Advances in Biomechanics and Applications, *Vol. 1, No. 3 (2014) 159-167*
DOI: http://dx.doi.org/10.12989/aba.2014.1.3.159

The influence of disc wear on the behavior of the temporomandibular joint: a finite element analysis in a specific case

Ricardo J. Duarte[12a], António Ramos[1b] and Michel Mesnard[*2c]

[1]*DTEMA, Department of Mechanical Engineering, University of Aveiro, 3810-197 Aveiro, Portugal*
[2]*Université de Bordeaux, Institut de Mécanique et d'Ingénierie, CNRS UMR 5295, Talence, France*

(Received October 02, 2013, Revised March 11, 2014, Accepted June 27, 2014)

Abstract. The aim of this study was to evaluate the influence of disc thickness on the normal behavior of the temporomandibular joint. Based on a specific patient case, CT scan images showing accentuated wear in the right disc were reconstructed and the geometrical and finite element model of the temporomandibular joint structures (cranium, mandible, articular cartilages and articular discs) was developed. The loads applied in this study were referent to the five most relevant muscular forces acting on the temporomandibular joint during daily tasks such as talking or eating. We observed that the left side structures of the temporomandibular joint (cranium, mandible and articular disc) were the most affected as a consequence of the wear on the opposite articular disc (right side). From these results, it was possible to evaluate the differences in the two sides of the joint and understand how a damaged articular disc influences the behavior of this joint and the possible consequences that can arise without treatment.

Keywords: articular disc wear; finite element models; muscular forces; numerical analysis; temporomandibular joint

1. Introduction

The temporomandibular joint (TMJ) is a very complex joint; it combines a wide hinge motion range and high frequency of motion, about 2000 cycles per day (Guarda-Nardini *et al.* 2011, Ramos *et al.* 2014). Although the TMJ is used in many daily activities, it is during mastication that the highest forces are transmitted (Chowdhury *et al.* 2011).

This joint is composed of skull, mandible and articular cartilages and discs. These articulating surfaces are highly incongruent, and this is the main reason for the large mobility of this joint. Between the articular cartilages of the mandible and the mandibular fossa is the cartilaginous articular disc which works as a shock absorber, decreasing the contact pressure between surfaces (Beek *et al.* 2000).

Due to the loads on daily activities to which this joint is subjected, it is estimated that TMJ

∗Corresponding author, Professor, E-mail: michel.mesnard@u-bordeaux.fr
[a] Ph.D. student
[b] Ph.D., Assistant Professor

http://www.techno-press.org/?journal=aba&subpage=7 ISSN: 2287-2094 (Print), 2287-2272 (Online)

disorders affect 20-25% of the population (Arabshahi *et al.* 2011, Pérez del Palomar and Doblaré 2006). TMJ disorders could originate from several factors such as trauma, fracture or ankylosis, but it is osteoarthritis that is responsible for the most severe pain or restricted mouth opening in the patient (Speculand *et al.* 2000) and this is extremely dependent on the articular disc (Pérez del Palomar and Doblaré 2006).

Several studies have been performed to evaluate problems related to the articular disc, especially disc misalignment or dislocation between the mandibular condyle and fossa (Chase *et al.* 1995, Westesson *et al.* 1986). It is known that in some cases, due to the forces at play in this joint, the articular disc suffers an abnormal dislocation that compromises the normal behavior of the joint.

Disc degeneration is also a recurrent problem related with TMJ. This usually requires surgical intervention and replacement of the damaged joint (mandible condyle and articular fossa) by prosthesis. Although replacing the joint is an effective solution, it is also important to understand what leads to the disc degeneration and the consequences of this in the normal behavior of the temporomandibular joint. Based on computational models and finite element analysis, this study intends to evaluate the influence of a damaged articular disc on the normal behavior of the temporomandibular joint and the consequences that it can provoke in the bone due to the unequal load transfer.

2. Materials and Methods

In this study, a finite element model of the complete temporomandibular joint (TMJ) structures was developed. The model was based on computed tomography images of an 84-year-old female with [0.89 × 0.89 × 1.80] mm resolution. Using the Simpleware software Scan IP, the skull, mandible, articular discs and articular cartilages were converted into a geometrical model.

