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Influence of teeth contact alternation to TMJ stress distribution ---- Three-dimensional finite element study [*]

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Abstract. Objective: To reconstruct three-dimensional FEM model including lower dentition、mandible and bilateral condyles for analyzing the regularities of Temporomandibular Joint (TMJ) stress distribution response to dental occlusion alteration by using Finite Element Methods. Methods and Materials: A skull sample was selected and scanned by CT at the direction parallel to the Frankfort Horizontal plane. Occlusion surface of the plaster casts were scanned with a 3D scanner. Then the cast's digital parameter and CT image's parameter were converted into one coordinate system. Also a simulated disc was added on each of the condyles. In FEA software ANSYS the same boundary constraints were applied to the TMJ FEM model with different load cases. According to three different occlusal area loads on the second mandibular molar, that were ICO load, distal load and buccal load, the stress value of condyles of the FEM model were calculated. Results: The FEM model containing bilateral condyles, simulated discs, and lower dentition was formed after meshing. The condyle stresses on TMJ FEM model in three loading cases are diverse not only in stress' character but also in stress distribution style. The maximum value of Von Mises in opposite condyle is 51.513MPa when ICO load was applied. But when the distal load or the buccal load was applied the maximum value of Von Mises in opposite condyle increased to 72.145MPa or 69.566Mpa respectively. Conclusion: Alteration of occlusal contact condition affects the TMJ condyle stress distribution significantly. The same level but different direction of occlusal force that resulted from difference of loading spots by changing the occlusal contact area would induce different stress features on bilateral condyles.

Keywords: temporomandibular joint (TMJ), occlusion, finite element method (FEM), 3-D reconstruction, modelling.

1. Introduction

Temporomandibular joint (TMJ) is the only joint that keeps relatively active reconstruction ability for all one's life. The load on TMJ is very important for its physiological function and the development of some diseases. The occlusal patterns have very important function in changing of direction or magnitude of the stress in root apex [1]. Occlusal force is the most direct origin of that load, which has varying directions, different types and individual diversity. Therefore, investigation on the law of stress distribution in TMJ under different occlusal pattern is very important for further understanding of reconstructive feature of TMJ and its relationship with occlusion. Many finite element (FE) analyses have been reported to probe the biomechanical status in the TMJ [2–4].Three-dimensional (3-D) and individual work, however, have been limited, and their concern was focused on the muscle forces. But the occlusal force is also an important factor correlating to the biomechanical environment of TMJ.

It was the object of our study to develop a Finite Element model containing TMJ and lower dentition based on CT and 3D scanner to simulate the stress environment of TMJ in different occlusal pattern. Moreover, the whole mandible and TMJ model was loaded with the different occlusal force vectors by direction in lower second molar. Ultimately, the objective of this study is to evaluate the effective laws of different occlusal pattern to TMJ stress.

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2. Materials and Methods

3D-finite element approach divides a geometric model into a finite number of elements in which the variables of interest are approximated with some mathematical functions. Biomedical applications of this method are already known in some fields of TMJ.

In our study, a 3D FEM model of mandible, TMJ and lower dentition was realized. The first step was the solid model generation in which the shapes of mandible, TMJ and lower dentition were obtained. The outline for the articular disc was also generated. Then the solid model was filled with elements, creating the mesh, and the material properties of mandible and disc were assigned to the elements, which filled the corresponding regions. Thus the FEM model was obtained. Subsequently, loads and geometric conditions were applied.

To study the correlation of teeth contact shape and TMJ stress, the key-point of TMJ FEM model is the teeth contact shape. As reported in latest studies about foundation of mandible FEM model, CT and MRI are mostly used to getting data of dentition. In our study, a 3D FEM model of mandible , upper and lower dentitions by combining CT data of mandible and digital data of both dentitions using 3D scanner.

2.1. Mandible solid model generation

A skull sample with aneutral skeletal relationship and normal dentition was selected and scanned from the chin to the condylar head using a Philip Tomoscan SR 7000 CT scanner at the direction parallel to the Frankfort Horizontal plane. A total of 54 serial CT scans in 2.0mm increments was obtained. The set of CT scans were scanned by AGFA Arcus II scanner (Agfa-Gevaert Group, Germany). An edge detection algorithm was run with Adobe Photoshop 6.0(Adobe, San Jose, CA) to distinguish cortical bone from cancellous bone and to detect the boundary of various components of the mandible.

Geometrical information of mandible in the CT images was extracted. Occlusion surface of its plaster casts were scanned with a 3D scanner (accuracy: 0.5mm). The cast's parameter and CT image's parameter were converted into the same coordinate system. A simulated disc was added on each of the condyles. Constraints were applied to the upper surface of disc and angle of mandible.

Upon reconstruction of the condyle, a disc was added with a uniform thickness of 2 mm [5]. With regard to the articular disc, the upper and lower boundaries based on the shape of the condyle.

