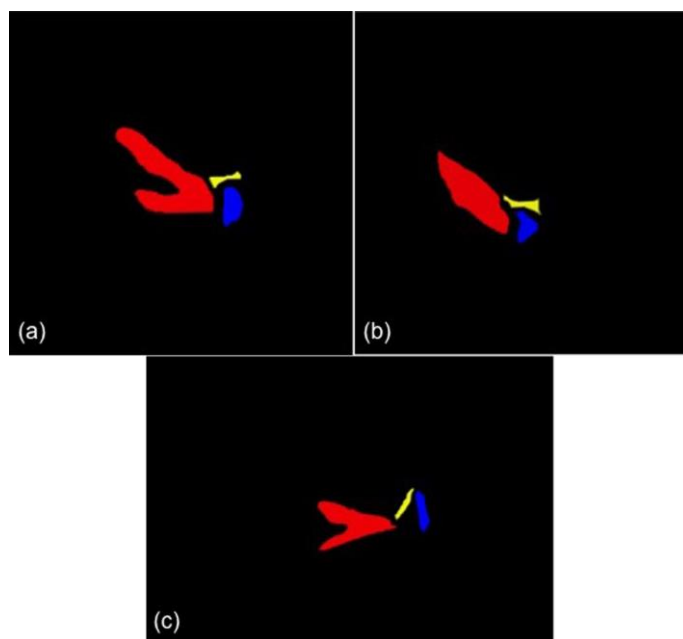


Fig. 6. Three-dimensional images of different insertion types of the upper head of the lateral pterygoid muscle: (a) insertion type I, (b) insertion type II and (c) insertion type III. The upper head (red), articular disc (yellow) and condyle (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2

Distribution of the sample according to type of insertion of the lateral pterygoid upper head, articular disc morphology, effusion signal, and articular disc displacement.

Characteristic	Side			
	Right		Left	
	n	%	n	%
<i>Insertion type</i>				
I	1	4.2	3	12.5
II	12	50.0	18	75.0
III	11	45.8	3	12.5
<i>Disc morphology</i>				
Normal	11	45.8	7	29.2
Altered	13	54.2	17	70.8
<i>Effusion</i>				
Absent	17	70.8	19	79.2
Present	7	29.2	5	20.8
<i>Disc displacement</i>				
Absent	15	62.5	16	66.7
Without reduction	7	29.2	7	29.2
With reduction	2	8.3	1	4.2
Total	24	100.0	24	100.0

and 0.998, $p < 0.0001$, and Lin's concordance correlation coefficient (CCC) for the two measurements ranged between 0.898 and 0.999.

As evidenced by the standard deviation values shown in Table 4, muscle volumes varied considerably from the average, suggesting that median values may provide a more solid basis for analysis. Thus, the median volumes of the upper heads of the muscle on both sides and both mouth positions were lower than those from the lower head of the muscle. Additionally, muscle volumes were lower in the open-mouth compared to the closed-mouth position.

Table 3

Analysis of correlation and reproducibility.

Muscle/mouth position	Measure	Average (mm ³)	SD	Spearman's correlation [*]	Lin's		
					CCC	CI 95%	
Total/closed	1	4649.2	1325.6	0.9984	0.9994	0.9987	0.9997
	2	4641.5	1313.8				
Total/opened	1	5188.8	4394.1	0.9850	0.9993	0.9986	0.9997
	2	5115.2	4456.9				
Upper/closed	1	1598.7	431.1	0.9973	0.9973	0.9947	0.9987
	2	1582.4	443.8				
Lower/closed	1	2953.0	1070.4	0.8571	0.8986	0.7938	0.9516
	2	3015.7	1044.2				
Upper/opened	1	2053.1	1917.2	0.9467	0.9983	0.9962	0.9992
	2	2007.9	1913.7				
Lower/opened	1	3068.9	2530.1	0.9836	0.9994	0.9987	0.9997
	2	3039.7	2526.6				

^{*} $p < 0.0001$ for all estimates.

Table 4

Total, upper head, and lower head volumes of pterygoid muscles.

Volumes in mm ³							
Mouth position	Side	Muscle part	Min	Max	Med	Avg	SD
Closed	Right	Upper	693.2	5121.7	1787.6	2021.7	962.4
		Lower	1057.5	17,535.8	3340.4	3964.5	3156.6
		Total	2187.5	23,030.7	5053.0	6160.5	3984.3
	Left	Upper	558.6	3315.0	1809.4	1844.4	634.2
		Lower	1027.9	5605.1	3061.3	3140.2	1165.0
		Total	1663.8	7593.0	4938.6	4932.1	1604.6
Opened	Right	Upper	745.6	6964.6	1435.3	1815.3	1211.0
		Lower	719.5	10,024.7	2937.3	3164.5	1802.3
		Total	2003.1	17,215.0	4429.9	5081.8	2906.3
	Left	Upper	818.2	11,221.2	1755.9	2546.4	2581.5
		Lower	1492.0	15,051.7	2762.3	3580.3	2991.7
		Total	2262.8	26,335.9	4657.1	6230.9	5595.3

Table 5

Likelihood ratio test for comparisons between average muscle volumes in the open- and closed-mouth positions.

	Differences between averages for the open- and closed-mouth positions	p-value
Total	622.0	0.0004
Upper head	109.5	0.5090
Lower head	501.5	0.0015

The likelihood ratio test validated this observation for total muscle volume and for the lower head of the muscle (Table 5).

To evaluate potential effects of side, gender, age group, type of insertion, disc morphology, effusion signal, and anterior displacement, we employed mixed models of linear regression, controlling for the variability of repeated measures on the right and left sides. According to the Shapiro–Wilks test, the residuals departed from normality ($p > 0.05$).

Type of insertion had a significant effect on total muscle volume in the closed-mouth position (Table 6). If we take the type II insertion as a reference for comparison, patients with type III insertion had significantly larger muscle volume ($p = 0.0020$). Similarly, patients with type III insertions had larger volumes than those with type I ($p = 0.0338$).

When assessing muscle volume in the open-mouth position, we detected an effect of gender (Table 7). Total muscle volume was significantly larger in male compared to female patients ($p = 0.0272$).

Table 8 shows that, in the closed-mouth position, the volume of the upper head of the lateral pterygoid muscle was significantly larger among male patients ($p = 0.0002$).

Three co-variables significantly affected the volume of the upper head of the lateral pterygoid in the open-mouth position: gender, insertion type, and anterior articular disc displacement (Table 9). In

Table 6

Linear regression analysis correlating patient variables and the volume of the lateral pterygoid muscle in the closed-mouth position.

Variable	Category	Total Volume					
		Simple linear mixed model			Multiple linear mixed model		
		Avg	SE	<i>p</i> ^a -value	Beta	SE	<i>p</i> ^b -value
Intercept	–	–	–		4845.6	324.2	<0.0001
Side	Right	5276.7	341.1	0.0898	53.3 ^c	450.4	0.9060
	Left	4932.1	338.7				
Gender	Female	4909.6	407.0	0.4105			
	Male	5455.3	560.4				
Age group	≤39	5423.3	413.7	0.1958			
	≥40	4587.8	518.6				
Insertion type	I	4898.9	497.9	0.0070			
	II	4845.6	324.3				
	III	5873.1	392.2	1027.5	332.9	0.0020	
Format	Normal	5283.3	415.9	0.4670			
	Altered	4977.4	370.1				
Effusion	No	4916.4	347.5	0.0998			
	Yes	5605.8	448.6				
Displacement	No	5039.6	359.7	0.6827			
	Yes	5197.5	409.8				

^a Refers to the likelihood ratio test of differences among averages.^b Refers to the *t*-test comparing the beta coefficient to zero.^c Reference category used for the comparisons.

the simple linear model, differences were not significant, although they obtained a *p*-value that was close to 0.05. In the multiple linear model, in fact, male patients displayed a significantly larger volume of the upper head of the lateral pterygoid compared to females ($p = 0.0288$). Patients with type I insertion had significantly larger volumes than type III insertion patients ($p = 0.0130$), whereas there was only a tendency for type II insertion patients to have larger volumes than type III insertion patients ($p = 0.0684$). Patients with any degree of articular displacement had larger upper head volumes than those without displacement ($p = 0.0358$). This finding could result from a confounding or associative effect of displacement-gender, displacement-insertion and/or gender-insertion. However, when we evaluated the joint effect of these three co-variables, all of them displayed a significant effect.

Table 10 shows that the lower head muscle volume in the closed-mouth position was significantly larger in patients with type III insertion in comparison with type II ($p = 0.0033$). In the open-mouth position (Table 11), the lower head volume was larger on the right side relative to the left ($p = 0.0412$).

4. Discussion

In previous studies, authors have diverged about the number of insertion patterns of the upper head of the LPM. While some authors (Omami and Lurie, 2012; Taskaya-Yilmaz et al., 2005) report two types of insertion – a single insertion in the articular disc, or simultaneous insertion in the disc and in the head of the mandible – others claim there are three types of insertion (Dergin et al., 2012; Imanimoghaddam et al., 2013; Mazza et al., 2009). After detailed evaluation of the MRI files, we indeed find that three types of insertion can be described for the upper head of the muscle (Fig. 2) (Imanimoghaddam et al., 2013; Mazza et al., 2009). Based on the interpretation of parasagittal MR images of the LPM in the open- and closed-mouth positions, we observed that type II represented the most frequent insertions, whereas type I represented the least frequent (Table 2). Other studies reported similarly higher frequencies for type II insertions (Dergin et al., 2012). Besides, some authors (Imanimoghaddam et al., 2013) reported the highest prevalence for type I (63.8%) and the lowest for type III (12.5%) insertions.

Table 7

Linear regression analysis correlating patient variables and the volume of the lateral pterygoid muscle in the open-mouth position.

Variable	Category	Total volume					
		Simple linear mixed model			Multiple linear mixed model		
		Avg	SE	<i>p</i> ^a -value	Beta	SE	<i>p</i> ^b -value
Intercept	–	–	–		4033.4	307.5	<0.0001
Side	Right	4530.3	273.3	0.6984	1173.5 ^c	531.2	0.0272
	Left	4491.4	274.2				
Gender	Female	4175.2	305.6	0.0500			
	Male	5232.2	446.8				
Age group	≤39	4725.2	350.1	0.3222			
	≥40	4203.7	420.3				
Insertion type	I	4502.8	346.5	0.9866			
	II	4502.7	280.4				
	III	4531.8	300.6				
Format	Normal	4558.8	309.3	0.7513			
	Altered	4482.2	285.8				
Effusion	No	4523.8	274.6	0.8110			
	Yes	4470.5	320.6				
Displacement	No	4421.8	273.9	0.1156			
	Yes	4724.6	300.1		353.4	192.1	0.0655

^a Refers to the likelihood ratio test of differences among averages.^b Refers to the *t*-test comparing the beta coefficient to zero.^c Reference category used for comparisons.

Table 8

Linear regression analysis correlating patient variables and the volume of the upper head of the lateral pterygoid muscle in the closed-mouth position.

Variable	Category	Volume of the upper head of the lateral pterygoid muscle					
		Simple linear mixed model			Multiple linear mixed model		
		Avg	SE	p ^a -value	Beta	SE	p ^b -value
Intercept	–	–	–		1648.8	130.9	<0.0001
Side	Right	2021.7	169.9	0.4233	c	817.4	0.0002
	Left	1844.4	169.9				
Gender	Female	1648.8	130.9	0.0005	c	221.9	0.0002
	Male	2466.1	179.2				
Age group	≤39	1877.5	166.0	0.5771	c	221.9	0.0002
	≥40	2019.4	207.1				
Insertion type	I	2151.3	395.6	0.1563	c	221.9	0.0002
	II	1769.7	152.8				
	III	2268.8	234.3				
Format	Normal	1919.3	203.6	0.9254	c	221.9	0.0002
	Altered	1941.9	164.3				
Effusion	No	1935.8	149.3	0.9731	c	221.9	0.0002
	Yes	1925.3	247.0				
Displacement	No	2017.0	159.0	0.3633	c	221.9	0.0002
	Yes	1790.0	205.8				

^a Refers to the likelihood ratio test of differences among averages.^b Refers to the t-test comparing the beta coefficient to zero.^c Reference category used for comparisons.

Despite studies reporting only two types of insertion (Omami and Lurie, 2012; Taskaya-Yilmaz et al., 2005), in one of them (Omami and Lurie, 2012), 62.5% of patients had the upper head of the muscle connected to both the disc and the head of the mandible, corroborating our findings. In the other study (Taskaya-Yilmaz et al., 2005), the authors reported no type I insertions, possibly resulting from differences in methodology. These authors only evaluated MR images in the closed-mouth position, meaning that they were not able to visualize the entire upper head of the muscle, which can only be seen with the contraction in the open-mouth position (Mazza et al., 2009).

A clear association between type of insertion and anterior articular disc displacement has yet to be unveiled (Dergin et al., 2012; Omami and Lurie, 2012; Taskaya-Yilmaz et al., 2005). However, upper head insertion in the articular disc alone may render an individual more susceptible to anterior articular disc displacement. Thus, clearly defining insertion patterns has prognostic relevance (Taskaya-Yilmaz et al., 2005). The lateral pterygoid muscle has been

implicated in anterior articular disc displacement and, as a consequence, in TMD (Balcioglu et al., 2009; Barriere et al., 2009; Costa et al., 2008a; D'Ippolito et al., 2010; Dergin et al., 2012; Omami and Lurie, 2012; Taskaya-Yilmaz et al., 2005). Anterior displacement represents the most frequent sign of TMD (Murray et al., 2007). In cases of displacement with reduction, the upper head of the lateral pterygoid muscle may be normal or hypertrophied (D'Ippolito et al., 2010; Taskaya-Yilmaz et al., 2005). Moreover, in cases of displacement with no reduction, the upper head may have undergone atrophy (Taskaya-Yilmaz et al., 2005) [26].

Interestingly, muscle volume on both sides was statistically smaller in the open-mouth compared to the closed-mouth position (Table 4). This difference held true for both total muscle volume and lower head (Table 5), reflecting the smaller contribution of the upper head to the volume of the LPM. Presumably, volumetric alterations in the different mouth positions result from the functions of the pterygoid muscle heads. The lower head lowers and protrudes the mandible, whereas the upper head raises the mandible and/or

Table 9

Linear regression analysis correlating patient variables and the volume of the upper head of the lateral pterygoid muscle in the open-mouth position.

Variable	Category	Volume of the upper head of the lateral pterygoid muscle					
		Simple linear mixed model			Multiple linear mixed model		
		Avg	SE	p ^a -value	Beta	SE	p ^b -value
Intercept	–	–	–		1774.1	353.6	<0.0001
Side	Right	1815.3	250.8	0.1214	c	453.1	0.0288
	Left	1991.6	252.9				
Gender	Female	1589.1	284.7	0.0661	c	453.1	0.0288
	Male	2467.4	390.4				
Age group	≤39	1773.0	327.1	0.5563	c	453.1	0.0288
	≥40	2054.4	373.2				
Insertion type	I	2266.9	329.0	0.0655	c	453.1	0.0288
	II	1962.5	251.1				
	III	1655.9	276.9				
Format	Normal	1785.0	295.6	0.5463	c	453.1	0.0288
	Altered	1973.5	273.8				
Effusion	No	1931.5	247.7	0.4953	c	453.1	0.0288
	Yes	1762.6	311.7				
Displacement	No	1783.6	245.5	0.1199	c	453.1	0.0288
	Yes	2124.2	278.1				

^a Refers to the likelihood ratio test of differences among averages.^b Refers to the t-test comparing the beta coefficient to zero.^c Reference category used for comparisons.

Table 10

Linear regression analysis correlating patient variables and the volume of the lower head of the lateral pterygoid muscle in the closed-mouth position.

Variable	Category	Volume of the lower head of the lateral pterygoid muscle					
		Simple linear mixed model			Multiple linear mixed model		
		Avg	SE	p^a -value	Beta	SE	p^b -value
Intercept	–	–	–		2935.6	210.7	<0.0001
Side	Right	3302.5	244.1	0.4705			
	Left	3140.2	240.4				
Gender	Female	3204.8	270.3	0.9268			
	Male	3241.5	374.9				
Age group	≤39	3450.8	268.6	0.1538			
	≥40	2847.8	339.1				
Insertion type	I	3415.3	472.8	0.0192	479.7 ^c	493.6	0.3311
	II	2935.6	210.7				
	III	3951.1	313.3		1015.5	345.0	
Format	Normal	3197.4	308.1	0.9002			
	Altered	3231.6	259.4				
Effusion	No	3076.9	241.2	0.1768			
	Yes	3606.5	355.3				
Displacement	No	3141.1	254.9	0.5802			
	Yes	3345.3	309.8				

^a Refers to the likelihood ratio test of differences among averages.^b Refers to the *t*-test comparing the beta coefficient to zero.^c Reference category used for comparisons.

stabilizes the TMJ [24]. One study (Goto et al., 2002) also observed a significant reduction (–6.7%) in the volume of the LPM as the mandible opened.