Based on a previous study by Bujtar *et al.* (2010), the mandible bone structures were discretized into cancellous and cortical bone and the skull only as a cortical structure. This discretization was based on the Hounsfield units presented by Bujtar *et al.* (2010) [600-1300] HU and [1300-1600] HU for cancellous and cortical bone respectively. The whole lower part was modeled in order to evaluate the strain distribution in that area and to understand if the changes are relevant or not in the remaining bone.

The articular disc and cartilages were manually refined to differentiate them from the adjacent soft bone. At this point, the damaged region of the right disc was defined due to the reduced disc thickness evaluated in the CT scans. Due to a lack of information about the teeth on the CT scan images, these were not considered. The temporomandibular joint solid structures were assembled using the Dassault Systems software CATIA V5 R19. As shown in Fig. 1, a slight mandible angulation of 2.4º can be identified between the right and left condyle.

Based on previous studies, the mechanical properties of the TMJ structure were assigned as shown in table 1 (Chase *et al.* 1995, Hsu *et al.* 2011, Boryor *et al.* 2008, Tanaka *et al.* 2004). The materials were considered isotropic and linear elastic, meshed with tetrahedral elements of four nodes each for all joint components, although in the reality the articular disc has a viscoelastic behavior.

The models were considered restrained in all directions on the top of the skull and in Y and Z directions on the incisal tooth. In this study the five most relevant muscular forces acting on the TMJ were considered, as shown in Fig.3 (Ramos *et al.* 2011).

Table 1 Material and mesh properties

Component	**Material**	***E* (MPa)**	**υ**	**Mesh properties**	
				Nb. of nodes	**Nb. of elts**
Skull	Cortical bone	15000	0.3	45299	188784
Cortical Mandible	Cortical bone	13700	0.3	31919	128500
Cancellous Mandible	Cancellous bone	7930	0.3	8961	33591
Articular Discs	Disc	44.1	0.4	32023	142062
Articular Cartilage	Cartilage	0.49	0.49	4345	16429

