Finite element analysis of a human temporomandibular joint disc: Preliminary results

Conference Paper *in* AIP Conference Proceedings · July 2018

DOI: 10.1063/1.5043814

5 authors, including:

David Serrano Faustino Angelo
Instituto Português da Face

Paula Pascoal-Faria
Polytechnic Institute of Leiria

Artur Mateus
Polytechnic Institute of Leiria

Nuno Alves
Polytechnic Institute of Leiria

Finite element analysis of a human temporomandibular joint disc: Preliminary results

Sara Gomes, David Faustino Ângelo, Paula Pascoal-Faria, Artur Mateus, and Nuno Alves

Citation: AIP Conference Proceedings **1978**, 160004 (2018); doi: 10.1063/1.5043814
View online: https://doi.org/10.1063/1.5043814
View Table of Contents: http://aip.scitation.org/toc/apc/1978/1
Published by the American Institute of Physics

Finite Element Analysis of a Human Temporomandibular Joint Disc: Preliminary Results

Sara Gomes[1], David Faustino Ângelo[1,3], Paula Pascoal-Faria[1,2 a)], Artur Mateus[1] and Nuno Alves[1]

[1] *Centre for Rapid and Sustainable Product Development, Polytechnic Institute of Leiria, Portugal*
[2] *Department of Mathematics, School of Technology and Management, Polytechnic Institute of Leiria, Rua General Norton de Matos, Apartado 4133, 2411-901 Leiria – Portugal*
[3] *Portuguese Facial Institute, Portugal*

[a)] Corresponding author: paula.faria@ipleiria.pt

Abstract. The temporomandibular joint (TMJ) is an important joint that plays a paramount role during the mandibular movement. TMJ disc is an essential component in the normal TMJ, interposed between the mandibular condyle and temporal fossa with the following functions: it distributes the intra-articular load, stabilizes the joints during translation and decreases the wear of the articular surface. The mechanical behaviour study of this element is therefore essential to provide alternative solutions when its replacement becomes essential. The aim of this study is to present a preliminary three dimensional mechanical model to study the stresses distributions at TMJ disc and to provide an efficient tool as an alternative to experimental preclinical studies. The human mandibular condyle, the TMJ disc and the temporal fossa were considered to build the finite element model; additionally, two types of connections were used between the disc and the bone simulating the retrodiscal tissue and lateral pterygoid muscle: frictionless and bonded. At this stage, the elastic behaviour of materials was taken into account. Results show that the computed von Mises stresses are in accordance with previous studies.

INTRODUCTION

The temporomandibular joint (TMJ) is the most frequently used joint in the human body. The TMJ opens and closes 1500 to 2000 times daily and is essential for everyday functions of the mouth, such as mastication, speech, deglutition, yawning, and snoring, involving special mandatory synergy of both articular sides. The TMJ disc is an essential component in the normal TMJ and has the following functions: (1) it distributes the intra-articular load, (2) it stabilizes the joints during translation, and (3) it decreases the wear of the articular surface preventing the articular surfaces deterioration [4].

Patients suffering from severe temporomandibular disorders (TMD) can have dislocated disc, perforated disc leading to serious degenerative problems with limited treatment options. Most surgical approaches, such as TMJ discectomy, do not restore the structural or biological properties of the articulation and disc. The absence of efficacious options to substitute the TMJ disc increased the potential of tissue engineering in TMJ domain.

Preclinical trials are essential to test efficacious options to substitute the TMJ disc, however finite element analysis can be important solutions to: evaluate potential biomaterials before preclinical trials, to validate preclinical trial results and to improve knowledge regarding diseases mechanisms. During the last decades different groups have demonstrated interest in this domain: e.g., Tanaka *et al*. [1], Bekcioglu *et al*. [2], Turner and Burr [3], Commisso *et al*. [4], Chen *et al*.[5], Mori *et al*. [6], Gregolin *et al*. [7], Koolstra and Eijden [8], Beek *et al*. [9], Chen and Xu [10], Korioth and Hannam [11]. The development of these numerical models allowed to quantify the stresses and strains at TMJ during clenching, that usually is difficult to obtain experimentally [4].

