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Three Dimensional Model of the Human Mandible

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ABSTRACT

A new biomechanical three-dimensional (3D) model for the human mandible is proposed. A simple two-dimensional model cannot explain the biomechanics of the human mandible, where muscular forces through occlusion and condylar surfaces are in a state of dynamical 3D equilibrium. All forces are resolved into components according to a selected coordinate system. The muscular forces, which during clenching act on the jaw, along with the necessary force level for chewing, also act as some kind of stabilizers of the mandibular condyles preventing dislocation and loading of nonarticular tissues.

Introduction

Biomechanical studies of the orofacial skeleton play a significant role in the study of the regularity of the inner structure, shapes and functional relationships in the whole oromaxillary system. Therefore, an adequate biomechanical model of the human mandible can be of great value in understanding the different forces working on the temporomandibular joint (TMJ).

In the relevant literature several biomechanical models have been proposed[1–3] in the form of planar stationary beams that should satisfy mandibular equilibrium conditions. These models were assumed to be constrained by means of a fixed joint, with the exception one report[1] in which the temporomandibular joint is presented as a movable joint, but only in vertical and posterior directions. In such case it was possible to calculate also the horizontal force that must be stabilized by means of the muscular force to prevent the posterior dislocation of the mandibular joint.

In our opinion the above mentioned models are inadequate, because they are of planar type and consequently they are in some way unnatural, because we cannot neglect lateral movements of the

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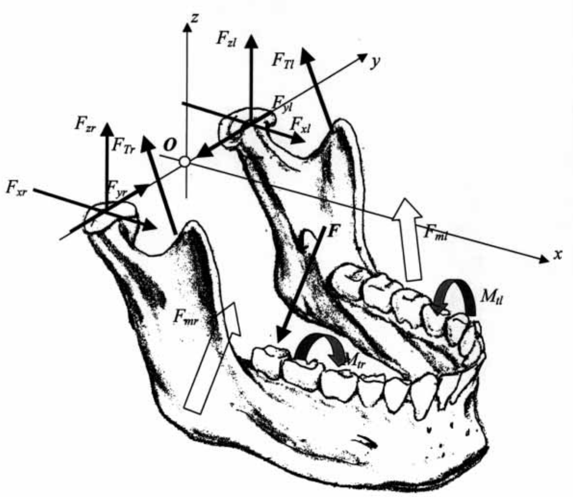

Fig. 1. Human mandible as a three dimensional model. $\boldsymbol{F_{mr}}$ *is a resultant force of the right masseter and pterygoid muscles supposed to be parallel with plane xz;* $\boldsymbol{F_{ml}}$ *is the equivalent force on the left side of the mandible.* ***F*** *is the occlusive resultant force that is supposed to act obliquely, making the angles with the axes of the coordinate system.* $\boldsymbol{F_{Tl}}$ *and* $\boldsymbol{F_{Tr}}$ *are the resultant forces of the temporal muscles, respectively from the left and right side of the mandible.* F_{xr}*,* F_{yr} *and* F_{zr} *then* F_{xl} F_{yl} *and* F_{zl} *are the components of the reactions in temporomandibular joints.* M_{tr} *and* M_{tl} *are torsional moments that act on both sides, left and right.*

mandible during clenching. The human mandible should function as a simple, but three dimensional support, where all the muscular forces act in a three dimensional way, and all of them should be in equilibrium with both active and reactive forces generated by other anatomic structures.

The purpose of this investigation was to propose a new three-dimensional model of mandibular mechanics where the component of muscular forces is not always parallel to the temporal articular plane, because of a possible frequent nonsymmetrical loading of the mandible.

Material and Methods

Model

A spatial three-dimensional model was developed for a simplified analysis on the basis of anatomical considerations and on average literature. Figure 1 shows the proposed model with the applied forces, moment and reactions. A coordinate system Oxyz is chosen as it is shown in the figure, so that the origin of the system lies in the midsplane of temporomandibular joints. Acting force F is supposed to act obliquely on the last tooth. The actions of the temporal muscles F_{tl} and F_{tr}, as well as maseter forces F_{ml} and F_{mr} and the torsion moment on the left and right side are included in the system of forces, together with three-dimensional reactions in the temporomandibular condyles.

Measuring of characteristic mandibular points

To prove that the motion of the mandible during clenching process is not a planar one, we decided to measure the spatial movement of characteristic points of the mandible.

Description of the measuring system

The ELITE system as a motion analyzer was designed by BTS in Milan in Italy. This system is designed as a modular system based on the central unit that can support up to three subunits with one personal computer interface, using an infrared lighting camera, to avoid any kind of disturbance of movable subjects. The marker's detection that is based on the pattern recognition, also the possibility to vary the pattern that is recognized, gives to the system a great flexibility for multifactorial investigation of the motion. This system acts with very highly accurate analysis of macro and micro movements.