Construction of the entire model with the addition of the disc was completed by ANSYS 7.0 (Swanson Analysis Systems, Houston, TX) preprocessing program software.

2.2. Lower dentition solid model generation

This procedure is the key point in this study. Impression of lower dentition was taken and then dental cast model was made by plaster to precisely provide the occlusal surface.

The Frankfort Horizontal plane was signed in the skull sample according to the anatomical symbol and was cut out by bone saw based on the plane. Then the skull sample was inversed on the working plane to make the Frankfort Horizontal plane parallel to the horizontal plane. After replacing the mandible with the lower dental cast, intercuspal central occlusion was reached between the maxillary and mandibular teeth. Then plaster was used to make the bottom of the cast parallel to the Frankfort Horizontal plane.

A 3-D surface-scanning system Roland PIX-30 (Roland corp. Japan) was used to measure the dental cast [6]. The resolution in the X-direction was 0.5 mm, and that in the Y-direction also was 0.5 mm. The point cloud file of the lower dentition was created after the scanning. Then it was imported in Geomagic studio 6 (Raindrop Geomagic, USA), Reversing Engineer software. Afterwards the point cloud was converted into surface model. And the surface model was imported in Pro-Engineer Wildfire 2.0 (Parametric Technology Co., Waltham, MA, USA) to generate the solid model.

2.3. FEM model generation

The solid model was exported into ANSYS 7.0, using the PRT format. In ANSYS the two solid models were combined into one solid model according to the reference points in lower central incisor. The volume was redefined and meshed with solid brick 8-node 185 element, resulting in an 123396-element and 35728-node structure as shown in Fig.1..Different material properties were assigned to the elements according to the volume definition. The TMJ model was realized. Material properties are listed in Table 1.

Some assumption was made in order to simplify the calculation. Absolute bonding was considered among the upper surface of disc and the angle of mandible. Despite their intrinsic anisotropic nature, teeth and mandible can be assumed homogeneous and isotropic. Furthermore, all materials were considered elastic. The biomechanical properties of the cortical and cancellous bone [7, 8], and the elastic properties of the articular disc of the mandible, were shown in Table1. As based on Saint Venant Principle, the elastic module and Poisson's ratios of the mandible and teeth were defined the average value of the cortical and cancellous bone which is 1.1×10^4MPa and 0.30.

Table 1 Mechanical properties of various components of the TMJ

Material	Young's modulus（Mpa）	Poission's ratio
Cortical bone	1.37×10^4	0.30
Cancellous bone	7.93×10^3	0.30
Articular disc	4.41×10	0.40

2.4. Stress analysis in the TMJ

According to three different occlusal area loads on the lower second molar, that were Intercuspal occlusion (ICO) load [1], distal load and buccal load. The load pattern was 100MPa pressure on the surface selected in three load conditions which can provide the occlusal force vertical to the surface selected as the occlusal spot. It's better to simulate the occlual conditions like hyper-erupted upper third molar and second molar cross-bite in clinic. Then the stress value of condyles in the FEM model were calculated and concluded.

3. Results

After meshing the FEM model containing bilateral condyles, simulated discs, and lower dentition was formed (Fig.1).