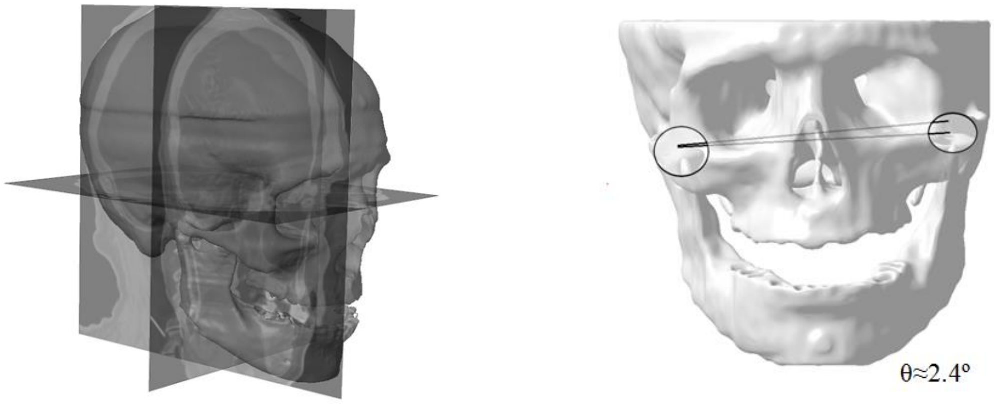


Fig.1 Temporomandibular joint reconstruction

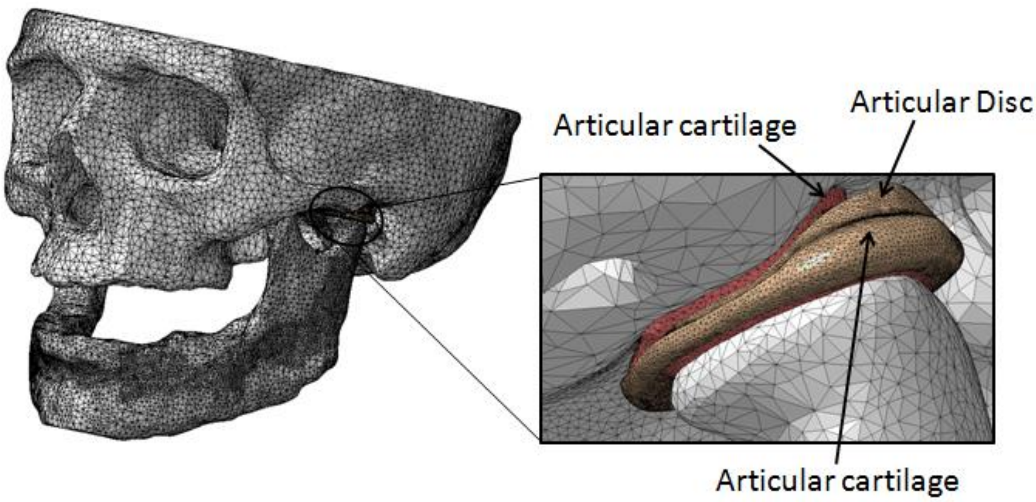
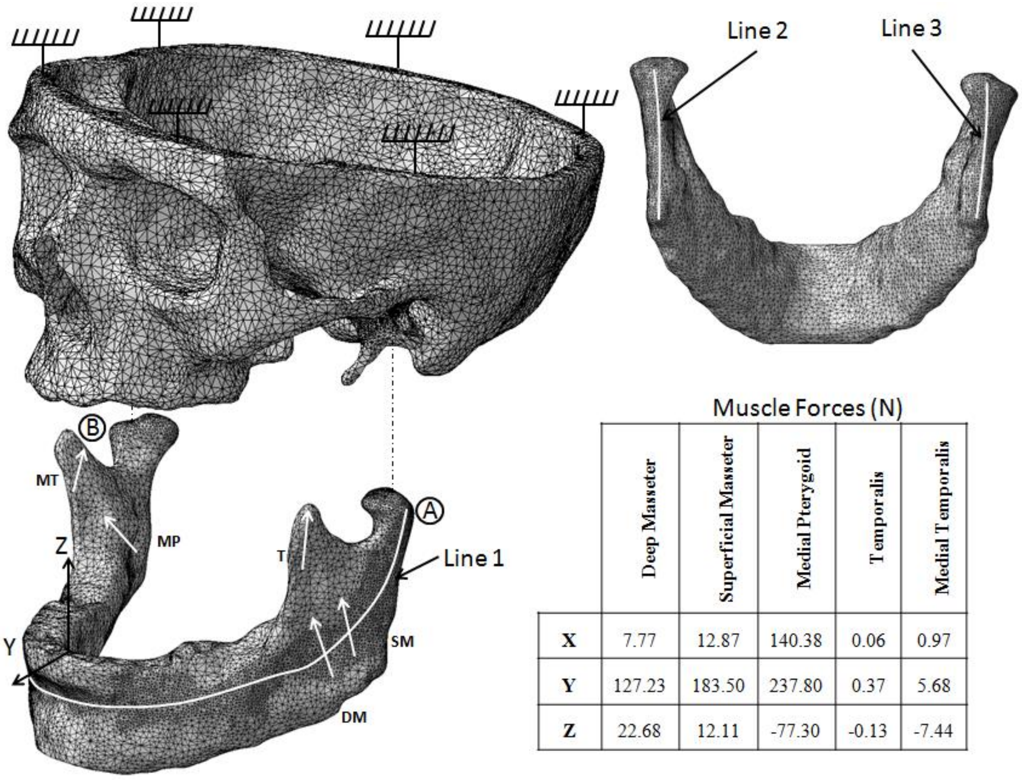


Fig. 2 Temporomandibular joint structures



Muscle Forces (N)

	Deep Masseter	Superficial Masseter	Medial Pterygoid	Temporalis	Medial Temporalis
X	7.77	12.87	140.38	0.06	0.97
Y	127.23	183.50	237.80	0.37	5.68
Z	22.68	12.11	-77.30	-0.13	-7.44

Fig. 3 Finite element model constraints and applied forces

The cortical and cancellous bone interface in the mandible was considered glued. Based on previous studies by Tanaka *et al.* (2004) and Pérez Del Palomar and Doblaré (2006) a friction ratio of 0.0001 was considered between the articular cartilage and the healthy disc (left disc) and 0.01 between the articular cartilage and the damaged disc (right side).

To analyze strain distribution posteriorly on the model, three different lines were set on the mandible, one along the mandible and one in each condyle, as shown in Fig. 3.

3. Results

The structures were analyzed in terms of principal strain and von Mises equivalent stresses in a few different regions.