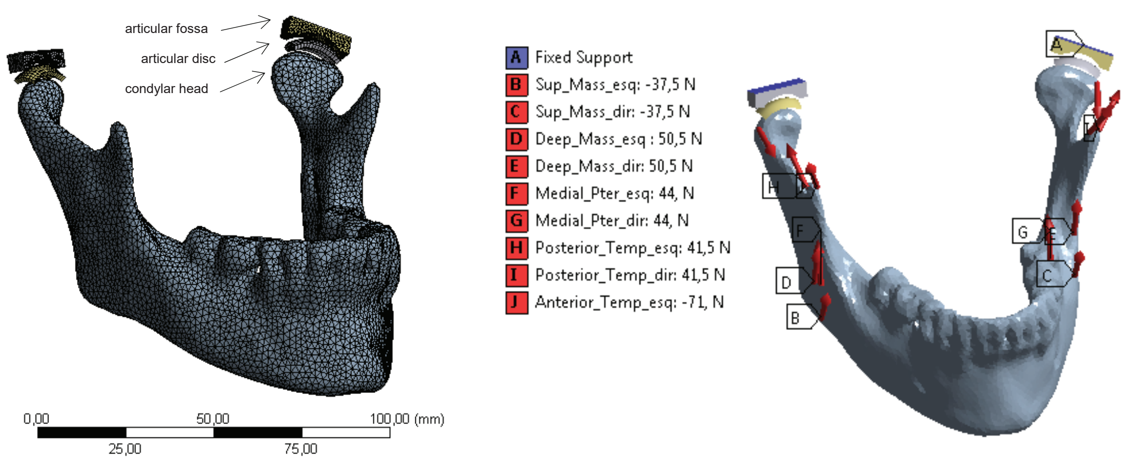
International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2017)
AIP Conf. Proc. 1978, 160004-1–160004-5; https://doi.org/10.1063/1.5043814
Published by AIP Publishing. 978-0-7354-1690-1/$30.00

This paper presents a numerical model of the mechanical behaviour of the human TMJ. The material was defined considering elastic models and contact between the disc and the bones were studied. The objective of this study was to develop a preliminary model to study the effect of muscular forces in the TMJ disc. This model will serve as the basis for a more complex model of sheep in a later stage.

NUMERICAL MODEL

A numerical model considering the human mandibular, the articular disc and the temporal fossa was built (see **FIGURE 1** (a)). The CAD model was obtained through CT scan of an adult and healthy human and the discs were modelled with a thickness of 1.5 mm [12]. Discs shape were modelled to fit the condylar head. Elastic and static analysis were carried out, assuming a Young's modulus of 44.1 MPa and a Poisson's ratio of 0.35 for the discs and a Young's modulus of 15000 MPa and a Poisson's ratio of 0.3 for the mandibular condyle and the temporal fossa [2].

The three-dimensional model was implemented in ANSYS. Tetrahedral elements were considered to model the bones and shell elements to model the discs, in a total of 119179 elements (see FIGURE 1 (a)). Two types of connections between disc and bone were studied: i) the bonded, to simulate no penetration, no separation and no sliding; and ii) the frictionless, to simulate no penetration and free sliding between parts. The boundary and load conditions, shown in **FIGURE 1** (b), were assumed according to Tanaka *et al*. [1]. The model was constrained at the articular fossa - superior region. Each force vector represents the existing muscle forces and was determined according to the different areas of muscles, and a resultant force of 500 N was adopted [1].

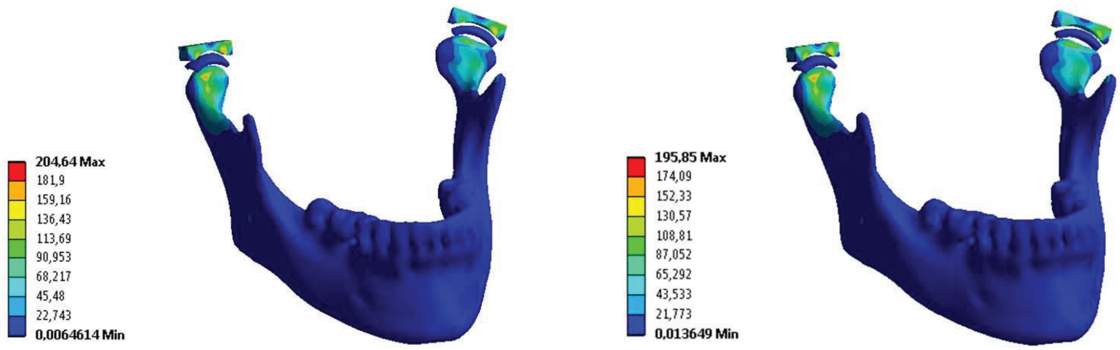


(a) (b)

FIGURE 1. – Numerical model: (a) adopted mesh; and (b) boundary and load conditions of the numerical model [1].