The ELITE system we used in this work for the preliminary experiments was controlled by a personal computer, and it was supplied with a wide range of software packages that are modularly organized. A basic software package was used to compute the exact 3D coordinates of all measuring markers.

Figure 2 shows the applied system with two IR cameras and respective force-measuring platform.

The calibration of the ELITE system

In our analysis we used two IC – cameras (infrared), which have in their objectives installed IC respective flashes. Reflected light beams from markers are registered in both cameras, which enables the computer programming of the calculation of 3-D coordinates of the marker space position.

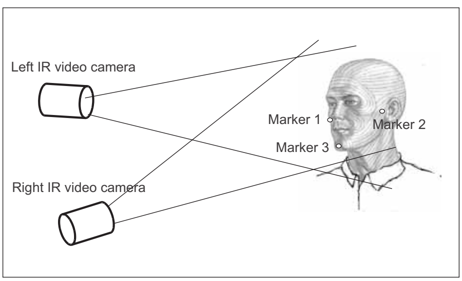

Fig. 2. The ELITE measuring system, with the subject and two infrared cameras.

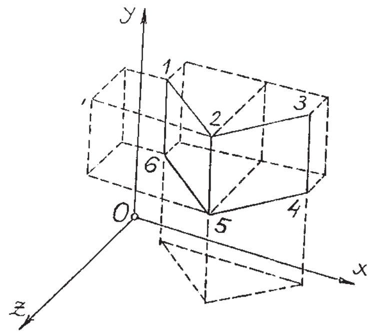

Fig. 3. Model for calibration of the system with marked characteristic points, and their known coordinates.

Before the processing by means of the ELITE system, it is necessary to do a special procedure, of the so-called calibration of the working space of the system. By means of the calibration process we define the working volume in which we shall record the movements of the characteristic markers positions. For this purpose, we install a comparative model with the regular distribution of the markers, as shown in Figure 3. In our case we determined the coordinates as shown by Table 1.

TABLE 1
DETERMINED COORDINATES

Marker	X	Y	Z
1	187	821	160
2	539	821	441
3	799	836	121
4	808	455	110
5	544	436	426
6	194	442	145

After calibration, the system forms its own coordinate system; by means of we define respective coordinates to the attached markers on the examined subject. To examine the accuracy of recorded results, we used as an example a parallelepiped of known dimensions, and with markers attached to the corners. Comparing the relative positions of the markers with coordinates in the table, we found out differences lower than 1.5%.

The described recording procedure was typically asymmetric one, because the analyzed subject had also asymmetrically attached markers. Number, what in our case was from 1 to 8, nominates markers. Connecting the markers in the preferred order we created the so-called »wire« model of the subject, which provides the basis for further analyses.

Results and Discussion

Because of the preliminary character of the present biomechanical analysis aimed only at finding out just the possibilities of such an analysis, we analyzed only one person – one of the authors of the work.

The diagrams given in Figure 4 shows the trajectories of the frontal movements of markers 2 and 3 produced by computer. From this diagram it is obvious that the vertical movement of the marker 2 is in the range of 10 mm, and that the horizontal movement is also about 10 mm. The vertical movement of the marker 3 is within the range of 28 mm, but its horizontal movement is about 6 mm. This in the same time proves that during the chewing process we have recognized motions in three directions.

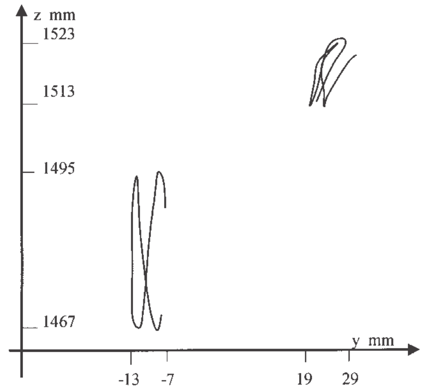

Fig. 4. The trajectories of the frontal movements of the markers 2 and 3.

At the same time, that means that the forces e.g. in temporomandibular joints could be different, and that the only position when they are similar is in the case of the exact symmetrical position of the loading.

In the same way we defined the values of all other markers, as can be seen in Figures recorded by the computer.

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TRODIMENZIONALNI MODEL MANDIBULE

S A Ž E T A K

U radu je prikazan novi trodimenzionalni model mandibule. Jednostavan dvodimenzionalni model ne može objasniti biomehaniku mandibule i stanje dinamičke trodimenzionalne ravnoteže mišićnog djelovanja u području okluzivnih i kondilarnih segmenata. Djelovanje mišića razlaže se u komponente prema odabranom koordinatnom sustavu. Pri zatvaranju čeljusti sile mišića djeluju na čeljust, omogućuju žvakanje te imaju funkciju stabilizatora mandibularnih zglobova u prevenciji dislokacije i opterećenja okolnih tkiva.