In general, type III insertions – upper head directly inserted in the disc – were associated with larger muscle volumes (Tables 6, 7, 8, 10 and 11). A reduction in muscle upper head volume in the open-mouth position (Table 9) constitutes the sole exception to this pattern, and may indicate a reduction in the function of this component. Previous work supports the idea that type III insertions are more frequently associated with disc displacement without reduction, which would reduce muscle function and, consequently, volume (Taskaya-Yilmaz et al., 2005). Type III insertions could correlate with worse prognosis, because of a greater susceptibility to displacement without reduction (Mazza et al., 2009). Nevertheless, if we take into account the morpho-functional division of the lateral pterygoid muscle in upper and lower heads (Omami and Lurie, 2012), we should not expect similar volumetric alterations for both components, and the volume of the lower head should be larger.

In this sense, and in agreement with our results, the lower head contributes substantially to total lateral pterygoid volume, and has fewer implications for TMD.

We evaluated this sign of effusion because it correlates well with anterior articular disc displacement with and without reduction (Almasan et al., 2013) and also represents a biomarker for TMD-associated cephalgia (Costa et al., 2008a). Presumably, the relatively low frequency of anterior displacements observed (17 joints; 35.4%) explains the low number of joints with effusion (Table 2). Moreover, more than half of the joints displayed some degree of alteration to articular disc morphology, 54.2% of the right side joints and 70.8% of the left side joints. Thus, even though more than 60% of joints had normally positioned discs, morphological alterations occurred with relative high frequency and should be considered clinically. Such alterations suggest the existence of TMJ pathologies and may progressively lead to anterior disc displacement (Amaral Rde et al., 2013; Fujita et al., 2001). In line with our own work, a previous study found a high frequency of

Table 11

Linear regression analysis correlating patient variables and the volume of the lower head of the lateral pterygoid muscle in the open-mouth position.

Variable	Category	Volume of the lower head of the lateral pterygoid muscle					
		Simple linear mixed model			Multiple linear mixed model		
		Avg	SE	p^a -value	Beta	SE	p^b -value
Intercept	–	–	–		2612.5 ^c	236.96	<0.0001
Side	Right	2852.7	207.7	0.0490			
	Left	2653.3	208.6		–199.55 ^c	97.71	0.0412
Gender	Female	2520.3	229.8	0.0638			
	Male	3267.6	335.6		754.87	411.64	0.0667
Age group	≤39	2889.7	262.6	0.4140			
	≥40	2569.0	314.9				
Insertion type	I	2487.8	291.2	0.2175			
	II	2715.3	216.6				
	III	2914.4	239.4				
Format	Normal	2897.7	251.3	0.3562			
	Altered	2670.1	224.7				
Effusion	No	2772.3	208.0	0.7881			
	Yes	2710.8	266.3				
Displacement	No	2731.5	208.4	0.6468			
	Yes	2822.6	245.7				

^a Refers to the likelihood ratio test of differences among averages.^b Refers to the *t*-test comparing the beta coefficient to zero.^c Reference category used for comparisons.

biplanar alterations on the right (55%) and left (45%) sides in cases of normal disc positioning (Amaral Rde et al., 2013). The morphological differences between the biconcave normal disc and the biplanar altered disc are subtle and may explain why disc positioning remains normal in spite of format changes (Amaral Rde et al., 2013).

Linear regression analyses did not provide any evidence of effects that effusion and altered disc format might have on muscle volume (Tables 6–11). Previous work suggested that disc format alterations might occur in the initial phases of functional changes to the TMJ (Taskaya-Yilmaz and Ogutcen-Toller, 2001). Instead, articular effusion is significantly associated with displacements with or without reduction. One research (Almasan et al., 2013) have suggested that disc displacement without reduction, as a chronic alteration, could induce changes in the shape of the mandibular head and in its association with the articular fossa, leading to the accumulation of fluid (i.e., effusion).

Nevertheless, anterior articular disc displacement seems to affect total and upper head muscle volume in the open-mouth position (Tables 7 and 9). Upper head muscle volume in the open-mouth position was significantly larger in joints with disc displacement ($p = 0.0358$). D'Ippolito et al. (2010) diagnosed disc displacement in 20.4% of their patients and, although they did not measure LPM, suggested that TMD could cause changes in this muscle's thickness. According to these authors, the increased muscle thickness could be associated with anterior disc displacement and articular hypermobility. It could be further inferred that the increase in thickness should be associated with displacement with reduction, because displacement without reduction has been associated with muscle atrophy (Taskaya-Yilmaz et al., 2005). In a population of 46 patients ranging between 14 and 69 years of age, nine exhibited muscle hypoplasia, atrophy and/or fatty substitution of the LPM along with TMD (Schellhas, 1989). One patient with severe TMD displayed atrophy of the entire set of muscles of mastication (Schellhas, 1989).

Some authors performed visual qualitative analyses of the LPM in patients with or without TMD (D'Ippolito et al., 2010). However, no studies have attempted to use 3D images to quantify entire muscle, lower and upper head volume and independently associate these measurements with signs of TMD. Despite the division of the lateral pterygoid into two components with distinct (albeit reciprocal) functions, the existing literature does not treat these components as separate muscles (Murray et al., 2007; Omami and Lurie, 2012). According to some authors (Dergin et al., 2012), the LPM functions as a single motor unit, in which the upper and lower heads become active during mouth movements, with no correlation according to insertion type, presence or absence of displacement, disc or joint degeneration.

In the current study, gender affected muscle volume. In the open-mouth position, male patients had significantly larger total volumes (Table 7). Furthermore, the smaller upper head component was significantly larger in male patients in both mouth positions (Tables 8 and 9). This finding may reflect the general trend of men having larger muscles than women (Benington et al., 1999).

Distinct hypotheses attempt to associate functional alterations in the lateral pterygoid and TMD, including muscular hyperactivity, hypoactivity and poor coordination between muscle components that could lead to disc displacement (Costa et al., 2014; Hoglund and Scott, 2012). Anterior articular disc displacement affects the volume of the upper head of the lateral pterygoid (Table 9). The indication for physiotherapy should take into account not only TMD symptoms, but also the volumes of the muscles of mastication (Hoglund and Scott, 2012).

In conclusion, the total and lower head muscle volumes on both sides were significantly smaller in the open- compared to the closed-mouth position. Gender affected muscle volume, especially

that of the upper head component. Furthermore, insertion type also seems to affect volume.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.aanat.2016.05.007>.

References

- Almasan, O.C., Hedesiu, M., Baciut, G., Leucuta, D.C., Baciut, M., 2013. Disk and joint morphology variations on coronal and sagittal MRI in temporomandibular joint disorders. *Clin. Oral Investig.* 17 (4), 1243–1250.
- Amaral Rde, O., Damasceno, N.N., de Souza, L.A., Devito, K.L., 2013. Magnetic resonance images of patients with temporomandibular disorders: prevalence and correlation between disk morphology and displacement. *Eur. J. Radiol.* 82 (6), 990–994.
- Balcioglu, H.A., Uyanikgil, Y., Yuruker, S., Tuna, H.S., Karacayli, U., 2009. Volumetric assessment of lateral pterygoid muscle in unilateral chewing: a stereologic study. *J. Craniofac. Surg.* 20 (5), 1364–1366.
- Barriere, P., Lutz, J.C., Zamanian, A., Wilk, A., Rhiem, S., Veillon, F., Kahn, J.L., 2009. MRI evidence of lateral pterygoid muscle palpation. *Int. J. Oral Maxillofac. Surg.* 38 (10), 1094–1095.
- Benington, P.C., Gardener, J.E., Hunt, N.P., 1999. Masseter muscle volume measured using ultrasonography and its relationship with facial morphology. *Eur. J. Orthod.* 21 (6), 659–670.
- Costa, A.L., D'Abreu, A., Cendes, F., 2008a. Temporomandibular joint internal derangement: association with headache, joint effusion, bruxism, and joint pain. *J. Contemp. Dent. Pract.* 9 (6), 9–16.
- Costa, A.L., Yasuda, C.L., Appenzeller, S., Lopes, S.L., Cendes, F., 2008b. Comparison of conventional MRI and 3D reconstruction model for evaluation of temporomandibular joint. *Surg. Radiol. Anat.* 30 (8), 663–667.
- Costa, A.L., Yasuda, C.L., Franca Jr., M., de Freitas, C.F., Tedeschi, H., de Oliveira, E., Cendes, F., 2014. Temporomandibular dysfunction post-craniotomy: evaluation between pre- and post-operative status. *J. Craniofac. Surg.* 42 (7), 1475–1479.
- D'Ippolito, S.M., Borri Wolosker, A.M., D'Ippolito, G., Herbert de Souza, B., Fenyo-Pereira, M., 2010. Evaluation of the lateral pterygoid muscle using magnetic resonance imaging. *Dentomaxillofac. Radiol.* 39 (8), 494–500.
- Dergin, G., Kilic, C., Gozneli, R., Yildirim, D., Garip, H., Moroglu, S., 2012. Evaluating the correlation between the lateral pterygoid muscle attachment type and internal derangement of the temporomandibular joint with an emphasis on MR imaging findings. *J. Craniofac. Surg.* 40 (5), 459–463.
- Dworkin, S.F., 2010. Research diagnostic criteria for temporomandibular disorders: current status & future relevance. *J. Oral Rehabil.* 37 (10), 734–743.
- Dworkin, S.F., LeResche, L., 1992. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications, critique. *J. Craniofac. Disord.* 6 (4), 301–355.
- Farrugia, M.E., Bydder, G.M., Francis, J.M., Robson, M.D., 2007. Magnetic resonance imaging of facial muscles. *Clin. Radiol.* 62 (11), 1078–1086.
- Fujita, S., Iizuka, T., Dauber, W., 2001. Variation of heads of lateral pterygoid muscle and morphology of articular disc of human temporomandibular joint – anatomical and histological analysis. *J. Oral Rehabil.* 28 (6), 560–571.
- Goto, T.K., Tokumori, K., Nakamura, Y., Yahagi, M., Yuasa, K., Okamura, K., Kanda, S., 2002. Volume changes in human masticatory muscles between jaw closing and opening. *J. Dent. Res.* 81 (6), 428–432.
- Hoglund, L.T., Scott, B.W., 2012. Automobilization intervention and exercise for temporomandibular joint open lock. *J. Man. Manip. Ther.* 20 (4), 182–191.
- Imanmoghadam, M., Madani, A.S., Hashemi, E.M., 2013. The evaluation of lateral pterygoid muscle pathologic changes and insertion patterns in temporomandibular joints with or without disc displacement using magnetic resonance imaging. *Int. J. Oral Maxillofac. Surg.* 42 (9), 1116–1120.
- Lamey, P.J., Burnett, C.A., Fartash, L., Clifford, T.J., McGovern, J.M., 2001. Migraine and masticatory muscle volume, bite force, and craniofacial morphology. *Headache* 41 (1), 49–56.
- Lopes, S.L., Costa, A.L., Cruz, A.D., Li, L.M., de Almeida, S.M., 2012. Clinical and MRI investigation of temporomandibular joint in major depressed patients. *Dentomaxillofac. Radiol.* 41 (4), 316–322.
- Mazza, D., Marini, M., Impara, L., Cassetta, M., Scarpato, P., Barchetti, F., Di Paolo, C., 2009. Anatomic examination of the upper head of the lateral pterygoid muscle using magnetic resonance imaging and clinical data. *J. Craniofac. Surg.* 20 (5), 1508–1511.
- Murray, G.M., Bhutata, M., Peck, C.C., Phanachet, I., Sae-Lee, D., Whittle, T., 2007. The human lateral pterygoid muscle. *Arch. Oral Biol.* 52 (4), 377–380.
- Ng, H.P., Foong, K.W., Ong, S.H., Goh, P.S., Huang, S., Liu, J., Nowinski, W.L., 2009. Quantitative analysis of human masticatory muscles using magnetic resonance imaging. *Dentomaxillofac. Radiol.* 38 (4), 224–231.
- Omami, G., Lurie, A., 2012. Magnetic resonance imaging evaluation of discal attachment of superior head of lateral pterygoid muscle in individuals with symptomatic temporomandibular joint. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol.* 114 (5), 650–657.

- Schellhas, K.P., 1989. MR imaging of muscles of mastication. *Am. J. Roentgenol.* 153 (4), 847–855.
- Taskaya-Yilmaz, N., Ceylan, G., Incesu, L., Muglali, M., 2005. A possible etiology of the internal derangement of the temporomandibular joint based on the MRI observations of the lateral pterygoid muscle. *Surg. Radiol. Anat.* 27 (1), 19–24.
- Taskaya-Yilmaz, N., Ogutcen-Toller, M., 2001. Magnetic resonance imaging evaluation of temporomandibular joint disc deformities in relation to type of disc displacement. *J. Oral Maxillofac. Surg.* 59 (8), 860–865, discussion 865–866.
- Tomas, X., Pomes, J., Berenguer, J., Quinto, L., Nicolau, C., Mercader, J.M., Castro, V., 2006. Mr imaging of temporomandibular joint dysfunction: a pictorial review. *Radiographics* 26 (3), 765–781.
- Yushkevich, P.A., Piven, J., Hazlett, H.C., Smith, R.G., Ho, S., Gee, J.C., Gerig, G., 2006. User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability. *Neuroimage* 31 (3), 1116–1128.

3.4. Artigo 4

Nascimento Falcão I, Cal Alonso MBC, da Silva LH, Lopes SLPC, Comar LP, Costa ALF. 3D Morphology Analysis of TMJ Articular Eminence in Magnetic Resonance Imaging. *Int J Dent.* 2017;2017:5130241. doi: 10.1155/2017/5130241. Epub 2017 Jun 21.

Este trabalho foi realizado em parceria com pesquisadores da Universidade da Cidade de São Paulo, UNICIC.

Abstract:

Purpose. The objective of this study was to evaluate the computational reconstruction of the articular eminence of the temporomandibular joint (TMJ) based on magnetic resonance imaging (MRI) and semiautomatic volumetric segmentation techniques for morphological classification of the TMJ structure. **Materials and Methods.** A total of 36 MRI scans of TMJ individuals were selected and formatted by using the ITK-SNAP software, consisting of MRI segmentation and generation of 3D models. The TMJ articular eminences were also classified according to the morphology analysis of the articular eminence in 3D reconstructions. Two independent trained and calibrated investigators performed the image analysis, which was repeated after thirty days. **Results.** There was no association between sex and eminence shape ($p = 0.456$). Fisher's test revealed no statistically significant association between disc classification and eminence shape on both sides ($p = 0.629$). Chi-square test showed a significant statistically association between disc classification and disc displacement ($p = 0.000$). Intra- and interrater correlation coefficients showed excellent reproducibility values. **Conclusions.** Anatomical variability of the sample investigated was found, with predominantly round shape and presence of correlation between this shape and normal disc position. The correlation of flattened and convex shapes with disc position reduction indicated that type of disc derangement is more prevalent.

Research Article

3D Morphology Analysis of TMJ Articular Eminence in Magnetic Resonance Imaging

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Academic Editor: Manuel Lagraverre

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Purpose. The objective of this study was to evaluate the computational reconstruction of the articular eminence of the temporomandibular joint (TMJ) based on magnetic resonance imaging (MRI) and semiautomatic volumetric segmentation techniques for morphological classification of the TMJ structure. **Materials and Methods.** A total of 36 MRI scans of TMJ individuals were selected and formatted by using the ITK-SNAP software, consisting of MRI segmentation and generation of 3D models. The TMJ articular eminences were also classified according to the morphology analysis of the articular eminence in 3D reconstructions. Two independent trained and calibrated investigators performed the image analysis, which was repeated after thirty days. **Results.** There was no association between sex and eminence shape ($p = 0.456$). Fisher's test revealed no statistically significant association between disc classification and eminence shape on both sides ($p = 0.629$). Chi-square test showed a significant statistically association between disc classification and disc displacement ($p = 0.000$). Intra- and interrater correlation coefficients showed excellent reproducibility values. **Conclusions.** Anatomical variability of the sample investigated was found, with predominantly round shape and presence of correlation between this shape and normal disc position. The correlation of flattened and convex shapes with disc position reduction indicated that type of disc derangement is more prevalent.