RESULTS

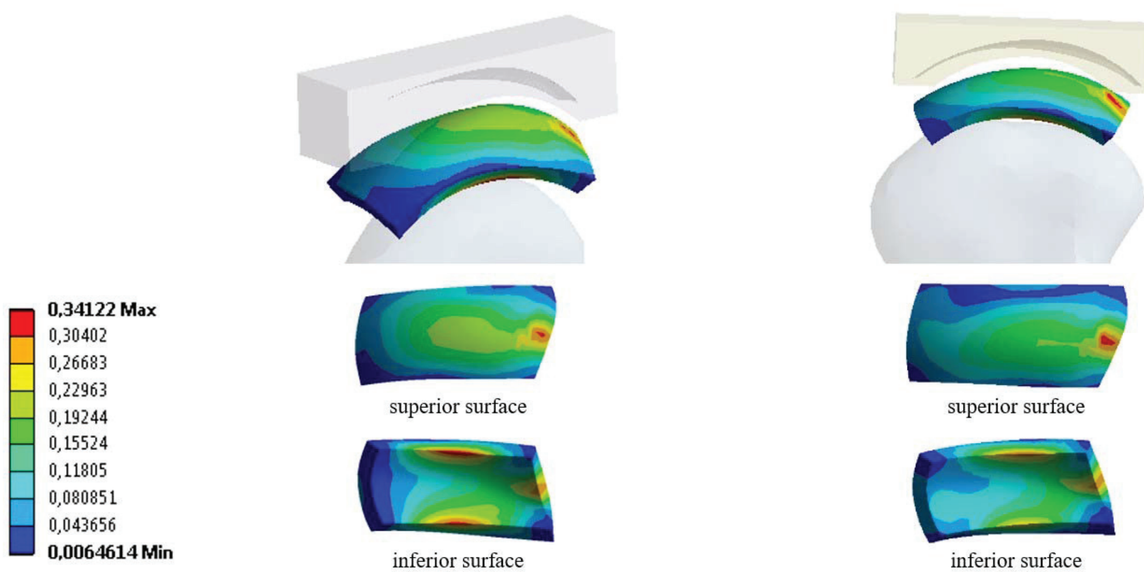
The performed analysis allowed evaluating the von Mises stresses distribution at discs. FIGURE 2 shows the stress distribution over the bone and discs when frictionless and bonded connections are considered. There are some stresses peaks at condyle head that may result from geometric imperfections related with the mandibular scanning, overpassing the human limit bone that is between 130-190 MPa [3]. However, these stresses are not considered real because appear in very constrained areas. The remaining stresses are below 23 MPa (dark blue). The comparison between the two analyses allowed concluding that results are similar at the mandibular condyle.



(a) (b)

FIGURE 2. – Von Mises stress (MPa) distribution of the overall model considering the discs connected using: (a) frictionless; and (b) bonded.

When discs are analysed in detailed, it is possible to verify that the von Mises stresses are below 0.35 MPa when frictionless is considered (see FIGURE 3) and below 1.35 MPa when the bonded connection is considered (see FIGURE 4). The presented results are in the same order of magnitude already presented in other works, such as [1][4][5]. The maximum stress verified when bonded connection is considered is almost four times higher than when frictionless is considered. This is related with the fact that the bonded does not allow penetration, separation and sliding, leading to higher stresses and not representing the reality. On the other hand, the frictionless connection gets closer to the reality since it allows sliding between parts.



(a) (b)

FIGURE 3. – Von Mises stresses (MPa) at disc considering frictionless for connections: (a) left disc; and (b) right disc.