The maximum and minimum principal strains ($\varepsilon 1$ and $\varepsilon 3$) along line 1, between points A and B (Fig. 3) show similar behavior in both halves of the mandible.

In this case it can be seen that the principal strain distribution is almost symmetrical. In the case of ε1 we observed that on the left side (A) of the mandible, where the disc is healthy, the strains at some points are higher than on the right side (B). However, despite these differences the ε1 are almost symmetrical. Concerning $\varepsilon 2$ we observed a similar strain behavior. In this case, the strains are higher on the healthy side (A) than on the damaged one (B), registering a difference of 74% between the maximum on the right side and the maximum on the left side.

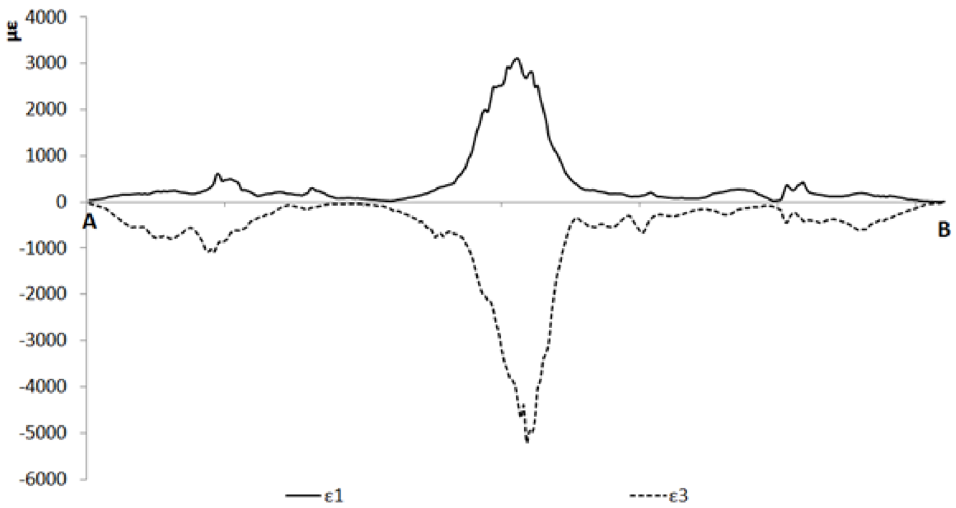


Fig. 4 Maximum and minimum principal strains along line 1

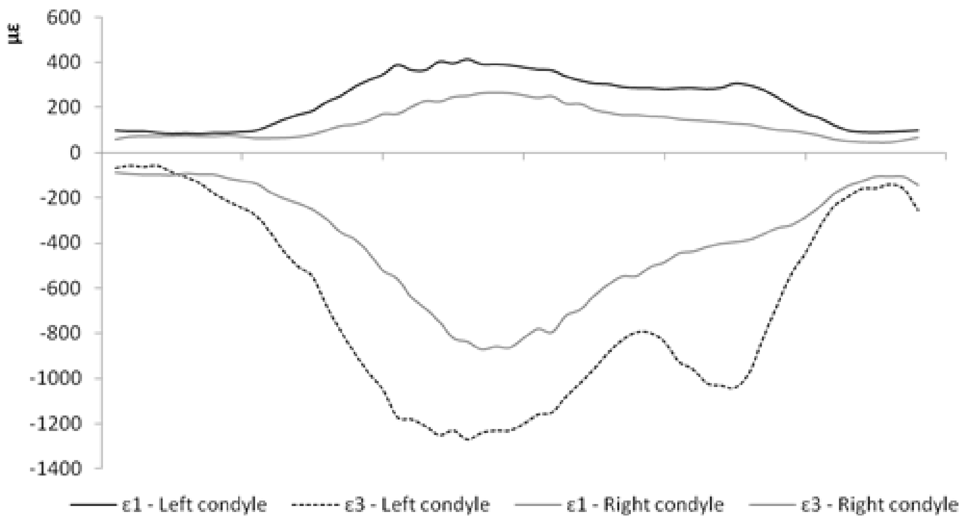


Fig. 5 Maximum and minimum principal strain along the right (line #2) and left (line #3) condyles

Comparing strain behavior on line #2 and line #3, in each condyle we observed that the strains on the left condyle are considerably higher than on the right condyle.

In terms of $\varepsilon 1$ we observed that this difference reaches 75%. Concerning the minimum principal strains, we observed that the maximum difference between left and right condyle is 50%.