1. Introduction

The temporomandibular joint (TMJ) has a disc located between two bones composed of mandibular fossa and articular eminences of the temporal bone and mandibular condyle [1]. The complexity of TMJ, with anatomic and biomechanical involvement, increases its susceptibility to pathological changes [2].

The articular eminence has an important role in the biomechanics of the TMJ [3–5], with some authors suggesting that its morphology may be a factor in the etiology of temporomandibular disorders (TMD). Also, the eminence shape has an effect on determining whether a displaced disc is reducible; it may be reducible when it returns spontaneously to the glenoid cavity, or nonreducible when the disc remains dislocated [3, 6–11].

The morphological evaluation of TMJ bony structures is object of interest in the improvement of the image quality in CT and especially MRI for a reliable diagnosis of TMD [12]. The TMD diagnosis may pose a challenge to the dentist/radiologist, especially when considering the size and degree of involvement of the joint [13]. Moreover, there are overlapping findings with other joint changes, especially degenerative processes. Magnetic resonance imaging (MRI) has been the preferred method to aid in the diagnosis of various TMJ pathologies [14–17]. This is due in part to the wealth of details provided by MRI compared to other imaging methods, including the fact that this technique is not limited to produce images of cross-sections and there is nonionizing radiation [18], as is the case with other modalities such as CT [12]. However, the spatial resolution of MRI

is not sufficient for accurate images of the entire TMJ due to contrast variation, resulting in inconspicuous or invisible images of the anatomy and thus leading to misdiagnosis [19], mainly in the bone tissue [20, 21].

Three-dimensional (3D) reconstruction model based on MRI can play an important role in the TMD diagnosis [19, 21, 22] by revealing the morphological features of TMJ with simplicity, speed, accuracy, and limited user interaction [23], thus being a powerful tool for characterizing different patterns of TMJ pathologies [24].

The purpose of this article is to demonstrate the use of 3D model to classify the morphology of the articular eminence by correlating signs and symptoms of TMD to articular disc displacement on MRI images.

2. Material and Methods

2.1. Image Data. This study has been conducted in accordance with universally accepted rules and precepts for research involving human subjects, being approved by the local research ethics committee of the University of São Paulo City.

From an initial sample of 60 individuals, we have selected a set of images from 36 individuals (28 women, with mean age of 37.79 ± 15.68 , and 8 men, with mean age of 37.63 ± 1.42) attending the Clinic Hospital of the University of Campinas (UNICAMP). Images showing the region of interest not clearly enough were discarded. The images were acquired on a commercially available 2 Tesla scanner (Elcint Prestige, Haifa, Israel) with bilateral surface coils of 40 mm in diameter dedicated to TMJ imaging, according to the following parameters: T1-weighted sagittal images (TR = 650 msec, TE = 22 msec, matrix = 316×240.160 , flip angle, thickness of 1.5 mm, field of view = $10 \text{ cm} \times 10 \text{ cm}$, NEX 1, voxel size $0.29 \text{ mm} \times 0.29 \text{ mm} \times 0.3 \text{ mm}$ voxel) were acquired at spin-echo sequence with mouth closed.

2.2. MRI Segmentation and Generation of 3D Models. The MRicro software (<http://www.mricro.com>) was used to convert the original Digital Imaging and Communication in Medicine (DICOM) format into ANALYZE format. After format conversion, the ITK-SNAP software [25] (<http://www.itksnap.org/download/snap>) was used for segmentation. This software can provide semiautomatic segmentation using level set methods, as well as manual delineation and image navigation [26, 27]. A 3D model of the target structure was generated after segmentation, thus allowing us to see the object from any view point by zooming, rotating, and panning [27] (Figure 1). The 3D-graphical model of the right and left articular eminences was generated by the software, in which the cortical bone was delineated with semiautomatic discrimination of the structures to allow for manual editing and slice-by-slice review in all three planes.

Two independent trained researchers used semiautomatic segmentation to delineate the articular eminence edge and to define image voxels and boundary [25]. The segmentation resulted in a 3D model of the bone.

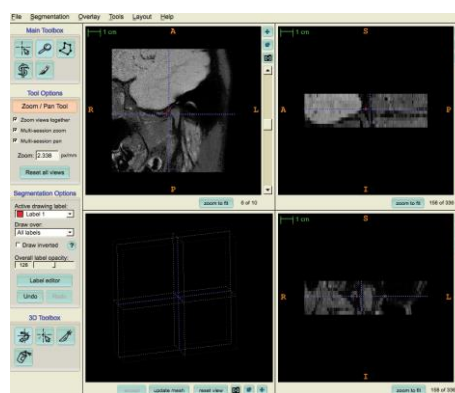


FIGURE 1: Software interface showing delimitation of the articular eminence in the sagittal plane on MRI.

2.3. Morphological Assessment of the Joint. Each evaluator performed the morphological analysis of the articular eminence in the 3D reconstructions (Figure 2), classifying them into four types according to criteria by Kurita et al. [10]:

- (a) Box
- (b) Sigmoid
- (c) Flattened
- (d) Deformed

In assessing 3D models, the evaluator could visualize the articular eminence from any view point. The evaluation was repeated by each examiner within an interval of 30 days.

2.4. Statistical Analysis. All the information obtained was analysed by using the SAS 9.4 and Minitab 16 statistical software, with concordance analysis being performed in two moments for eminence classification. First, the agreement between both evaluations of the eminence classifications was analysed on the left side, and then the same analysis was performed for evaluations on the right side. Repetition agreement and inter- and intrarater reliability analysis were performed by using Fleiss' kappa, Cohen's kappa, and Kendall's coefficients. All analyses were conducted at confidence level of 95%.

3. Results

Table 1 shows that no significant statistical difference was observed between age groups ($p = 0.978$), regardless of sex. Our results showed that age was not a determining factor for TMJ disc shape. For analysis of the eminence classification on the left side, the results showed Fleiss' kappa value = 0.79877, Cohen's kappa value = 0.79955, and Kendall's coefficient value = 0.793050. For evaluations on the right side, the results showed Fleiss' kappa value = 0.88060, Cohen's kappa value = 0.88119, and Kendall's coefficient value = 0.839011.

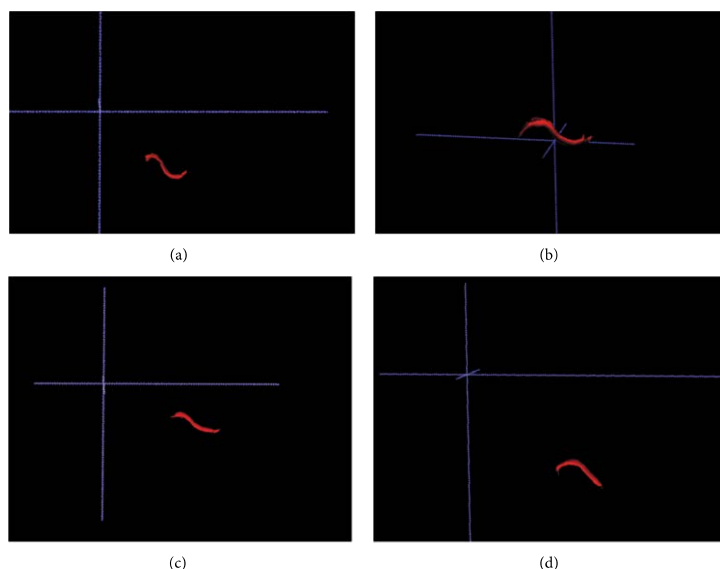


FIGURE 2: 3D reconstruction of the articular eminence characterizing it as (a) box, (b) sigmoid, (c) flattened, and (d) deformed.

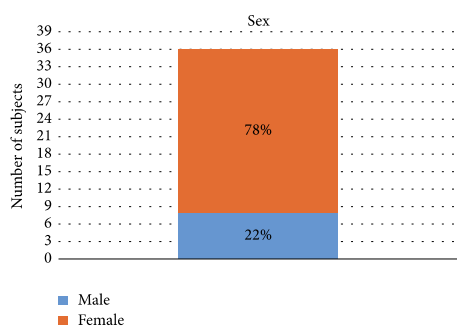


FIGURE 3: Distribution of the sample according to sex.

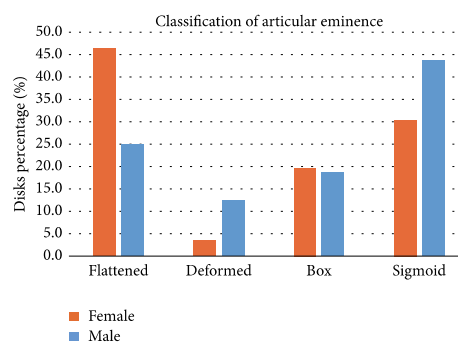


FIGURE 4: Distribution of the sample according to sex and articular eminence morphology.

Figure 3 shows that there was a significant difference between sexes, since women corresponded to 78% of the sample. Figure 4 shows the results of Fisher's exact test performed with Freeman-Halton extension. Our intention was to verify whether sex has any association with the articular eminence shape. The shapes observed on the left and right sides of men and women were added. There was no association between sex and eminence shape ($p = 0.456$).

Figures 5 and 6 show the results of Fisher's exact test performed with Freeman-Halton extension. There was no statistically significant association between disc classification

TABLE 1: Analysis of the comparison between sexes.

Sex	<i>n</i>	Age (years)	Groups*	<i>p</i> value
Female	28	37.79 ± 15.68	A	0.978
Male	8	37.63 ± 13.42	A	

* Equal letters represent statistical similarity at the significance level of 5% by Student's *t*-test.

and eminence shape on the left side ($p = 0.629$) as well as on the right side ($p = 0.629$).

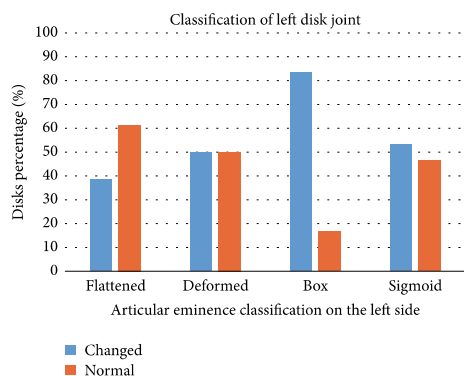


FIGURE 5: Association between the morphology of the left articular eminence with the disk classification on the left side.

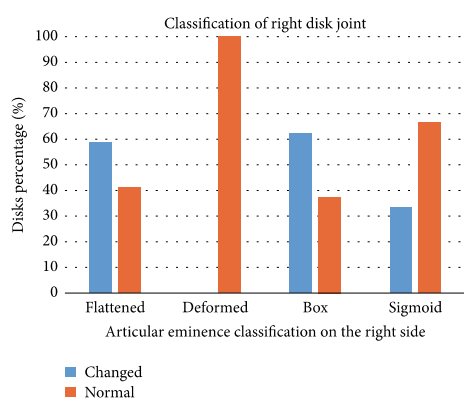


FIGURE 6: Association between the morphology of the articular eminence and disk classification on the right side.

Figures 7 and 8 show the results of Chi-square test (χ^2) in which a significant association was found between disc classification and disc displacement classification on the right side ($p = 0.000$) as well as on the left side ($p = 0.000$).

4. Discussion

It is important to correctly identify bone abnormalities in the TMJ because there are anatomical variations depending on both patient and influences of clinical factors. MRI is a widely used tool for diagnosis of TMDs, but because of the lack of contrast between different tissues, it may not be precise enough for analysis of structures [19], especially in bone tissues [20]. It has been reported that the three-dimensional (3D) reconstruction model based on MRI can play an important role in TMD diagnosis [19, 21, 22] by revealing morphological features of TMJ [23], thus being a

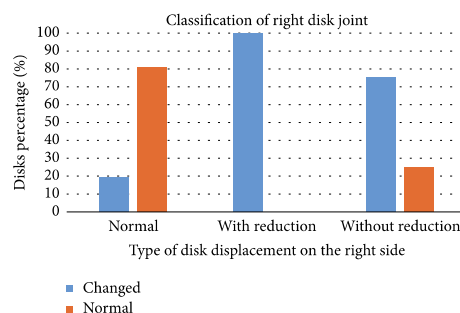


FIGURE 7: Association between disk classification and disc classification on the right side.

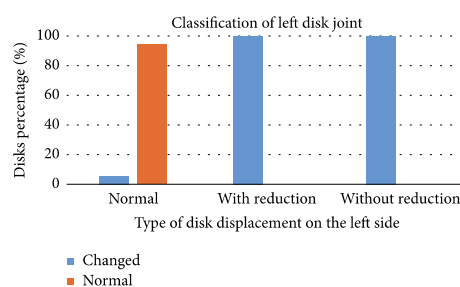


FIGURE 8: Association between disc classification and classification of disc displacement on the left side.

powerful tool for characterizing different patterns of TMJ pathologies [24]. Therefore, the present study aimed to demonstrate the use of 3D model to classify the morphology of the articular eminence by correlating signs and symptoms of TMD to articular disc displacement on MRI images and clarify whether 3D reconstruction can be used safely and reliably.

Hirata et al. (2007) showed in their study that some alterations in the morphology of both articular eminence and disc may influence the occurrence of nonreducing disc displacement on the affected side. Changes in occlusion (i.e., missing teeth, orthognathic surgery, and orthodontics), parafunctional habits, and positioning changes between articular disc and mandibular condyle can contribute to the remodeling of the joint structures in the TMJ [1, 6]. The authors defined that the main mechanical factors causing changes in the TMJ structure are occlusal therapy, parafunction, macrotrauma, and unstable occlusion. For the authors, these factors can occur alone or interconnectedly. When two or more than 11 factors are present, it is more likely that morphological changes occur, or if the patient has limited bone adaptation capacity, condylar changes will be more pronounced. Based on our results, it can be observed that of a total of 36 patients studied, 71.4% had articular eminence in

the form of box, 50% had flattened articular eminence, 43.9% had sigmoid articular eminence, and 25% had deformed articular eminences, all presenting alterations in the shape of the articular disc. Dental occlusion plays an important role as a predisposing factor, since it changes the masticatory system enough to increase the risk of developing TMJ dysfunction [9]. Parafunctional habits and dental malocclusion induce the production of microtraumas in TMJ by causing degenerative lesions in the condyle and articular disc, which in turn tend to be thickened to compensate for the resulting damage [7].

Our results have shown that no association was found between gender and eminence shape based on the eminence classification (p value = 0.456). According to Figure 4, it was noticed that the shape variation happens in a similar way in both genders, although alterations occurred more in women than in men (as expected), a finding corroborated by Hirata (2007) and Kurita (2000).

The results of intrarater variation with Cohen's kappa statistics suggest that reproducibility was very good, having a high standard of agreement.

We agree that 3D models are valuable for improving the visualization of anatomical structures [22, 25, 26]. The experimental results revealed that 3D reconstruction approach can generate an accurate 3D model and thus can assist the dental radiologist in the diagnosis of articular eminence. Although dental radiologists are trained to interpret MRI scans, they often find difficulty to analyse them [24].

5. Conclusions

According to the methodology used, it can be concluded that there is a relationship between the presence of changes in the articular discs and shape of their articular eminence. Thus, a higher incidence of deformations in articular eminences was classified as being of box shape. We emphasize the relevance of our findings and the importance of carrying out complementary studies into this field so that our findings can be replicated in larger samples.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

All the authors have made significant contributions to this work, with all coauthors approving the final version of this article and agreeing with its submission for publication.