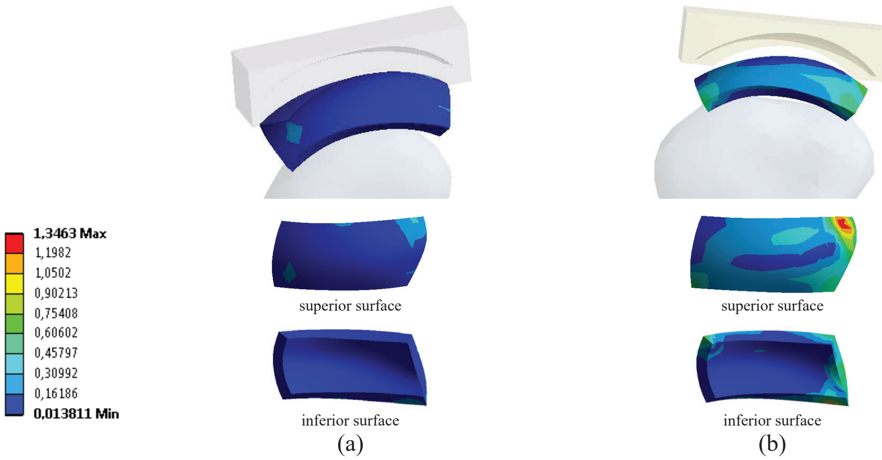


FIGURE 4. – Von Mises stresses (MPa) at disc considering bonded for connections: (a) left disc; and (b) right disc.

CONCLUSIONS

This paper presents a finite element model based on a human TMJ. The TMJ disc geometry was considered approximated. Results show peaks of von Mises stresses in the mandibular condyle, probably due to local geometric imperfections. The von Mises stresses at discs are in accordance with previous studies [1][5], in which report values of the same order of magnitude, i.e. up to 0.66 MPa [1] of the mean principal stresses or 8.0 MPa [5] of the von Mises stresses. The von Mises stresses are lower when connections are considered using frictionless, mainly because this type of connection allows penetration and sliding. On the other hand, when bonding is considered, higher stresses are verified due to a more constrained connection.

This pilot study intend to progress to a more complex model for human TMJ. A finite element model for Black Merino sheep is also planed to increase the quality of preclinical studies in TMJ domain.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support from Fundo Europeu de Desenvolvimento Regional (FEDER), Programa Portugal 2020, through the Programa Operacional Regional do Centro 2020 (CENTRO-01-0145-FEDER-022158).

REFERENCES

[1] E. Tanaka, K. Tanne and M. Sakuda, A three-dimensional finite element model of the mandible including the TMJ and its application to stress analysis in the TMJ during clenching, Med. Eng. Phys., 16, 316-322 (1994).
[2] B. Bekcioglu, E. Bulut and B. Bas, The effects of unilateral alloplastic temporomandibular joint replacement on the opposite-side natural joint: a finite-element analysis, J. Oral Maxillofac. Surg., 1-7 (2017).
[3] C. H. Turner and D. B. Burr, Basic biomechanical measurements of bone: a tutorial, Elsevier: Bone, 14, 595-608 (1993).
[4] M. S. Commisso, J. Martínez-Reina, J. Ojeda and J. Mayo, Finite element analysis of the human mastication cycle, J. Mech. Behav. Biomed., 41, 23-35 (2015).
[5] J. Chen, U. Akyuz, L. Xu and R. M. V. Pidapart, Stress analysis of the human temporomandibular joint, Med. Eng. Phys., 20, 565-572 (1998).
[6] H. Mori, S. Horiuchi, S. Nishimura, H. Nikawa, T. Murayama, K. Ueda, D. Ogawa, S. Kuroda, F. Kawano, H. Naito, M. Tanaka, J. H. Koolstra and E. Tanaka, Three-dimensional finite element analysis of cartilaginous tissues in human temporomandibular joint during prolonged clenching, Arch, Oral Biol., 55, 879-886 (2010).

[7] R. F. Gregolin, C. A. C. Zavaglia, R. C. Tokimatsu and J. A. Pereira, Biomechanical Stress and Strain Analysis of Mandibular Human Region from Computed Tomography to Custom Implant Development, Adv. Mater. Sci. Eng., 9 (2017).
[8] J. H. Koolstra and T. M. G. J. van Eijden, Combined finite-element and rigid-body analysis of human jaw joint dynamics, J. Biomech., 38, 2431-2439 (2005).
[9] M. Beek, J. H. Koolstra, L. J. van Ruijven and T. M. G. J. van Eijden, Three-dimensional finite element analysis of the human temporomandibular joint disc, J. Biomech., 33, 307-316 (2000).
[10] J. Chen and L. Xu, A finite element analysis of the human temporomandibular joint, J. Biomed. Eng., 116, 401-407 (1994).
[11] T. W. P. Korioth and A. Hannam, Mandibular forces during simulated tooth clenching, J. Oralfacial, 8, 178-189 (1994).
[12] M. Commisso, Biomechanics of the Human Mandible Including the Temporomandibular Joint, Ph.D thesis, University of Seville (2012).