From observing the strains on the articular fossa it can be seen that on the damaged side of the TMJ, strain distribution is more concentrated in one contact point, reaching -1300 $\mu\varepsilon$. Strains on the left side are lower, reaching a maximum of -650 $\mu\varepsilon$, however they are propagated over a large area, as shown in Fig. 6.

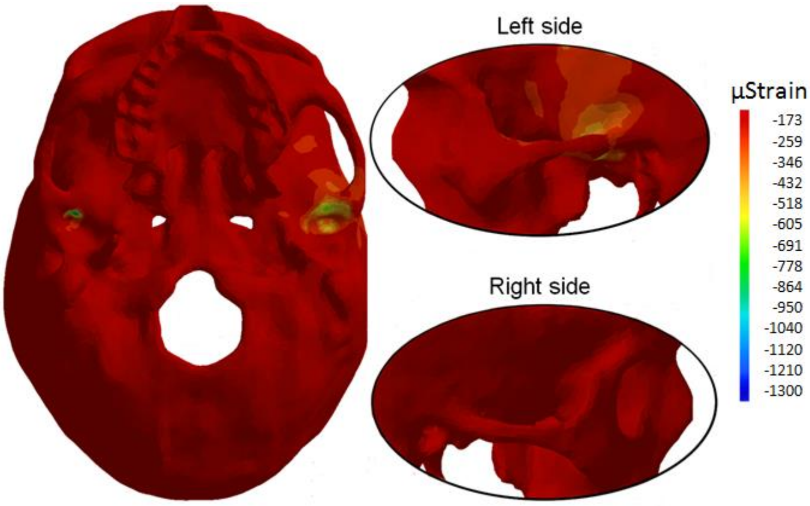


Fig. 6 Cranium minimum principal strain distribution

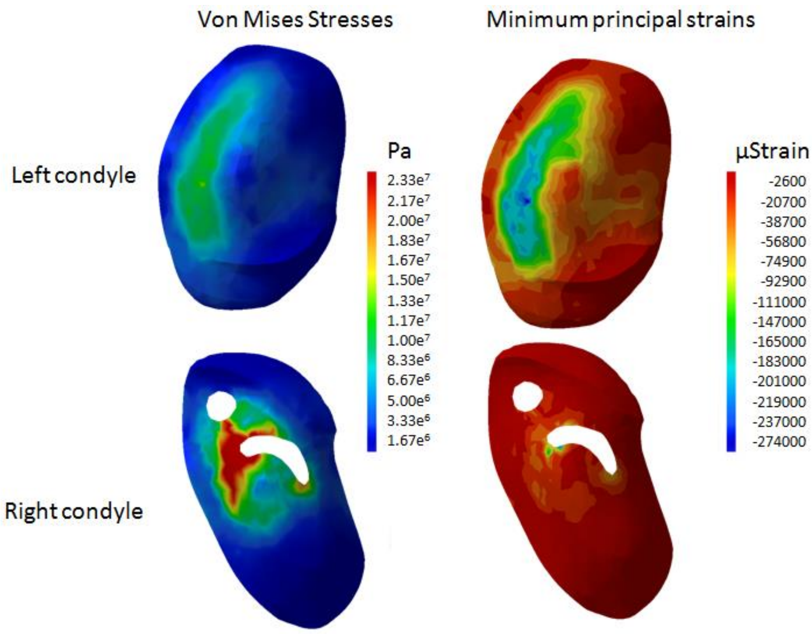


Fig. 7 Von Mises stress and minimum principal strain in both articular discs

Concerning the articular disc, it can be seen that the von Mises stresses are higher in the right condyle, especially surrounding the damaged region. In the left condyle a maximum stress of 14 MPa was reached although in the right condyle stresses reached 23 MPa.

Comparing the minimum principal strains on the left and right condyles, we observed that the affected area in the left condyle is larger than in the right one, this being the most affected articular disc.

4. Discussion

Temporomandibular joint disorders are a common problem. It is estimated that 20 to 25% of the world population suffers from this kind of disorder (Arabshahi *et al.* 2006, Pérez del Palomar and Doblaré 2006). Although, the joint is extremely requested, performing very complex movements, joint disorders are sometimes underestimated.