References

- [1] A. Ikai, M. Sugisaki, K. Young-Sung, and H. Tanabe, "Morphologic study of the mandibular fossa and the eminence of the temporomandibular joint in relation to the facial structures," *American Journal of Orthodontics and Dentofacial Orthopedics*, vol. 112, no. 6, pp. 634–638, 1997.
- [2] S. L. P. C. Lopes, A. L. F. Costa, A. D. Cruz, L. M. Li, and S. M. De Almeida, "Clinical and MRI investigation of temporomandibular joint in major depressed patients," *Dentomaxillofacial Radiology*, vol. 41, no. 4, pp. 316–322, 2012.
- [3] F. H. Hirata, A. S. Guimaraes, J. X. de Oliveira, C. R. Moreira, E. T. T. Ferreira, and M. G. P. Cavalcanti, "Evaluation of TMJ articular eminence morphology and disc patterns in patients with disc displacement in MRI," *Brazilian Oral Research*, vol. 21, no. 3, pp. 265–271, 2007.
- [4] J. Kranjic, D. Vojvodic, D. Zabarovic et al., "Differences in articular–eminence inclination between medieval and contemporary human populations," *Archives of Oral Biology*, vol. 57, no. 8, pp. 1147–1152, 2012.
- [5] S. Sato, H. Kawamura, K. Motegi, and K. Takahashi, "Morphology of the mandibular fossa and the articular eminence in temporomandibular joints with anterior disk displacement," *International Journal of Oral and Maxillofacial Surgery*, vol. 25, no. 3, pp. 236–238, 1996.
- [6] R. D. Kinniburgh, P. W. Major, B. Nebbe, K. West, and K. E. Glover, "Osseous morphology and spatial relationships of the temporomandibular joint: comparisons of normal and anterior disc positions," *Angle Orthodontist*, vol. 70, no. 1, pp. 70–80, 2000.
- [7] H. Kurita, A. Ohtsuka, H. Kobayashi, and K. Kurashina, "Flattening of the articular eminence correlates with progressive internal derangement of the temporomandibular joint," *Dentomaxillofacial Radiology*, vol. 29, no. 5, pp. 277–279, 2000.
- [8] A. Ozkan, H. A. Altug, M. Sencimen, and B. Senel, "Evaluation of articular eminence morphology and inclination in TMJ internal derangement patients with MRI," *International Journal of Morphology*, vol. 30, no. 2, pp. 740–744, 2012.
- [9] S. Shahidi, M. Vojdani, and M. Paknahad, "Correlation between articular eminence steepness measured with cone-beam computed tomography and clinical dysfunction index in patients with temporomandibular joint dysfunction," *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology*, vol. 116, no. 1, pp. 91–97, 2013.
- [10] H. Kurita, A. Ohtsuka, H. Kobayashi, and K. Kurashina, "Is the morphology of the articular eminence of the temporomandibular joint a predisposing factor for disc displacement?" *Dentomaxillofacial Radiology*, vol. 29, no. 3, pp. 159–162, 2000.
- [11] T. Sulun, T. Cemgil, J. P. Duc, P. Rammelsberg, L. Jager, and W. Gernet, "Morphology of the mandibular fossa and inclination of the articular eminence in patients with internal derangement and in symptom-free volunteers," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, vol. 92, no. 1, pp. 98–107, 2001.
- [12] J. C. Vilanova, J. Barcelo, J. Puig, S. Remollo, C. Nicolau, and C. Bru, "Diagnostic imaging: magnetic resonance imaging, computed tomography, and ultrasound," *Seminars in Ultrasound, CT and MRI*, vol. 28, no. 3, pp. 184–191, 2007.
- [13] J. M. Petscavage-Thomas and E. A. Walker, "Unlocking the jaw: advanced imaging of the temporomandibular joint," *American Journal of Roentgenology*, vol. 203, no. 5, pp. 1047–1058, 2014.
- [14] T. A. Larheim, "Role of magnetic resonance imaging in the clinical diagnosis of the temporomandibular joint," *Cells Tissues Organs*, vol. 180, no. 1, pp. 6–21, 2005.
- [15] X. Tomas, J. Pomes, J. Berenguer et al., "MR imaging of temporomandibular joint dysfunction: a pictorial review," *Radiographics*, vol. 26, no. 3, pp. 765–781, 2006.
- [16] F. Molinari, P. F. Manicone, L. Raffaelli et al., "Temporomandibular Joint Soft-Tissue Pathology, I: disc abnormalities," *Seminars in Ultrasound, CT and MRI*, vol. 28, no. 3, pp. 192–204, 2007.

- [17] T. Sano, M. Otonari-Yamamoto, T. Otonari, and A. Yajima, "Osseous abnormalities related to the temporomandibular joint," *Seminars in Ultrasound, CT and MRI*, vol. 28, no. 3, pp. 213–221, 2007.
- [18] T. Sano, M. Yamamoto, and T. Okano, "Temporomandibular joint: MR imaging," *Neuroimaging Clinics of North America*, vol. 13, no. 3, pp. 583–595, 2003.
- [19] N. Kitai, L. Eriksson, S. Kreiborg, A. Wagner, and K. Takada, "Three-dimensional reconstruction of TMJ MR images: a technical note and case report," *Cranio*, vol. 22, no. 1, pp. 77–81, 2004.
- [20] V. Milano, A. Desiate, R. Bellino, and T. Garofalo, "Magnetic resonance imaging of temporomandibular disorders: classification, prevalence and interpretation of disc displacement and deformation," *Dentomaxillofacial Radiology*, vol. 29, no. 6, pp. 352–361, 2000.
- [21] Y. Hayakawa, C. Kober, M. Otonari-Yamamoto, T. Otonari, M. Wakoh, and T. Sano, "An approach for three-dimensional visualization using high-resolution MRI of the temporomandibular joint," *Dentomaxillofacial Radiology*, vol. 36, no. 6, pp. 341–347, 2007.
- [22] R. A. Chirani, J.-J. Jacq, P. Meriot, and C. Roux, "Temporomandibular joint: a methodology of magnetic resonance imaging 3-D reconstruction," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, vol. 97, no. 6, pp. 756–761, 2004.
- [23] P. Cascone, F. Rinaldi, M. Pagnoni, T. M. Marianetti, and M. Tedaldi, "Three-dimensional temporomandibular joint modeling and animation," *Journal of Craniofacial Surgery*, vol. 19, no. 6, pp. 1526–1531, 2008.
- [24] A. L. F. Costa, C. L. Yasuda, S. Appenzeller, S. L. P. C. Lopes, and F. Cendes, "Comparison of conventional MRI and 3D reconstruction model for evaluation of temporomandibular joint," *Surgical and Radiologic Anatomy*, vol. 30, no. 8, pp. 663–667, 2008.
- [25] P. A. Yushkevich, J. Piven, H. C. Hazlett et al., "User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability," *NeuroImage*, vol. 31, no. 3, pp. 1116–1128, 2006.
- [26] C. L. Yasuda, A. L. F. Costa, M. Franca Jr. et al., "Postcraniotomy temporalis muscle atrophy: a clinical, magnetic resonance imaging volumetry and electromyographic investigation," *Journal of orofacial pain*, vol. 24, no. 4, pp. 391–397, 2010.
- [27] L. H. S. Cevidanes, L. J. Bailey, G. R. Tucker Jr. et al., "Superimposition of 3D cone-beam CT models of orthognathic surgery patients," *Dentomaxillofacial Radiology*, vol. 34, no. 6, pp. 369–375, 2005.

3.5. Artigo 5

Montesinos GA, de Castro Lopes SLP, Trivino T, Sánchez JA, Maeda FA, de FreitasCF, CostaALF. Subjective analysis of the application of enhancement filters on magnetic resonance imaging of the temporomandibular joint. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2019 Jun;127(6):552-559. doi: 10.1016/j.oooo.2018.11.015. Epub 2018 Dec 2.

Este trabalho foi realizado em parceria com pesquisadores da Universidade da Cidade de São Paulo, UNICIC.

Abstract:

Objective. The aim of this study was to investigate the effect of enhancement filters on magnetic resonance imaging (MRI) of the temporomandibular joint (TMJ). **Study Design.** In total, 66 MRI scans of the TMJ were analyzed without filtration and with the application of 2 filters: Sharpen 1 and Sharpen 2 (OnDemand software). Two dentomaxillofacial radiologists examined the original and filtered images individually. Intra- and interobserver concordance was measured by using generalized estimating equations. The observers evaluated the subjective image quality and the visibility of 3 components of the TMJ: disk, condyle, and articular eminence. The images were ranked on a 4-point scale, from poor to excellent. The image quality of all filtered images was compared by using the X^2 test and Bonferroni correction for multiple comparisons. **Results.** Intra and interobserver concordance was good. The images filtered with Sharpen 1 and Sharpen 2 provided better definition of the structures compared with nonfiltered images, providing the highest scores for subjective image quality for all structures ($p < .0001$). **Conclusions.** The use of enhancement filters led to improved subjective quality and may improve the diagnostic efficacy of MRI in TMJ evaluation.

Subjective analysis of the application of enhancement filters on magnetic resonance imaging of the temporomandibular joint

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Objective. The aim of this study was to investigate the effect of enhancement filters on magnetic resonance imaging (MRI) of the temporomandibular joint (TMJ).

Study Design. In total, 66 MRI scans of the TMJ were analyzed without filtration and with the application of 2 filters: Sharpen 1 and Sharpen 2 (OnDemand software). Two dentomaxillofacial radiologists examined the original and filtered images individually. Intra- and interobserver concordance was measured by using generalized estimating equations. The observers evaluated the subjective image quality and the visibility of 3 components of the TMJ: disk, condyle, and articular eminence. The images were ranked on a 4-point scale, from poor to excellent. The image quality of all filtered images was compared by using the χ^2 test and Bonferroni correction for multiple comparisons.

Results. Intra- and interobserver concordance was good. The images filtered with Sharpen 1 and Sharpen 2 provided better definition of the structures compared with nonfiltered images, providing the highest scores for subjective image quality for all structures ($P < .0001$).

Conclusions. The use of enhancement filters led to improved subjective quality and may improve the diagnostic efficacy of MRI in TMJ evaluation. (Oral Surg Oral Med Oral Pathol Oral Radiol 2018;000:1–8)

Magnetic resonance imaging (MRI) is considered the gold standard for evaluation of the temporomandibular joint (TMJ), including normal bone and soft tissues, as well as pathologic changes (i.e., bone marrow edema, active synovitis, and disk displacement).^{1,2} MRI allows for evaluation of the joint without the use of ionizing radiation.

Anatomic structures on MRI scans show different characteristics, depending on the type of tissue and sequence used for image acquisition.¹ Sagittal oblique proton-density or T1-weighted images are used to evaluate the normal morphology of the joint (soft tissue and osseous components).^{2,3} The articular disk, cortical bone of the condyle, articular eminence, and glenoid fossa produce low signal intensity, whereas the bone marrow of the condyle has high signal intensity.^{3–6}

MRI may have certain limitations that often adversely affect the performance of visual inspection

during diagnosis, mainly with regard to spatial resolution. Another MRI characteristic of the TMJ making analysis difficult is the weak contrast variation between joint structures and their anatomic localization.⁷ The final result may be poor visualization of the anatomic structures and inaccurate analysis.¹

Image enhancement can facilitate better diagnostic accuracy.^{8,9} Image enhancement comprises changes in gray scale, contrast management, noise reduction, edge crispness and sharpening, filtering, interpolation, and magnification.¹⁰

The use of digital filters¹¹ for softening and processing images can permit the enhancement of the original images to increase the accuracy of visual analysis. Some studies report an improvement in image quality with the use of enhancement filters for assessing different tissues in brain MRI.^{12–14} To our knowledge, there are no studies specifically investigating the subjective quality of MRI for TMJ evaluation by using enhancement filters.

The objective of this study was to assess the subjective quality of MRI for the TMJ disk, condyle, and

This work was supported by the São Paulo Research Foundation FAPESP (grant number 12/16953-4).

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Received for publication Jul 21, 2018; returned for revision Oct 11, 2018; accepted for publication Nov 21, 2018.

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2212-4403/\$-see front matter

<http://doi.org/10.1016/j.oooo.2018.11.015>

Statement of Clinical Relevance

Enhancement of the image quality is obtained by implementing filtering tools. This is the first study using enhancement filters on magnetic resonance imaging of the temporomandibular joint to investigate the subjective quality of the images.

articular eminence by comparing nonfiltered images and scans that were enhanced with 2 filtration algorithms. The null hypothesis stated that there was no significant difference in image quality between nonfiltered and filtered images of any of the 3 anatomic structures.

MATERIALS AND METHODS

The images were originally acquired as part of a previous TMJ research project, and the present study was conducted in accordance with universally accepted rules and precepts for research involving human patients. It was approved by the research ethics committee of the University of Campinas (protocol No. 055/2005). All patients signed an informed consent form in accordance with the Declaration of Helsinki. Patients who had undergone TMJ surgery or who had a history of systemic inflammatory joint disease, facial growth disorders, direct trauma, or fracture of facial bones were excluded. Only patients with no signs or history of TMJ dysfunction were included. Of these patients, only those with images characterized by complete visualization of the joint with excellent density and contrast were included in the study. Patients with images having impaired visualization of the TMJ, poor sharpness resulting from patient movement during scanning, and presence of metallic prosthetics and accessories were excluded. In all, 33 patients (66 TMJs) were selected.

An MRI scanner operating at 1.5 T and using an 8.5-cm bilateral surface coil (Signa; GE Medical Systems, Milwaukee, WI) was used for acquisition of parasagittal images in spin-echo and proton-density weighted formats (repetition time = 51200.0 ms; echo time = 513.7 ms; ST = 53.0 mm; field of view = 515 × 06150 mm; and matrix 512 × 512).

MRI scans were analyzed with imaging software (OnDemand, CyberMed Inc., Seoul, Korea) in which files in DICOM (Digital Imaging and Communications in Medicine) format were imported and processed. A dentomaxillofacial radiologist assessed the sagittal slices, selected the most illustrative slice for each of the 66 TMJs, and used the X-Report tool for

manufacturing templates in PDF (portable document format) for the sagittal sections of each joint. Versions without filter application (WF), which served as the control images, and with application of Sharpen-1 (F1) and Sharpen-2 (F2) filters were created (Figure 1). The filters accentuate the transitions in density levels, making boundaries more evident between the different structures. Sharpen-1 enhances images at a mild level and Sharpen-2 enhances images at a high level.

In total, 198 templates were obtained. The templates were then randomized and assigned a number. Each template was assessed separately on a blinded basis by 2 other dentomaxillofacial radiologists (observers 1 and 2),^{15,16} each with 15 years' experience in MRI of the TMJ. Before the examination sessions, the observers were given verbal and practical instructions and were told not to make any adjustment of brightness and contrast. All the evaluations were performed on a 15.6-inch LCD monitor with resolution of 1920 × 1080 pixels (ASUS G51 Jx, ASUSTek Computer Inc. Taipei City, Taiwan).

The observers independently scored the quality of each image, depending on contrast, density, and sharpness for visualization of each structure individually (i. e., disk, condyle, and articular eminence) and according to the following scale parameters adapted from Verner et al.¹⁵:

1. Bad (relevant anatomy of structure is not visible)
2. Poor (<50% of relevant anatomy of structure is visible)
3. Good (>50% of relevant anatomy of structure is visible)
4. Excellent (relevant anatomy of structure is well visualized)

To learn how to score the images, the investigators were shown a sample set of TMJ scans (not from the study sample) before they started the scoring process.

After a 15-day interval, all the measurements were repeated for analysis of intraobserver agreement.

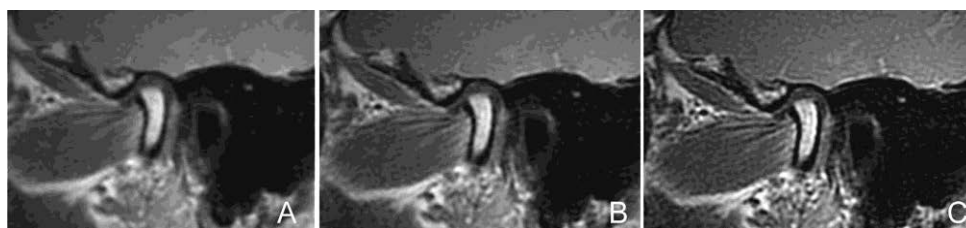


Fig. 1. Parasagittal magnetic resonance imaging (MRI) of the temporomandibular joint (TMJ) in a proton density-weighted image. (A) Image without filter. (B) Image with application of filter 1. (C) Image with application of filter 2.

Statistical analysis

Exploratory data analysis was performed by using frequency, percentages, and graphs. To determine intra- and interobserver concordance, the results were analyzed with generalized estimating equations (GEEs). The nonfiltered and filtered images were compared by using the χ^2 test with Bonferroni correction for multiple comparisons. The significance level was established at 5%.