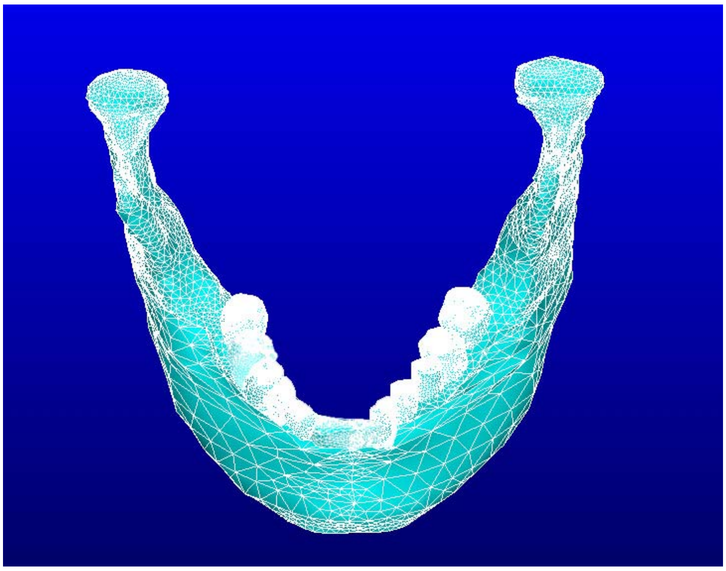
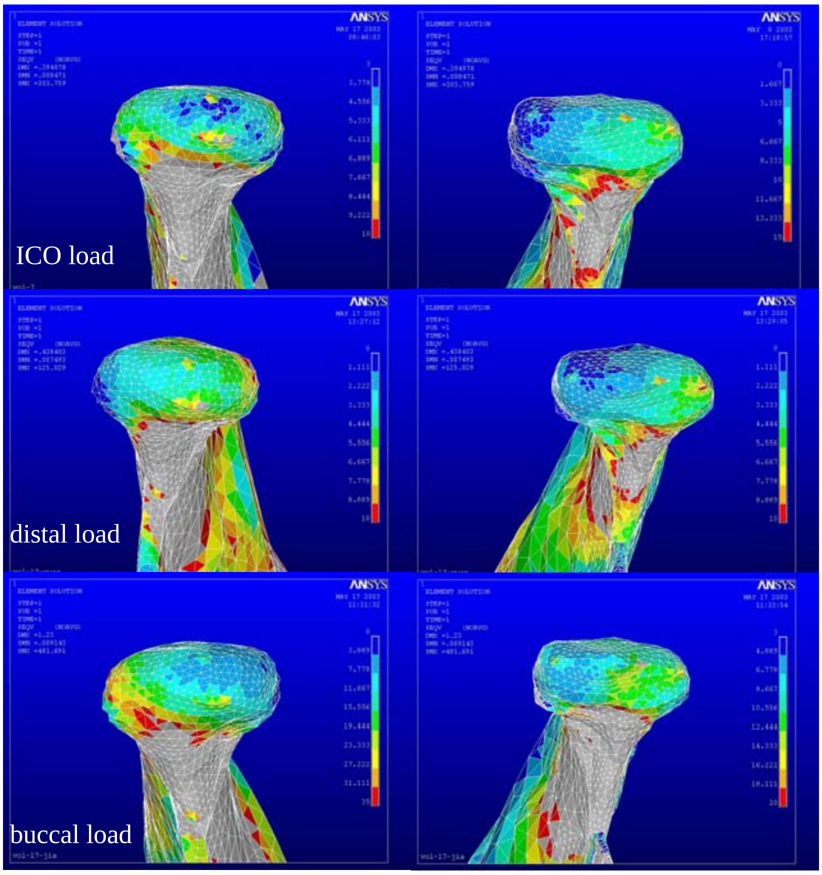


Fig.1 TMJ FEM model containing mandible,TMJ and lower dentition

All the analyses performed are linear static. As occlusal load was applied to different teeth contact area with various shape, the stress distribution of bilateral condyles were found different and asymmetrical. The condyle stresses on TMJ FEM model in three loading cases are diverse not only in stress' character but also in stress' distribution style. The maximum value of Von Mises in opposite condyle is 51.513MPa when ICO load was applied. But when the distal load or the buccal load was applied the maximum value of Von Mises in opposite condyle increased to 72.145MPa or 69.566Mpa respectively (Table.2).The distal load changing had much more influence on stress distribution of the loading side condyle' medial pole, the buccal load changing had much more influence on stress distribution of opposite condyle' medial pole (Fig.2). When the model loaded with different patterns of stress by altering load location，TMJ stress transformation can be inferred and relationship between occlusion and TMJ maybe revealed.

Table 2.Comparison of condyle's Max stress (MPa) in ICO occlusal load case ,distal load case and buccal load case

	a. ICO load		b. distal load		c. buccal load	
	opposite	loading	opposite	loading	opposite	loading
Max	61.812	72.477	69.514	52.225	63.248	49.733
Min	3.106	2.372	7.716	3.329	5.031	2.428
Mises	51.513	57.557	72.145	47.736	69.566	50.294



Loading side opposite side

Fig.2. Von Mises stress distribution graph in ICO occlusal load case, distal load case and buccal load case.

4. Discussion

The use of FEM model with detailed occlusal data to test the influence of different occlusal force on the stress distribution of TMJ seems to be of extreme help on understanding critical problems related to the complicated occlusal situations and TMJ deformation. Loaded by pressure on the occlusal surface makes the occlusal forces always are vertical to the surface which is the contact pattern in vivo.

The most pressed area was not only in the anterior slope and the medial pole of loading side condyle but also in the medial pole of the opposite condyle. The pressure level in the anterior slope increased in the opposite condyle in hyper-erupted upper third molar condition and in hyper-erupted lower third molar condition. And the TMJ stress level in the medial pole also raised in loading condyle in posterior teeth scissors-bite occlusion and in opposite condyle in partial posterior teeth cross-bite occlusion. Consequently, the reconstruction of TMJ was probably involved.

Under the same occlusal force, the directions, the values and the distributions of the stress transferred to

TMJ varied according to different occlusal types. Therefore, abnormal occlusion will influence the biomechanical environment of TMJ by alterations of either inclination direction and angle of long axis of teeth, or guiding orientation and degree of cuspal working plane [9–11].

5. Conclusion

The findings of this work suggest that the finite element analysis can play an important role in the study of effect of occlusion surface alteration on TMJ stress distribution. By adjusting occlusal load location on the same teeth, both sides condyle's stress distribution will induce corresponding changes. And this will be helpful to the biomechanical studies on effects of occlusion to TMJ stress.

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7. References

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