In the last decades the use of computational methods such as finite element (FE) has increased, and this tool is now commonly used in a wide range of studies and research, of which Biomechanics is just one. In biomechanics, research leads to very complex geometries and using just experimental tests it would be impossible to evaluate some of the important details that could explain some of the phenomena that happen in the human body. Thus in biomechanics, the use of finite element analyses has started to become commonplace and they have been used in a wide range of studies, for example in the mandible, hip and knee (Ramos 2011 *et al.*, Ramos *et al.* 2014, Completo *et al.* 2013, Limbert *et al.* 2010).

In this study one of the problems that currently affect this joint, the wear of an articular disc, was assessed numerically. This disorder can preclude the patient from leading a normal life due to the pain that it causes during the simplest daily routines such as talking or eating.

We observed that disc wear in one side of the mandible will influence load transfer in the joint, increasing the loads on the opposite side. This is explained by the rotation that this joint undergoes due to the loadings. These findings support observations by Ramos *et al.* (2014).

Further strong evidence of unequal load transfer is found when the condyle behavior is analyzed. We observed that the left condyle (healthy side) is solicited much more than the right condyle and due to the values registered for it, according to Roberts *et al.* 2004 this may be where changes in bone structures originate in this side of the joint.

This evidence is also noted on the cranium. In this TMJ structure we observed that the left side is solicited more compared with the right side, and it can be observed that in the left side, the greater strain distribution affects a larger area than in the right side, where it is confined to a smaller restricted area. These results could be explained by the contact area between the mandible and the cranium. Since the right articular disc is damaged, the contact point between these two structures is concentrated, thus increasing the stresses and strains in that structure and causing the pain reported previously by the patient. On the healthy side, as the contact area is larger and is covered by soft tissue, moving the joint will be painless.

Two analyses were carried out on the articular discs, one based on the Von Mises stresses and the other on the principal strain distribution. We observed a maximum peak of 14 MPa on the healthy disc and 23 MPa on the damaged disc. This is understandable since the damaged disc promotes friction between the two articular cartilages, increasing the stresses on that surface. Comparing our results with previous studies by Pérez del Palomar and Doblaré (2007), Pérez del Palomar and Doblaré (2008) we observed a few differences. Palomar and Doblaré noted maximum stresses of 6 MPa, which is not close to our results. This difference could be explained by the fact that in their study, the authors used an intact temporomandibular joint with two healthy articular discs and in our study one articulating part is damaged, which will naturally influence the response of the other structures and consequently increase this parameter. Another hypothesis to explain these differences is respecting the material properties and different boundary conditions used in these two studies. One also believe that the fact that an elastic disc's behavior was adopted won't change much the final results, since a static load case was used and the compression won't be high enough to promote a considerable difference in that component. Considering this, although other authors used different material properties, one considered that in this preliminary case it won´t be relevant (Pérez Del Palomar and Doblaré 2006, Roberts *et al.* 2004).

When analyzing strain distribution, it was once again on the left side that the strains registered the highest values and again over a larger area. This corroborates the fact that when one of the articular discs is damaged the joint will adapt to promote effort in a more sustainable region.

One of the points that could be improved in our study is the fact that real articular discs are hyperelastic structures, whereas we considered it as a linear elastic material. Despite this, we believe that this approach will not skew our results from reality since the Poisson ratio used in these structures is close to 0.5, which indicates an almost linear behavior.

5. Conclusions

This study shows the influence that a damaged articular disc has on the adjacent bone structures. It is proved that, when one articular disc is damaged, the opposite side will support an extra load which could lead to early wear of the healthy disc and consequently to further joint complications.

Acknowledgments

The authors gratefully acknowledge the University of Bordeaux and funding from the PTDC/EME-PME/112977/2009.

References

Arabshahi, Z., Kashani, J., Abdul Kadir, M.R., and Azari, A. (2011), “Influence of Thickness and Contact Surface Geometry of Condylar Stem of TMJ Implant on Its Stability”, *Phys. Procedia*, **22**, 414-419.

Beek, M., Koolstra, J.H., van Ruijven, L.J., and van Eijden, T.M. (2000), “Three-dimensional finite element analysis of the human temporomandibular joint disc”, *J. Biomech.*, **33**(3), 307-316.