RESULTS

Table I shows the results of intra- and interobserver assessments. There was good intra- and interobserver concordance for all anatomic structures, as depicted on the control (without filtration) images and both sets of filtered images, according to the GEEs. For the disks on both the right and left sides, there were no significant intraobserver differences ($P_{WF} \geq 0.3075$; $P_{F1} \geq 0.3075$; $P_{F2} \geq 0.3173$) or interobserver differences ($P_{WF} \geq 0.0950$; $P_{F1} \geq 0.3075$; $P_{F2} \geq 0.3173$). With regard to both the right and left condyles, there were no significant differences in the intraobserver assessments ($P_{WF} \geq 0.1616$; $P_{F1} \geq 0.2214$; $P_{F2} \geq 0.2038$) or between the observers ($P_{WF} \geq 0.2973$; $P_{F1} \geq 0.0943$;

$P_{F2} \geq 0.2038$). For the right and left articular eminences, there were no significant intraobserver differences ($P_{WF} \geq 0.3191$; $P_{F1} \geq 0.5603$; $P_{F2} \geq 0.2659$) or interobserver differences ($P_{WF} \geq 0.3191$; $P_{F1} \geq 0.0588$; $P_{F2} \geq 0.1650$).

Tables II and III show the distribution of the scores and summary statistics for the qualitative results. The frequency of scores for filtered images was found to be significantly different ($P < .0001$) compared with nonfiltered images of all structures. Filtered images F1 and F2 were not significantly different from each other, and both were more highly rated than the nonfiltered images of the condyle and articular eminence on the right side and of the disk and articular eminence on the left side. For the right disk and left condyle, F2-filtered images were rated significantly higher compared with F1-filtered ones, and both were better than nonfiltered images. Figures 2 through 7 show the parameters of image quality rated with or without the use of filter application for each structure.

DISCUSSION

MRI plays a central role in the diagnosis and treatment planning of the TMJ, including follow-up of

Table I. Distribution of the scores and 2 assessments for anatomic structures by the observers and P value of the generalized estimating equations (GEEs)

Structures	Observer/Assessment	WF				F1				F2				P_1	P_2
		1	2	3	4	1	2	3	4	1	2	3	4		
Right disk	Obs1 Assessment 1	9	23	1	0	0	0	8	25	0	0	0	33	$P_{WF} = .2695$	$P_{WF} = .4230$
	Obs1 Assessment 2	8	25	0	0	0	0	9	24	0	0	0	33	$P_{F1} = .3075$	$P_{F1} = .3075$
	Obs 2 Assessment 1	9	23	1	0	0	0	8	25	0	0	0	33	$P_{F2} = 1.0000$	$P_{F2} = 1.0000$
Right condyle	Obs 2 Assessment 2	3	27	3	0	0	0	8	25	0	0	0	33		
	Obs1 Assessment 1	2	26	5	0	0	0	2	31	0	0	2	31	$P_{WF} = .1616$	$P_{WF} = .2973$
	Obs1 Assessment 2	4	24	5	0	0	0	3	30	0	0	1	32	$P_{F1} = .2214$	$P_{F1} = .0943$
Right articular eminence	Obs 2 Assessment 2	2	25	6	0	0	0	0	33	0	0	0	33	$P_{F2} = .2038$	$P_{F2} = .2038$
	Obs1 Assessment 1	2	28	3	0	0	0	4	29	0	0	2	31	$p_{WF} = 1.000$	$p_{WF} = 1.000$
	Obs1 Assessment 2	2	28	3	0	0	0	4	29	0	0	2	31	$p_{F1} = 1.0000$	$p_{F1} = 1.0000$
Left disk	Obs 2 Assessment 1	2	28	3	0	0	0	5	28	0	0	1	32	$P_{F2} = .2659$	$P_{F2} = .1650$
	Obs 2 Assessment 2	2	28	3	0	0	0	5	28	0	0	0	33		
	Obs1 Assessment 1	9	23	1	0	0	0	8	25	0	0	0	33	$P_{WF} = .3075$	$P_{WF} = .0950$
Left condyle	Obs1 Assessment 2	8	25	0	0	0	0	9	24	0	0	0	33	$P_{F1} = 1.0000$	$P_{F1} = 1.0000$
	Obs 2 Assessment 1	9	23	1	0	0	0	8	25	0	0	0	33	$P_{F2} = .3173$	$P_{F2} = .3173$
	Obs 2 Assessment 2	3	27	3	0	0	0	8	25	0	0	0	33		
Left articular eminence	Obs1 Assessment 1	3	30	0	0	0	0	7	26	0	0	0	33	$P_{WF} = .9448$	$P_{WF} = .9448$
	Obs1 Assessment 2	4	28	1	0	0	0	7	26	0	0	0	33	$P_{F1} = 1.0000$	$P_{F1} = 0.4142$
	Obs 2 Assessment 1	3	30	0	0	0	0	8	25	0	0	0	33	$P_{F2} = 1.0000$	$P_{F2} = 1.0000$
	Obs 2 Assessment 2	3	30	0	0	0	0	8	25	0	0	0	33		
	Obs1 Assessment 1	3	27	3	0	0	0	6	27	0	0	0	33	$P_{WF} = .3191$	$P_{WF} = .3191$
	Obs1 Assessment 2	3	28	2	0	0	0	7	26	0	0	0	33	$P_{F1} = .5603$	$P_{F1} = .0588$
	Obs 2 Assessment 1	3	27	3	0	0	0	4	29	0	0	0	33	$P_{F2} = 1.0000$	$P_{F2} = 1.0000$
	Obs 2 Assessment 2	3	27	3	0	0	0	4	29	0	0	0	33		

1 = Bad; 2 = Poor; 3 = Good; 4 = Excellent.

P_1 = P value of GEEs comparing the intrarater assessment in each image.

P_2 = P value of GEEs comparing the interrater assessment in each image.

F1, Sharpen-1 filter; F2, Sharpen-2 filter; Obs, observer; WF, without filter.

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Table II. Scores for image quality for the anatomic structures (right side)

Score	Disk			Condyle			Articular eminence		
	WF	F1	F2	WF	F1	F2	WF	F1	F2
Bad	9	0	0	2	0	0	2	0	0
Poor	23	0	0	26	0	0	28	0	0
Good	1	8	0	5	2	1	3	4	2
Excellent	0	25	33	0	31	32	0	29	31
P value	< .0001 (F2 > F1 > WF)			< .0001 (F2 = F1 > WF)			< .0001 (F2 = F1 > WF)		

F1, Sharpen-1 filter; F2, Sharpen-2 filter; WF, without filter.

Table III. Scores for image quality for the anatomic structures (left side)

Score	Disk			Condyle			Articular eminence		
	WF	F1	F2	WF	F1	F2	WF	F1	F2
Bad	6	0	0	3	0	0	3	0	0
Poor	24	0	0	30	0	0	27	0	0
Good	3	6	1	0	8	0	3	4	0
Excellent	0	27	32	0	25	33	0	29	33
P-value	< .0001 (F2 = F1 > WF)			< .0001 (F2 > F1 > WF)			< .0001 (F2 = F1 > WF)		

F1, Sharpen-1 filter; F2, Sharpen-2 filter; WF, without filter.

patients.^{4,6} However, the main problem regarding MRI visualization is the limitation in terms of spatial resolution and contrast, which can make it difficult to view the anatomic structures of the joint.^{1,7}

As visualization of TMJ images can be crucial for the work of health care professionals, it is important that dentomaxillofacial radiologists help them interpret the examination findings correctly. MRI is more complex than CT, and this may not be easily obvious to an untrained clinician.¹ A study indicated that even among dentomaxillofacial radiologists, there was no reproducibility in the interpretation of such images.¹⁷ Although

dentomaxillofacial radiologists are trained to interpret MRI scans, they sometimes encounter difficulty in analyzing them.¹⁸ This difficulty can lead to inaccuracy and controversial diagnoses because of intra- and interobserver variability.¹⁷

A number of image processing techniques can be used to improve the visualization of structures in MRI examinations.^{19,20} Image enhancement consists of manipulation of the gray scale and contrast, noise reduction, edge trimming, sharpness, and filtration.¹² These processing algorithms may improve diagnostic accuracy.

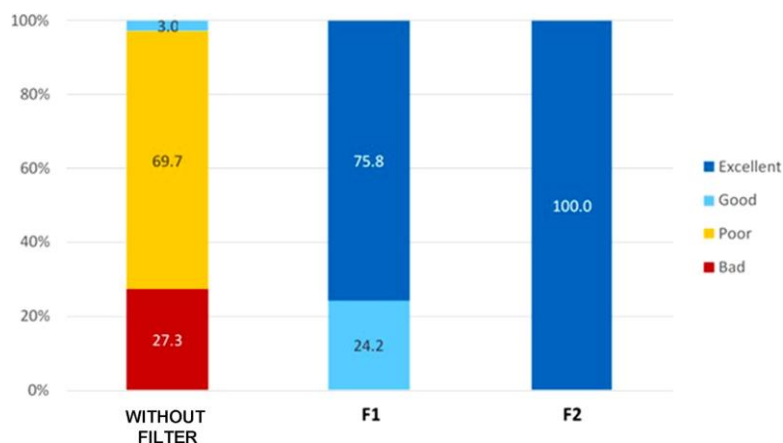


Fig. 2. Frequencies of assessments for the images without filter, with F1 (Sharpen-1 filter), and with F2 (Sharpen-2 filter) for the disk on the right side.

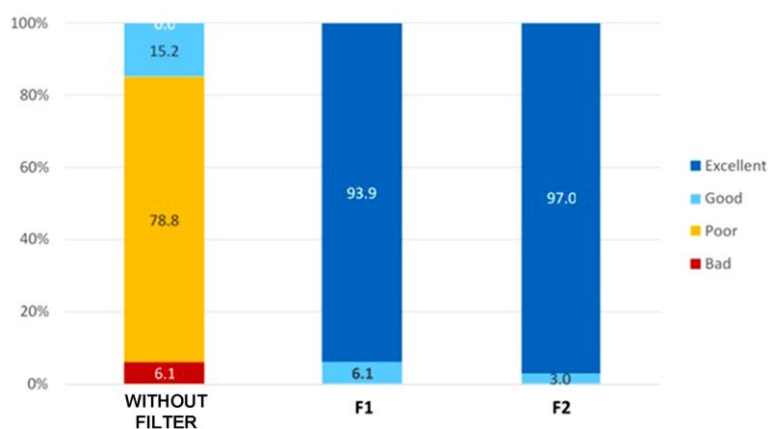


Fig. 3. Frequencies of assessments for the images without filter, with F1 (Sharpen-1 filter), and with F2 (Sharpen-2 filter) for the condyle on the right side.

Verner et al.¹⁵ demonstrated that the application of filters for the evaluation of cone beam computed tomography (CBCT) scans of TMJ bone structures could be very helpful in diagnosing alterations in the cortical bones of the condyle and articular eminence. The use of F1 and F2 filters provided excellent quality images compared with other filters used elsewhere. In the study by Verner et al., the filters were applied to CBCT images, whereas in our study, the filters were applied to MRI scans, but addition of filters resulted in good visualization with both imaging systems.

Enhancement filters have been extensively used in many applications of image processing, when the subjective quality of dental images is important for visual

analysis.^{8,15,19,21–23} A search for English-language reports on the PubMed and Medline databases did not reveal any work using this type of digital tool in MRI scans of the TMJ.

Because of the paucity of studies on the application of filters to MRI of the TMJ, we relied on medical evidence for the use of filters in brain MRI for comparison with our study findings. Jain et al.¹⁴ applied pre- and postprocessing image filters to MRI for diagnosis of brain tumors. The use of these 2 types of filters improved image visualization for diagnosis of tumors, and the filters were shown to be important procedures for further treatment planning and surgical procedures.

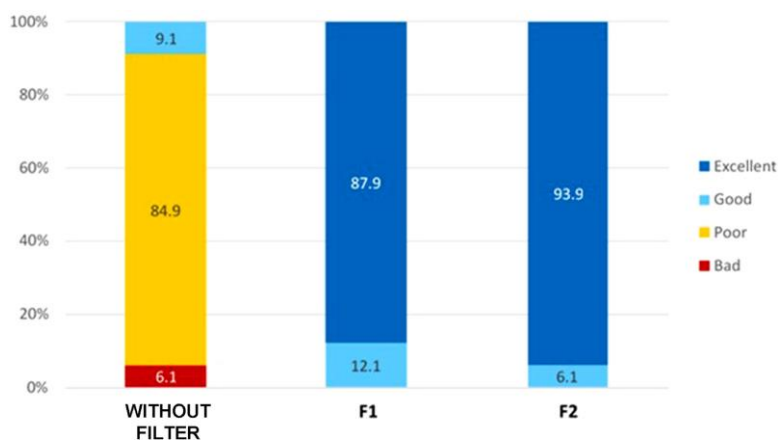


Fig. 4. Frequencies of assessments for the images without filter, with F1 (Sharpen-1 filter), and with F2 (Sharpen-2 filter) for the articular eminence on the right side.

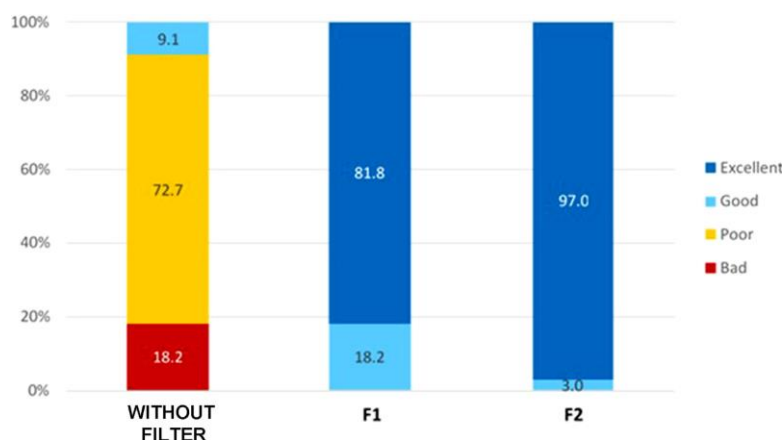


Fig. 5. Frequencies of assessments for the images without filter, with F1 (Sharpen-1 filter), and with F2 (Sharpen-2 filter) for the disk on the left side.

Jha et al.¹³ discussed the need to use filters in MRI for diagnosis of pathologic brain changes early in treatment. They used a new filtration technique (Weiner filter) in which the interpretation of filtered images was accurate and highly effective, showing that this filter was helpful in detecting pathologic changes in the brain.

In the analysis of image quality ratings by 2 evaluators, we found that filtered images were more favorably rated than the corresponding control images. In our study, the application of Sharpen-1 and Sharpen-2 filters (F1 and F2) showed better visualization of different anatomic structures of the TMJ compared with

nonfiltered images, with Sharpen-2 filters being slightly better than Sharpen-1 filters. Therefore, the removal of noise and blurring concomitantly allows for significant optimization of the image examination.

The capability to visualize structural details with any imaging method depends on the signal-to-noise ratio, contrast, and spatial resolution, which determine the limits of perceptibility of an image.²⁴ The low variation in evaluation between the 2 filters suggests that the use of a digital tool can increase the contrast of regions that could have been overlooked on the initial images,²³ including enhancement or detection of edges¹⁴ and delineation of anatomic structures.

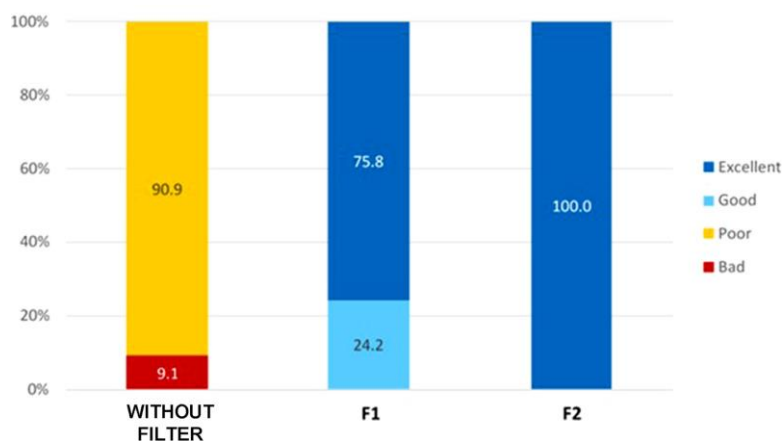


Fig. 6. Frequencies of assessments for the images without filter, with F1 (Sharpen-1 filter), and with F2 (Sharpen-2 filter) for the condyle on the left side.

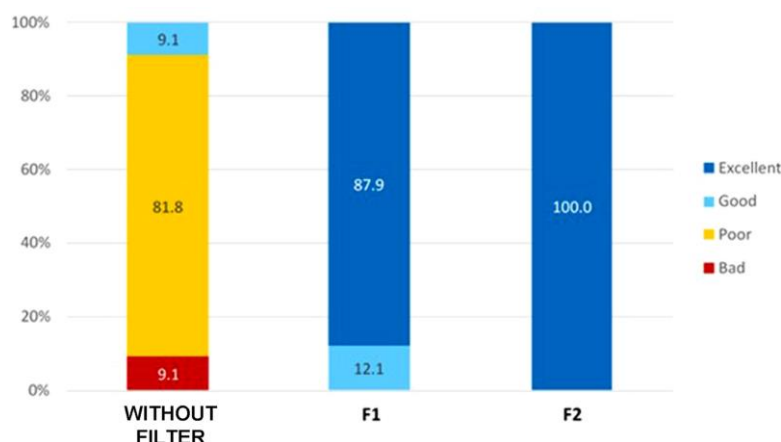


Fig. 7. Frequencies of assessments for the images without filter, with F1 (Sharpen-1 filter), and with F2 (Sharpen-2 filter) for the articular eminence on the left side.

Imaging hardware and software improvements, rater calibration software, and quantification techniques were found to reduce interobserver variability.²⁵ In our study, the inter- and intraobserver concordance was significantly higher for filtered images compared with nonfiltered ones. This indicates that the observers had excellent calibration and that the filtered images were visually superior, improving visualization of the 3 structures examined.

Our findings are in accordance with the results reported by earlier studies^{15,21,22,26} and add information on the diagnostic performance of enhancement filters for improving interpretation of digital images.

However, the present study has some limitations. The sample size was small. In addition, all of the study patients had no manifestations of TMJ disease, and no comparison with diseased joints was made.

Another limitation of the present work is that only 1 sagittal slice of each image volume was used in the analysis. Further studies using 3-dimensional volumetric rendering are needed to thoroughly assess the TMJ. We anticipate that the results of the present study will be very useful in motivating other researchers to conduct similar analyses.

The filtering techniques used in our study successfully eliminated the undesirable noise and enhanced the quality of the MRI scans. Our results suggest that the application of filters might improve the efficacy of the interpretation of TMJ structures with MRI.

CONCLUSIONS

MRI images of the TMJ filtered with Sharpen 1 and Sharpen 2 filters provided better definition of the disk, condyle, and articular eminence compared with

nonfiltered images, ensuring quality and effectiveness in the interpretation of MRI scans. Thus, enhancement techniques can potentially improve the diagnostic accuracy of MRI of the TMJ.

REFERENCES

- Costa AL, Yasuda CL, Appenzeller S, Lopes SL, Cendes F. Comparison of conventional MRI and 3-D reconstruction model for evaluation of temporomandibular joint. *Surg Radiol Anat.* 2008;30:663-667.
- Alomar X, Medrano J, Cabratosa J, et al. Anatomy of the temporomandibular joint. *Semin Ultrasound CT MR.* 2007;28:170-183.
- Tomas X, Pomes J, Berenguer J, et al. MR imaging of temporomandibular joint dysfunction: a pictorial review. *Radiographics.* 2006;26:765-781.
- Bag AK, Gaddikeri S, Singhal A, et al. Imaging of the temporomandibular joint: an update. *World J Radiol.* 2014;6:567-582.
- Molinari F, Manicone PF, Raffaelli L, Raffaelli R, Pirroni T, Bonomo L. Temporomandibular joint soft-tissue pathology. I: disc abnormalities. *Semin Ultrasound CT MR.* 2007;28:192-204.
- Larheim TA. Role of magnetic resonance imaging in the clinical diagnosis of the temporomandibular joint. *Cells Tissues Organs.* 2005;180:6-21.
- Hayakawa Y, Kober C, Otonari-Yamamoto M, Otonari T, Wakoh M, Sano T. An approach for three-dimensional visualization using high-resolution MRI of the temporomandibular joint. *Dentomaxillofac Radiol.* 2007;36:341-347.
- Wenzel A, Haider-Neto F, Frydenberg M, Kirkevang LL. Variable-resolution cone-beam computerized tomography with enhancement filtration compared with intraoral photostimulable phosphor radiography in detection of transverse root fractures in an *in vitro* model. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2009;108:939-945.
- de Azevedo Vaz SL, Vasconcelos TV, Neves FS, de Freitas DQ, Haider-Neto F. Influence of cone-beam computed tomography enhancement filters on diagnosis of simulated external root resorption. *J Endod.* 2012;38:305-308.
- Gandhi KR, Karnan M. Mammogram image enhancement and segmentation. In: *Institute of Electrical and Electronic*

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- Engineers*, ed. Proceedings of the Computational Intelligence and Computing Research (ICCIC) Conference, Dec 28-29, 2010, IEEE, Coimbatore, India; 2010.
11. Sagawa MMY, Hayakawa Y, Honda H. Comparison of two- and three- dimensional filtering methods to improve image quality in multiplanar reconstruction of cone-beam computed tomography. *Oral Radiol*. 2009;25:154-158.
 12. George EB, Karnan M. MRI brain image enhancement using filtering techniques. *Int J Comput Sci Engineer Tech*. 2012;3 (3):399-403.
 13. Jha D, Kim JI, Choi MR, Kwon GR. Pathologic brain detection using Weiner filtering, 2-D-discrete wavelet transform, probabilistic PCA, and random subspace ensemble classifier. *Comput Intell Neurosci*. 2017;2017:4205141.
 14. Jain NK, Karaulia DS. Pre-Processing and post-processing enhancement of MRI image using filters. *Int J Adv Res Comput Sci*. 2014;5:78-81.
 15. Verner FS, Visconti MAPG, Junqueira RB, Dias MI, Ferreira LA, Devito KL. Performance of cone-beam computed tomography filters for detection of temporomandibular joint osseous changes. *Oral Radiol*. 2014;31:90-96.
 16. Cara AC, Gaia BF, Perrella A, Oliveira JX, Lopes PM, Cavalcanti MG. Validity of single- and multislice CT for assessment of mandibular condyle lesions. *Dentomaxillofac Radiol*. 2007;36:24-27.
 17. Butzke KW, Batista Chaves KD, Dias da Silveira HE, Dias da Silveira HL. Evaluation of the reproducibility in the interpretation of magnetic resonance images of the temporomandibular joint. *Dentomaxillofac Radiol*. 2010;39:157-161.
 18. Nascimento Falcao I, Cal Alonso MBC, da Silva LH, Lopes S, Comar LP, Costa ALF. 3-D morphology analysis of TMJ articular eminence in magnetic resonance imaging. *Int J Dent*. 2017;2017:5130241.
 19. Gottfredsen E, Wenzel A, Grondahl HG. Observers' use of image enhancement in assessing caries in radiographs taken by four intra-oral digital systems. *Dentomaxillofac Radiol*. 1996;25:34-38.
 20. Shrout MK, Russell CM, Potter BJ, Powell BJ, Hildebolt CF. Digital enhancement of radiographs: can it improve caries diagnosis? *J Am Dent Assoc*. 1996;127:469-473.
 21. Ferreira LM, Visconti MA, Nascimento HA, Dallemolle RR, Ambrosano GM, Freitas DQ. Influence of CBCT enhancement filters on diagnosis of vertical root fractures: a simulation study in endodontically treated teeth with and without intracanal posts. *Dentomaxillofac Radiol*. 2015;44:20140352.
 22. Nascimento HA, Ramos AC, Neves FS, de-Azevedo-Vaz SL, Freitas DQ. The "Sharpen" filter improves the radiographic detection of vertical root fractures. *Int Endod J*. 2015;48:428-434.
 23. Belem MD, Ambrosano GM, Tabchoury CP, Ferreira-Santos RI, Haiter-Neto F. Performance of digital radiography with enhancement filters for the diagnosis of proximal caries. *Braz Oral Res*. 2013;27:245-251.
 24. Yalcinkaya S, Kunzel A, Willers R, Thoms M, Becker J. Subjective image quality of digitally filtered radiographs acquired by the Durr Vistascan system compared with conventional radiographs. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2006;101:643-651.
 25. Al-Saleh MA, Jaremkov JL, Alsufyani N, Jibri Z, Lai H, Major PW. Assessing the reliability of MRI-CBCT image registration to visualize temporomandibular joints. *Dentomaxillofac Radiol*. 2015;44:20140244.
 26. Botser IB, Herman A, Nathaniel R, Rappaport D, Chechik A. Digital image enhancement improves diagnosis of nondisplaced proximal femur fractures. *Clin Orthop Relat Res*. 2009;467:246-253.

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3.6. Artigo 6

Amorim MY, Alves MGO, Almeida JD, Montesinos GAP, Costa ALF, Lopes SLPC. Inclination of the condylar long axis is not related to temporomandibular disc displacement. *J Investig Clin Dent*. 2019 Feb;10(1):e12375. doi: 10.1111/jicd.12375. Epub 2018 Nov 26.

Este trabalho foi desenvolvido sob minha orientação a uma aluna de graduação em Odontologia, como Trabalho de Conclusão de Curso.

Abstract:

Aim: The aim of the present study was to correlate the angle formed by inclination of the condylar long axis and median sagittal plane to the presence of internal disc derangement, as well as changes in eccentric mandibular positions. Methods: The sample consisted of magnetic resonance images of 35 temporomandibular joint (TMJ) acquired with a 1.5T magnetic resonance imaging system with surface coils of 8.5 cm in diameter. Parasagittal images were used according to the following parameters: TMJ disc position with mouth closed, TMJ disc position with mouth open, TMJ disc function, and degrees of rotation and translation of the condyle. Next, we determined the angles between the condyle long axis and median sagittal plane by using axial images. Results: The results showed correlations between TMJ disc position and disc function ($p = 0.009$), as well as between disc position and degree of condylar rotation ($p = 0.008$). The main purpose of the present study was to assess the angle of the condylar long axis, with no statistical correlation being found between this variable and disc position ($p = 0.787$), disc function ($p = 0.091$), condylar translation ($p = 0.808$), and condylar rotation ($p = 0.115$). Conclusion: There was no relationship between inclination of the condyle long axis and parameters of internal derangements.

Received: 8 February 2018 | Accepted: 7 September 2018

DOI: 10.1111/jicd.12375

ORIGINAL ARTICLE

Oral and Maxillofacial Surgery

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Inclination of the condylar long axis is not related to temporomandibular disc displacement

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Abstract

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KEYWORDS

articular disc, condylar long axis, magnetic resonance imaging, median sagittal plane, temporomandibular joint

1 | INTRODUCTION

The human temporomandibular joint (TMJ) is a group of anatomical structures that are together responsible for the movements of the mandible, such as the chewing muscles. Among its components is the condylar process, the surface of the TMJ, articular tubercle of the temporal bone, articular disc, and intrinsic and extrinsic ligaments.^{1,2} The movements of the TMJ on one side are directly related to those on the other side; together they perform the mandibular movements harmoniously.³ As articulated surfaces of the TMJ are highly incongruent, they allow a large amount of movements involving a small set of structures. In this case, the articular disc between the condyle and

articular surfaces of the temporal bone has the ability to reduce any incongruence of the articular movements by increasing the area of the surfaces where the mandibular movements occur.^{1,4}

During rotational movements of the condyle in the articular eminence, the articular disc is slipped between the two structures. Although the degree of convergence between the condyle and articular eminence varies from person to person, changes occur within the pattern of normality.⁵ The imaging methods for anatomical evaluation of the TMJ are computed tomography and magnetic resonance imaging (MRI), with the former being the most commonly chosen for evaluating bone components, and the latter being the gold standard method for assessing disc derangements,⁶

as well as being used to study the condylar position and osseous changes.^{7,8}

The condyle has a wide anatomical variation, usually assuming an elliptical configuration, and therefore determining a long axis of two distinct poles: the medial and lateral poles. It has been observed that the lateral pole positions anterior to the medial ones, which leads to an angulation between the long axes of right and left condyles, vary between 140 and 160°.⁹

There are a few studies on the role of the condyle angle in relation to the various reference planes.¹⁰⁻¹² Therefore, the aim of the present study was to correlate the horizontal inclination of the condyle long axis to the presence of internal derangement and degrees of condyle rotation and translation.

2 | MATERIAL AND METHODS

For the present study, we followed the universally-accepted standards for research in humans. The study was approved by the Institutional Review Board of São Paulo State University, São José dos Campos, São Paulo, Brazil (no. 54710616.6.0000.0077). The sample consisted of MRI scans obtained from an imaging database used in an earlier study. The participants eligible for inclusion in the present study were those with no sign or history of temporomandibular disorders (TMD). Initially, 40 MRI scans of the TMJ were acquired with a 1.5T MRI system (Signa; GE Medical Systems, Milwaukee, WI, USA), with surface coils of 8.5 cm in diameter, for specific and individualized sequences for the TMJ study. From this initial sample, 35 scans (70 TMJ images) were selected because of their excellent definition of the TMJ structures. The final study sample had eight males and 27 females aged 18-75 years (mean age: 46.4 years).

Analysis was performed on parasagittal images (perpendicular to the condyle long axis), all acquired with the mouth closed (maximum habitual intercuspation) and open-mouth positions, T₁-weighted repetition time of 850 ms, echo time of 8.5 ms, section thickness of 5 mm, field of view of 180 × 180 mm, matrix of 256 × 256, number of excitations = 2, echo train length of 180°, radiofrequency of 4 MHz, and flip angle of 20°.

2.1 | Magnetic resonance imaging assessment

All sagittal images were evaluated by two specialists in maxillofacial radiology and experienced with interpreting MRI scans of the TMJ during their daily clinical practice. Both assessed the images together in order to establish clear definitions of the imaging characteristics. All of the images were reviewed on a 19-inch LCD monitor in a suitably darkened room. All parameters were analyzed by using eFilm Workstation software version 3.2 (Merge Healthcare, Chicago, IL, USA), except for the determination of angular measurements between the condyle long axis and median sagittal plane, which were performed by using a specific tool of the OnDemand 3D software (Cybermed, Tustin, CA, USA).

2.2 | Diagnostic protocols

2.2.1 | Disc position analysis

The position of the disc was in the anteroposterior and mediolateral positions and ranked as follows (Figure 1): normal, where the posterior band of the disc was positioned at the highest point of the condyle; and disc displacement, where the posterior band of the disc was positioned anterior to the highest point of condyle.¹³

2.2.2 | Disc function analysis

To study joint disc function, we analyzed the central parasagittal images acquired at maximum mouth opening. In those cases in which the disc had its intermediate portion interposed between the head of the mandible and temporal bone, it was considered that there was a functional reduction; otherwise no reduction (Figure 2).

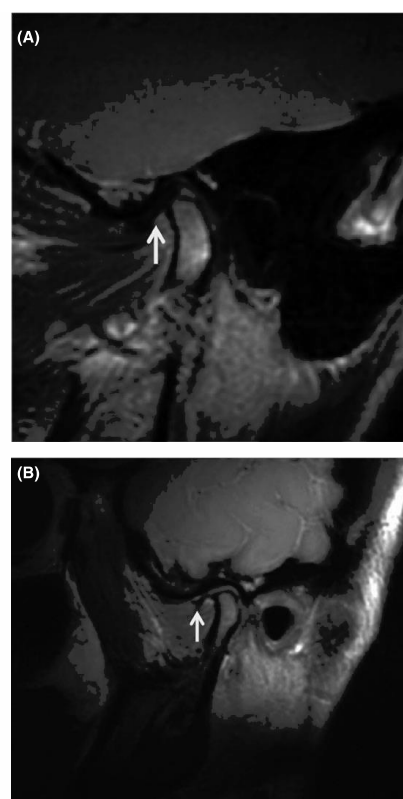


FIGURE 1 Analysis of the disc position in T₁-weighted parasagittal images: (A) normal disc position (arrow); (B) disc displacement (arrow)

2.2.3 | Rotational degree analysis

The parasagittal images (mouth closed and maximum mouth opening) were used to measure the rotational degree of the condyle. When the highest point of the condyle, at maximum mouth opening, was positioned in the middle portion of the disc, it was considered normal rotation; when the highest point of the condyle, at maximum mouth opening, was positioned in the anterior portion of the disc, it was limited rotation (Figure 3).

2.2.4 | Translational degree analysis

In the present study, the central parasagittal images were considered at the maximum mouth opening. The degree of normal translation was considered when the condyle was lined up with the articular eminence, whereas hypomobility was considered when the condyle was below the lowest point of the articular eminence. In those cases in which the condyle was anterior to the articular eminence, the degree of translation indicated hypermobility (Figure 4).