Boryor, A., Geiger, M., Hohmann, A., Wunderlich, A., Sander, C., Martin Sander, F., and Sander, F,G. (2008), “Stress distribution and displacement analysis during an intermaxillary disjunction--a three-dimensional FEM study of a human skull”, *J. Biomech.*, **41**(2), 376-382.

Bujtár, P., Sándor, G.K., Bojtos, A., Szucs, A., and Barabás, J. (2010), “Finite element analysis of the human mandible at 3 different stages of life”, *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.*, **110**(3), 301-309.

Chase, D.C., Hudson, J.W., Gerard, D.A., Russell, R., Chambers, K., Curry, J.R., Latta, J.E., and Christensen, R,W. (1995), “The Christensen prosthesis. A retrospective clinical study”, *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.*, **80**(3), 273-278.

Chowdhury, A.R., Kashi, A., and Saha, S. (2011), “A comparison of stress distributions for different surgical procedures, screw dimensions and orientations for a Temporomandibular joint implant”, *J. Biomech.*, **44**(14), 2584-2587.

Completo, A., Duarte, R., Fonseca, F., Simões, J.A., Ramos, A., and Relvas, C. (2013), “Biomechanical evaluation of different reconstructive techniques of proximal tibia in revision total knee arthroplasty: An in-vitro and finite element analysis”, *Clin. Biomech. (Bristol, Avon)*, **28**(3), 291-298.

Guarda-Nardini, L., Manfredini, D., and Ferronato, G. (2008), “Temporomandibular joint total replacement prosthesis: current knowledge and considerations for the future”, *Int. J. Oral Maxillofac. Surg.*, **37**(2),

103-110.
Hsu, J.T., Huang, H.L., Tsai, M.T., Fuh, L.J., and Tu, M.G. (2011), "Effect of screw fixation on temporomandibular joint condylar prosthesis", *J. Oral Maxillofac. Surg.*, **69**(5), 1320-1328.
Limbert, G., van Lierde, C., Muraru, O.L., Walboomers, X.F., Frank, M., Hansson, S., Middleton, J., and Jaecques, S. (2010), "Trabecular bone strains around a dental implant and associated micromotions--a micro-CT-based three-dimensional finite element study", *J. Biomech*., **43**(7), 1251-1261.
Pérez del Palomar, A., and Doblaré, M. (2006), "The effect of collagen reinforcement in the behaviour of the temporomandibular joint disc", *J. Biomech.*, **39**(6), 1075-1085.
Pérez del Palomar, A., and Doblaré, M. (2007), "An accurate simulation model of anteriorly displaced TMJ discs with and without reduction", *Med. Eng. Phys.*, **29**(2), 216-226.
Pérez del Palomar, A., and Doblaré, M. (2008), "Dynamic 3D FE modelling of the human temporomandibular joint during whiplash", *Med. Eng. Phys.*, **30**(6), 700-709.
Ramos, A., Completo, A., Relvas, C., Mesnard, M., and Simões, J.A. (2011), "Straight, semi-anatomic and anatomic TMJ implants: the influence of condylar geometry and bone fixation screws", *J. Craniomaxillofac. Surg.*, **39**(5), 343-350.
Ramos, A., Mesnard, M., Relvas, C., Completo, A., and Simões, J.A., (2014), "Theoretical assessment of an intramedullary condylar component versus screw fixation for the condylar component of a hemiarthroplasty alloplastic TMJ replacement system", *J. Craniomaxillofac. Surg.*, **42**(2), 169-174.
Roberts, W.E., Huja, S., Roberts, J.A. (2004), "Bone modeling: biomechanics, molecular mechanisms, and clinical perspectives", *Semin. Orthod.*, **10**(2), 123-161.
Speculand, B., Hensher, R., and Powell, D. (2000), "Total prosthetic replacement of the TMJ: experience with two systems 1988-1997", *Br. J. Oral Maxillofac. Surg.*, **38**(4), 360-369.
Tanaka, E., del Pozo, R., Tanaka, M., Asai, D., Hirose, M., Iwabe, T., and Tanne, K. (2004), "Three-dimensional finite element analysis of human temporomandibular joint with and without disc displacement during jaw opening", *Med. Eng. Phys.*, **26**(6), 503-511.
Westesson, P.L., Bronstein, S.L., Liedberg, J. (1986), "Temporomandibular joint: correlation between single-contrast videoarthrography and postmortem morphology", *Radiology*, **160**(3), 767-771.

CC