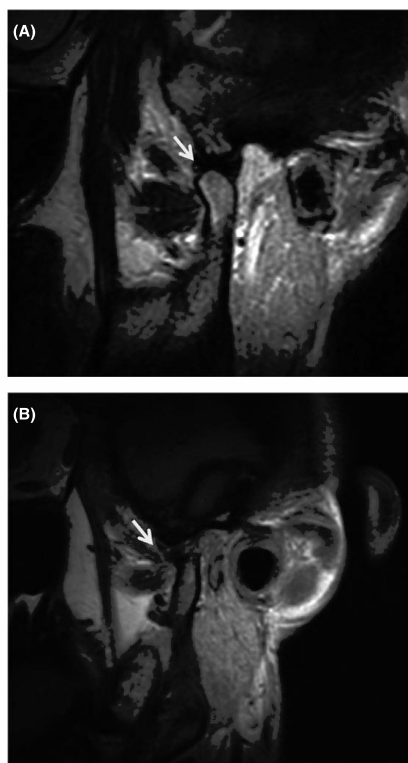


FIGURE 2 Analysis of the joint disc function in T₁-weighted parasagittal images: (A) disc reduction (arrow); (B) no reduction disc (arrow)

2.2.5 | Determination of the angle between the condyle long axis and median sagittal plane

This angle was determined by the condyle long axis and median sagittal plane. The T₁-weighted images in axial sequences were exported into DICOM (Digital Imaging and Communications in Medicine) format for analysis with OnDemand 3D software, as the angular measurement in degrees of angle could be performed.

In the axial window of the software, the axial section showed the condyle with a larger long axis, indicative of the medial and lateral poles. Next, the section was selected, the angle tool was chosen, and an angle was traced with one side consisting of the long axis of the condyle and the other consisting of the median sagittal plane, the guiding line corresponding to it (Figure 5).

2.3 | Statistical analysis

The resulting values were tabulated and then used to measure the angle of the condyle on the opposite side by using the same methodology.

The correlations between the variables (i.e. disc position with mouth closed, disc function with mouth open, degree of rotation and translation of the condyle, and angle between the median sagittal plane and condyle long axis) were explored by using the Spearman's correlation test at significance level of 5%.

3 | RESULTS

From the 70 TMJ, it was observed that the majority were at a normal position (50 discs, 71.43%) and that total displacement was more prevalent in cases of displaced discs (16 discs, 22.86%), with partial lateral found in three (4.28%) partial medial displacement being the least frequent, one disc (1.43%). It can be conclude that the total number of displaced discs was 20 discs (28.57%).

The frequencies of disc functions (normal and abnormal) found in the sample were assessed. The number of discs presenting normal position at maximum oral opening was very high, 63 (90%) compared to the seven that were not reduced (10%).

The frequency of degrees of condyle translation in the sample was determined. The result was divided into normal and altered (hypomobility and hypermobility). The highest frequency of abnormal mobility (N = 42, 60%) was observed in relation to normal cases (N = 28, 40%).

The frequency of normal rotation degree was higher (N = 56, 80%) compared to the altered ones (N = 14, 20%).

The correlations between the variables (i.e. disc position with mouth closed, disc function with mouth open, degree of rotation and translation of the condyle, and angle between the median sagittal plane and condyle long axis) were explored by using the Spearman's correlation test. There was a correlation between disc position and disc function, demonstrating that the disc displacements evaluated in the present study were mostly not reduced ($r = 0.314$, $P = 0.009$).

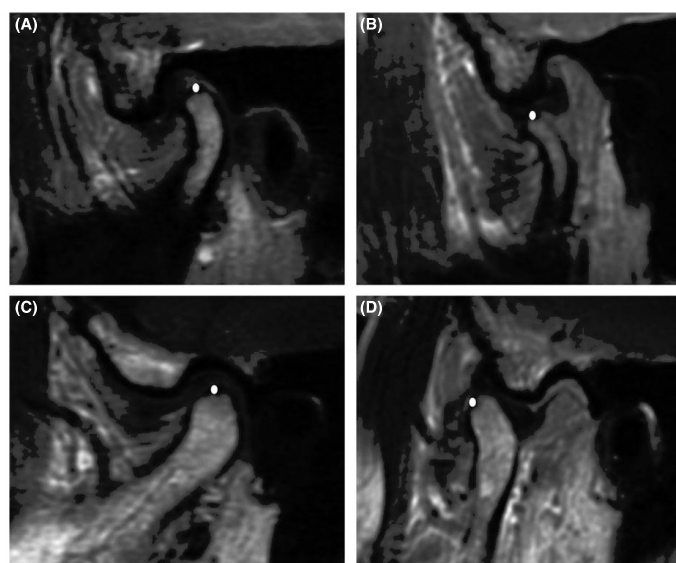


FIGURE 3 Analysis of the condyle rotation degree in T_1 -weighted parasagittal images. White spot indicates the higher point of the condyle in the closed-mouth and opened mouth positions. (A) normal rotation in closed-mouth position; (B) normal rotation with maximum opening; (C) limited rotation in closed-mouth position; (D) limited rotation maximum opening

There was also a correlation between disc position and condyle rotation, demonstrating that the disc displacements evaluated in the present study were within the limits of rotation degree for the corresponding condyle ($r = 0.316$, $P = 0.007$). There was no statistical significance between the condylar long axis angle and disc position, disc function, and rotation and translation of the condyle ($P > 0.05$).

4 | DISCUSSION

All the results reported in the present study were obtained from MRI, which is the gold standard method for evaluating the tissue structures of the TMJ.¹⁴ By analyzing the overall sample, we observed that most of the individuals (71.43%) presented the joint disc in a normal position, and that among those presenting disc displacement, the most frequent one was total displacement (22.86%). In their study, Tasaki et al determined the prevalence of disc displacements in symptomatic and asymptomatic individuals with TMD.¹⁵ They found that that patients presented disc displacement in 82% of symptomatic cases, whereas only 30% were asymptomatic.

We did not have access to the patients' clinical data in order to establish the frequency of TMD in the present study, but if we consider that the sample was randomly selected, it is plausible to say that disc displacement was seen in only 22.86% of cases. It is important to emphasize that the presence of disc displacement is not a decisive factor for painful TMD.¹⁶

Our results are in line with those of Foucart et al, who stated that the most common disc displacements were total and partial displacements anterolaterally (displacement only in the lateral portion of the disc), demonstrating that the greater prevalence of the latter

anteromedially would involve the insertion of the lateral pterygoid muscle in the medial portion of the disc, thus acting as a reinforcement to the medial ligament and consequently preventing its displacement.¹⁷

With regard to the function of the disc, that is, its image position at maximum oral opening, we found that the majority of individuals (90%) presented normally. Even in most cases of disc displacement, the images were acquired with the mouth closed; an interposed position between the head of the mandible and temporal bone. In addition, it was noted that there was a relationship between the function and position of the disc.

These results are in agreement with those of Milano et al,¹⁸ who found that 62% of the discs were in the closed-mouth position and assumed to be with normal open-mouth function.¹⁸ They also emphasized that reduction (normal function) occurred in most cases in which the displacement was partial, which is in contrast to our study, which showed a higher prevalence of total displacements. However, the finding that total disc displacement was the most frequent type in our sample was not corroborated by other studies.¹⁹

The Kaplan and Assael¹⁹ affirmed that disc reduction occurs more easily in partial displacements because the portion of the disc in the closed-mouth position induces the displaced disc to assume its normal position, which does not occur in the open-mouth position. According to the Kaplan and Assael¹⁹, in those cases of total displacements, the condyle is positioned closer to the articular tubercle, pressing the tissues of the posterior ligament, thereby reducing the possibility of disc reduction.

By analyzing the degree of disc translation, it was observed that the majority (60%) of cases presented the same alteration, that is, hypomobility and hypermobility, with no relation between this variable and others studied in our research.

Isberg-Holm reported that patients with TMJ hypermobility have a different composition of connective tissue, which causes generalized joint lassitude, but not necessarily with painful symptomatology.²⁰ Therefore, the study of the degree of disc translation plays an important clinical role in determining its importance. In our study, we did not take into account these clinical findings because our objective was to try to verify whether the long axis inclination of the condyle could be related to joint mobility, which was not observed. The degree of rotation of the condyle in most of the cases (80%) was normal, and a relationship between the mandible and disc position was also found. During mouth opening, we observed rotation of the articular disc in one direction and the condyle in the opposite direction, which allowed the disc to assume the final position at an ideal maximum oral opening, with its intermediate zone interposed between the condyle and articular tubercle. The perfect positioning of the disc in the closed-mouth

position plays a determining role for this rotation to occur favorably, which explains the relationship between these variables.²¹

With regard to the horizontal angle of the condylar long axis, the presence of internal disturbances (e.g. disc displacement) altered the disc function and changed the degrees of rotation and translation of the condyle, but our results did not show a direct relationship between them. The literature on this topic is scarce, as only a few studies with a similar objective and methodology to ours were found.

Alomar et al stated that the condylar long axis is anterior to the foramen magnum and that the angle between them ranges between 140 and 160°.²² In our study, we used an individualized angle formed by the condyle long axis and the median sagittal plane in order to correlate it with the corresponding findings of disc displacement.

In their study, Sulun et al assessed the influence of condyle morphology and its horizontal angle on the presence of disc displacement

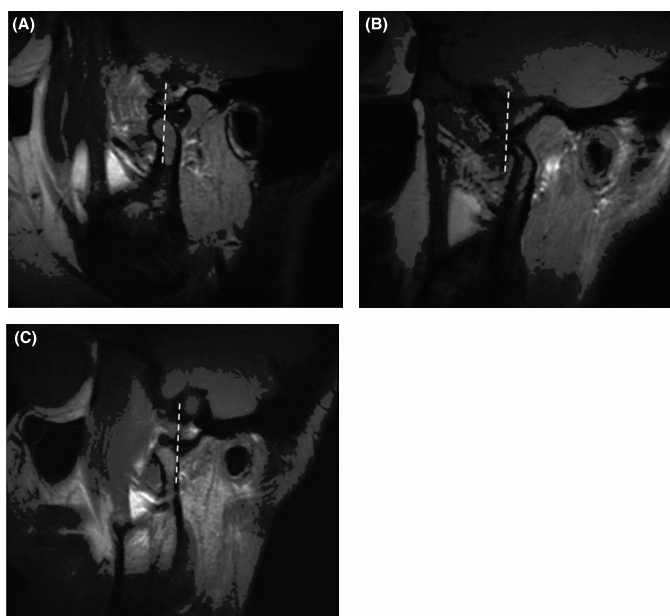


FIGURE 4 Analysis of the translational degree in T_1 -weighted parasagittal images. (A) normal; (B) hypomobility; (C) hypermobility

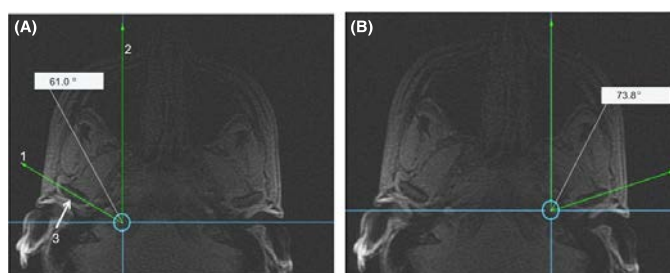


FIGURE 5 T_1 -weighted axial images showing the angle between the condylar long axis and median sagittal. (A) measurement of the right angle; (B) measurement of the left angle; 1, condyle axis; 2, sagittal reference line; 3, right condyle

in groups of symptomatic and asymptomatic patients.⁹ They found that higher angular values were associated with the development of internal TMJ disorders. In our study, however, we did not find a relationship between this angle and the presence of signs of disc displacements. It should be also emphasized that, in our study, we did not analyze the symptoms of internal disorders.

In their study, Westesson et al measured the horizontal angles of the mandible heads in groups with normal TMJ regarding disc displacement, with and without reduction, including the presence of degenerative articular disease.²³ They found higher angles and degrees of alteration, that is, patients with degenerative diseases showed higher values compared to other groups. Our objective was not to divide the individuals into groups, but to study the relationship between angles and different findings indicative of disorders. However, it was not possible to find a relationship between the studied parameters.

Rabelo et al reported that there was a strong association with condyle excursion angle in disc reduction.¹⁰ However, our results did not show a correlation between the inclination of the condylar long axis and disc displacement.

A limitation of the present study was the relatively small sample, which might reduce the statistical power and definitive conclusions.

With the methodology used in the present study, it can be concluded that there was no relationship between the inclination of the condylar long axis and parameters of internal disturbances.

ACKNOWLEDGMENT

This work was supported by São Paulo Research Foundation – FAPESP (grant number 12/16953-4).

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REFERENCES

- Costa AL, Yasuda CL, Appenzeller S, Lopes SL, Cendes F. Comparison of conventional MRI and 3D reconstruction model for evaluation of temporomandibular joint. *Surg Radiol Anat.* 2008;30:663-667.
- Costa AL, Yasuda CL, Franca M Jr, et al. Temporomandibular dysfunction post-craniotomy: evaluation between pre- and post-operative status. *J Craniomaxillofac Surg.* 2014;42:1475-1479.
- Villamil MB, Nedel LP, Freitas C, Maciel A. A model to simulate the mastication motion at the temporomandibular joint. SPIE MEDICAL IMAGING 2005—Physiology, Function, and Structure from Medical Images. San Diego, California, USA; 2005.
- Ingawale S, Goswami T. Temporomandibular joint: disorders, treatments, and biomechanics. *Ann Biomed Eng.* 2009;37:976-996.
- Ilguy D, Ilguy M, Fisekcioglu E, Dolekoglu S, Ersan N. Articular eminence inclination, height, and condyle morphology on cone beam computed tomography. *ScientificWorldJournal.* 2014;2014:761714.
- Vilanova JC, Barcelo J, Puig J, Remollo S, Nicolau C, Bru C. Diagnostic imaging: magnetic resonance imaging, computed tomography, and ultrasound. *Semin Ultrasound CT MR.* 2007;28:184-191.
- Gil C, Santos KC, Dutra ME, Kodaira SK, Oliveira JX. MRI analysis of the relationship between bone changes in the temporomandibular joint and articular disc position in symptomatic patients. *Dentomaxillofac Radiol.* 2012;41:367-372.
- Gateno J, Anderson PB, Xia JJ, Horng JC, Teichgraber JF, Liebschner MA. A comparative assessment of mandibular condylar position in patients with anterior disc displacement of the temporomandibular joint. *J Oral Maxillofac Surg.* 2004;62:39-43.
- Sulun T, Akkayan B, Duc JM, Rammelsberg P, Tuncer N, Gernet W. Axial condyle morphology and horizontal condylar angle in patients with internal derangement compared to asymptomatic volunteers. *Cranio.* 2001;19:237-245.
- Rabelo KA, Sousa Melo SL, Torres MGG, Campos PSF, Bento PM, Melo DP. Condyle excursion angle, articular eminence inclination, and temporomandibular joint morphologic relations with disc displacement. *J Oral Maxillofac Surg.* 2017;75:938.e1-938.e10.
- Gokalp H, Turkkahraman H, Bzeizi N. Correlation between eminence steepness and condyle disc movements in temporomandibular joints with internal derangements on magnetic resonance imaging. *Eur J Orthod.* 2001;23:579-584.
- Crusoe-Rebello IM, Campos PS, Rubira IR, Panella J, Mendes CM. Evaluation of the relation between the horizontal condylar angle and the internal derangement of the TMJ – a magnetic resonance imaging study. *Pesqui Odontol Bras.* 2003;17:176-182.
- Lopes SL, Costa AL, Cruz AD, Li LM, de Almeida SM. Clinical and MRI investigation of temporomandibular joint in major depressed patients. *Dentomaxillofac Radiol.* 2012;41:316-322.
- Larheim TA. Role of magnetic resonance imaging in the clinical diagnosis of the temporomandibular joint. *Cells Tissues Organs.* 2005;180:6-21.
- Tasaki MM, Westesson PL, Isberg AM, Ren YF, Tallents RH. Classification and prevalence of temporomandibular joint disk displacement in patients and symptom-free volunteers. *Am J Orthod Dentofacial Orthop.* 1996;109:249-262.
- Kircos LT, Ortendahl DA, Mark AS, Arakawa M. Magnetic resonance imaging of the TMJ disc in asymptomatic volunteers. *J Oral Maxillofac Surg.* 1987;45:852-854.
- Foucart JM, Carpentier P, Pajoni D, Marguelles-Bonnet R, Pharaboz C. MR of 732 TMJs: anterior, rotational, partial and sideways disc displacements. *Eur J Radiol.* 1998;28:86-94.
- Milano V, Desiate A, Bellino R, Garofalo T. Magnetic resonance imaging of temporomandibular disorders: classification, prevalence and interpretation of disc displacement and deformation. *Dentomaxillofac Radiol.* 2000;29:352-361.
- Kaplan AS, Assael LA. *Temporomandibular Disorders: Diagnosis and Treatment.* Philadelphia, PA: W.B. Saunders; 1991.
- Isberg-Holm A. *Temporomandibular Joint Dysfunction: A Practitioner's Guide.* Oxford: Isis Medical Media; 2001.
- Salaorni C, Palla S. Condylar rotation and anterior translation in healthy human temporomandibular joints. *Schweiz Monatsschr Zahnmed.* 1994;104:415-422.
- Alomar X, Medrano J, Cabratosa J, et al. Anatomy of the temporomandibular joint. *Semin Ultrasound CT MR.* 2007;28:170-183.
- Westesson PL, Bifano JA, Tallents RH, Hatala MP. Increased horizontal angle of the mandibular condyle in abnormal temporomandibular joints. A magnetic resonance imaging study. *Oral Surg Oral Med Oral Pathol.* 1991;72:359-363.

How to cite this article: Amorim MY, Alves MGO, Almeida JD, Montesinos GAP, Costa ALF, Lopes SLPDC. Inclination of the condylar long axis is not related to temporomandibular disc displacement. *J Invest Clin Dent.* 2019;10:e12375. <https://doi.org/10.1111/jicd.12375>

4 CONSIDERAÇÕES FINAIS

A complexidade anatomo-funcional das articulações temporomandibulares (ATM) e sua consequente suscetibilidade a alterações que podem suscitar nas chamadas Desordens Temporomandibulares (DTM) tem sido tema de diversos estudos que visam compreender o complexo mecanismo de sua etiopatogenia, além de fatores predisponentes. Os principais meios de investigação das ATM seguem um protocolo específico denominado de *Diagnostic Criteria for Temporomandibular Disorders* (DC/TMD), descrito em 1992, e revisto por Dworking et al. em 2014. Neste estudo, os autores ressaltam a importância de exames complementares de imagem na investigação de fatores relacionados com as DTM, destacando seu papel, e, em especial, o dos exames por imagens de ressonância magnética (RM), afirmando que estes exames possuem sensibilidade $\geq 0,70$ e especificidade $\geq 0,95$ quando recomendamos para diagnóstico de alterações nas ATM. Desta forma, observa-se a importância do conhecimento e interpretação de imagens de RM para uma perfeita compreensão das ATM.

As novas possibilidades que o desenvolvimento das tecnologia de computação gráfica trouxeram para a área de estudo por imagens possibilitaram um maior aproveitamento de todas as informações que as estas possam vir a trazer como exames complementares. Estudos com o de Weicknmeier et al., em 2017, tem sido realizados valendo-se de exames por imagens gerar modelos tridimensionais das estruturas das ATM, que possibilitam uma avaliação mais precisa das mesmas, incluindo modelos de computação gráfica com simulações de todo o sistema mastigatório melhorando o entendimento funcional de desordens e o planejamento cirúrgico.

Visando enfatizar a importância das imagens por RM como meio elucidativo no diagnóstico das DTM, com abordagens de diferentes fatores que poderiam contribuir tanto para etiologia, quanto para o aprimoramento da análise das imagens, esta tese realizou a compilação de 06 artigos científicos publicados em periódicos de impacto. Não foi objetivo realizar uma discussão minuciosa de cada um desses, uma vez que já fora realizada na ocasião da elaboração dos mesmos para suas publicações. Serão realizadas considerações que relatem seus objetivos e os resultados atingidos dentro do tema imagens por RM no estudo das DTM.

O *artigo 1* abordou o possível aspecto da presença da Depressão Maior, ou seja, um distúrbio mental, como fator que pudesse influenciar na presença dos sinais e sintomas de DTM. O estudo foi realizado por análise clínica dos sinais e sintomas de DTM, bem como sob os aspectos imaginológicos por RM, possibilitando avaliar a presença de deslocamento de disco articular, bem como os graus de rotação e translação da cabeça da mandíbula. Resultados indicaram que não houve relação, poucos estudos foram realizados com essa abordagem. Em um estudo realizado por Gallagher et al. (1991) a presença de DTM foi abordado do ponto de vista clínico apenas, em pacientes diagnosticados com depressão maior, sendo observado uma maior prevalência desta nos mesmos. Não houve porém, uma investigação por meio de imagens, o que ressalta a importância do artigo 1, que se valeu deste recurso. Acredita-se com veemência que mesmo não sendo demonstrado no artigo 1 a relação na amostra entre a DTM e depressão maior, haja uma associação entre as mesmas uma vez que é notório a somatização por meio de diferentes manifestações da dor, de efeitos psicossomáticos (Yap et al., 2002). Importante ressaltar também que esse foi o único estudo publicado, que se valeu das imagens de RM em pacientes com depressão maior, para estudo das ATM.

Procurando avaliar a relação entre as DTM e a presença de alterações sistêmicas/neurológicas, foi realizado o estudo do *artigo 2* desta compilação. Neste, foram selecionados pacientes diagnosticados com DTM e também aqueles que apresentavam cefaléia do tipo migrânea. A cefaléia foi escolhida como objeto de estudo, por ser uma queixa frequente em pacientes portadores de DTM. Apensar de outros trabalhos (Gil-Martínez et al., 2017; Contreras et al., 2018; Garrigós-Pedró et al., 2019) terem posteriormente abordado a relação entre cefaleia migrânea e DTM, o estudo do artigo 2 foi pioneiro, uma vez que abordou esta relação e sua influência no grupo muscular pterigóideo lateral, que se insere diretamente no disco articular nas ATM, utilizando por meio das imagens de RM, a análise de sua volumetria, uma vez que a palpação clínica deste grupo muscular é bastante questionável por seu acesso anatômico. Desta forma, a metodologia para sua avaliação mostrou-se objetiva e confiável. No estudo, houve uma relação entre DTM, migrânea e o aumento (hipertrofia) muscular deste grupo, mas isso não refletiu no aumento da prevalência de deslocamentos do disco, mesmo com a relação deste com o músculo pterigoideo. Este estudo mais uma vez reforça a importância a gama de possibilidades dos exames por imagens de RM para estudo das ATM.

As variações anatômicas dos componentes das ATM como fatores que podem estar associados a presença de DTM foram alvo de três dos estudos aqui selecionados (artigo 3, artigo 4 e artigo 6).

O *artigo 3* investigou os padrões de inserção dos ventres superior e inferior do músculo pterigoideo lateral e variações de seus volumes, em boca fechada e aberta. Mais uma vez, a tecnologia do cálculo de volume muscular, por meio de softwares computacionais de imagens, foi adotada como metodologia neste estudo, reforçando a grande possibilidade de que as imagens de RM fornecem no estudo das ATM. Concluiu-se haver diferença entre os

volumes deste grupo muscular (ventres superior e inferior) e esses variam em relação às posições de boca fechada e aberta.

O *artigo 4* estudou a influencia entre a forma da eminência (ou tubérculo) articular nas ATM e a posição do disco articular, em imagens de RM, com intuito de se verificar se a forma da mesma estaria relacionada a presença de deslocamento do disco articular, que é um tipo de desarranjo interno que pode estar associado às DTM, e à função do disco – reduzido ou não, uma vez que a translação de disco durante a abertura e fechamento da boca está intimamente ligada a seu deslize sobre as vertentes posteriores e zênite do Tubérculo articular. O estudo concluiu que morfologias aplainadas e convexas colaboram para que deslocamentos anteriores de disco apresentem redução em posição de máxima abertura bucal. Estudo posteriores foram realizado com metodologias similares a este (Litko et al., 2017; Bedran et al., 2019; Lei et al., 2019), também enfatizando da importância do estudo morfológico do tubérculo articular para classificação do tipo de deslocamento de disco articular e sua posição.

O *artigo 6* desta tese abordou a relação entre a inclinação do longo das cabeças da mandíbula, em relação ao plano sagital mediano, e a presença de desarranjos internos, como deslocamentos de disco, alterações do grau de translação das ATM, que pudessem predispor a DTM por análise de imagens por RM. Os resultados indicaram relação entre posição e função de disco e posição e grau de rotação da cabeça da mandíbula, porem não houve relação entre essas variáveis e a variação do dos ângulos dos longos eixos condilares. Posteriormente a este estudo, encontrou-se na literatura um trabalho (Piancino et al., 2018) abordando variáveis que incluíam os longos eixos condilares e a presença de DTM. Nesse estudo os autores encontraram relação entre a presença de DTM e assimetrias nos longos eixos condilares, de forma diferente do artigo

6 aqui selecionado. Porém naquele estudo, os autores utilizaram imagens de radiografias panorâmicas, além de imagens de RM, para estudar variáveis como altura do tubérculo articular e forma do mesmo, o que poderia ser um fator divergente do estudo 6, sabendo-se que a radiografia panorâmica, por si só possui efeitos de distorção e ampliação inerentes, sendo uma técnica não recomendada para medidas. Desta forma, enfatiza-se que, para o estudo das ATM, exames tomográficos – que possibilitam a obtenção de imagens seccionais reais, sem ampliação e sobreposições - como a Tomografia computadorizada e a RM são modalidades mais indicadas.

Finalmente, mas não menos importante, o *artigo 5* desta tese abordou o uso de filtros de realce ou filtros de pós-processamento de imagens como meio de melhoria na análise subjetiva para avaliação das ATM por meio de RM. Nota-se que, na literatura, não foram encontrados estudos com esta abordagem, apesar de serem observados alguns estudos prévios que abordassem o uso dos filtros de realce para detecção de lesões cariosas em radiografias (Ghoncheh et al., 2017; Shokri et al., 2018), bem como em análises de tomografia computadorizada de feixe cônico (Srinivasan et al., 2014; de Sousa, 2017). Os resultados do estudo 6 indicaram que o uso dos filtros de realce para as imagens de RM, levaram a uma maior capacidade de identificação das estruturas das ATM, como o disco articular e melhoraram a nitidez das imagens, desta forma capacitando o avaliador na melhoria da análise das imagens.

Os artigos aqui selecionados, mostraram a importância das imagens por RM no estudo das ATM e, portanto, como meio de exame complementar essencial para identificação de fatores relacionados às DTM, seja para análise anatômica, avaliação de fatores relacionados às alterações sistêmicas que contribuiriam para o desenvolvimento das alterações nas ATM e sempre se valendo das tecnologias disponíveis em imagens digitais, que possibilitam uma

ampla gama de ferramentas como novas abordagens das imagens, aliadas a capacitação e conhecimento dos profissionais da Imaginologia, para seu amplo aproveitamento.

REFERÊNCIAS*

Ak ę O, Yı ı G, K ę M. Patient symptoms and magnetic resonance imaging correlation in temporomandibular joint internal derangement. *Turk J Med Sci.* 2018 Dec 12;48(6):1092-1095. doi: 10.3906/sag-1707-173.

Bedran LM, Dos Santos AASMD. Changes in temporomandibular joint anatomy, changes in condylar translation, and their relationship with disc displacement: magnetic resonance imaging study. *Radiol Bras.* 2019 Mar-Apr;52(2):85-91. doi: 10.1590/0100-3984.2018.0020.

Contreras EFR, Fernandes G, Ongaro PCJ, Campi LB, Gonçalves DAG. Systemic diseases and other painful conditions in patients with temporomandibular disorders and migraine. *Braz Oral Res.* 2018 Jul 23;32:e77. doi: 10.1590/1807-3107BOR-2018.vol32.0077.

de Sousa ET, Pinheiro MA, Maciel PP, Sales MA. Influence of enhancement filters in apical bone loss measurement: A cone-beam computed tomography study. *J Clin Exp Dent.* 2017 Apr 1;9(4):e516-e519.

Dworking SF, et al. Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) for Clinical and Research Applications: Recommendations of the International RDC/TMD Consortium Network and Orofacial Pain Special Interest Group. *J Oral Facial Pain Headache.* 2014 Winter; 28(1): 6–27. doi: 10.11607/jop.1151.

Gallagher RM, Marbach JJ, Raphael KG, Dohrenwend BP, Cloitre M. Is major depression comorbid with temporomandibular pain and dysfunction syndrome? A pilot study. *Clin J Pain.* 1991 Sep;7(3):219-25.

Garrigós-Pedró M, La Touche R, Navarro-Desentre P, Gracia-Naya M, Segura-Ortí E. Widespread mechanical pain hypersensitivity in patients with chronic migraine and temporomandibular disorders: relationship and correlation between psychological and sensorimotor variables. *Acta Odontol Scand.* 2019 Apr;77(3):224-231. doi: 10.1080/00016357.2018.1538533. Epub 2019 Jan 10.

Ghoncheh Z, Kheirandish Y, Kaviani H, Kharazi Fard MJ, Sadeghi K. Diagnosis of Approximal Caries after Delayed Scanning of Photostimulable Phosphor Plates. *J Dent (Shiraz).* 2017 Sep;18(3):201-206.

* Baseado em: International Committee of Medical Journal Editors Uniform Requirements for Manuscripts Submitted to Biomedical journals: Sample References [Internet]. Bethesda: US NLM; c2003 [atualizado 04 nov 2015; acesso em 25 jan 2017]. U.S. National Library of Medicine; [about 6 p.]. Disponível em: http://www.nlm.nih.gov/bsd/uniform_requirements.html

Gil-Martínez A, Navarro-Fernández G, Mangas-Guijarro MÁ, Lara-Lara M, López-López A, Fernández-Carnero J, La Touche R. Comparison Between Chronic Migraine and Temporomandibular Disorders in Pain-Related Disability and Fear-Avoidance Behaviors. *Pain Med.* 2017 Nov 1;18(11):2214-2223. doi: 10.1093/pm/pnx127.

Larheim TA, Hol C, Ottersen MK, Mork-Knutsen BB, Arvidsson LZ. The Role of Imaging in the Diagnosis of Temporomandibular Joint Pathology. *Oral Maxillofac Surg Clin North Am.* 2018 Aug;30(3):239-249. doi: 10.1016/j.coms.2018.04.001. Epub 2018 Jun 1. doi: 10.1016/j.coms.2018.04.001. Epub 2018 Jun 1.

Larheim TA. Role of magnetic resonance imaging in the clinical diagnosis of the temporomandibular joint. *Cells Tissues Organs.* 2005;180(1):6-21.

Lei J, Yap AU, Li Y, Liu MQ, Fu KY. Clinical protocol for managing acute disc displacement without reduction: a magnetic resonance imaging evaluation. *Int J Oral Maxillofac Surg.* 2019 Jul 25.

Li k M B g M Szk ik J Różył -Kalinowska I. Correlation between direction and severity of temporomandibular joint disc displacement and reduction ability during mouth opening. *J Oral Rehabil.* 2017 Dec;44(12):957-963. doi: 10.1111/joor.12576. Epub 2017 Oct 6.

Lopes SLPL. Outros Métodos de Exames por Imagem. In: Campos FSF, Haiter-Neto F. *Diagnóstico por Imagem em Odontologia.* Nova Odessa: Napoleão, 2018.

Piancino MG MD, DDS, PhD, Tepedino M DDS, PhD, Cavarra F DDS, MSc, Bramanti E DDS, PhD, Laganà G DDS, MSc, PhD, Chimenti C MD, DDS, MSc, Cirillo S MD, MSrad. Condylar long axis and articular eminence in MRI in patients with temporomandibular disorders. *Cranio.* 2018 Oct 17:1-9. doi: 10.1080/08869634.2018.1532647.

Shokri A, Kasraei S, Lari S, Mahmoodzadeh M, Khaleghi A, Musavi S, Akheshteh V. Efficacy of denoising and enhancement filters for detection of approximal and occlusal caries on digital intraoral radiographs. *J Conserv Dent.* 2018 Mar-Apr;21(2):162-168. doi: 10.4103/JCD.JCD_213_17.

Srinivasan K, Mohammadi M, Shepherd J. Investigation of effect of reconstruction filters on cone-beam computed tomography image quality.

Australas Phys Eng Sci Med. 2014 Sep;37(3):607-14. doi: 10.1007/s13246-014-0291-8. Epub 2014 Aug 3.

Weickenmeier J, Jabareen M, Le Révérend BJD, Ramaioli M, Mazza E. Experimental and Numerical Characterization of the Mechanical Masseter Muscle Response During Biting. J Biomech Eng. 2017 Dec 1;139(12). doi: 10.1115/1.4037592.

Yap AU, Chua EK, Dworkin SF, Tan HH, Tan KB. Multiple pains and psychosocial functioning/psychologic distress in TMD patients. Int J Prosthodont. 2002 Sep-Oct;15(5):461-6.