THREE-DIMENSIONAL DISPLAY SYSTEM OF INDIVIDUAL MANDIBULAR MOVEMENT (OBSERVATION OF MANDIBULAR BORDER MOVEMENTS AND MASTICATIONS OF TWO SUBJECTS)

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1. ABSTRACT

This study deals with the display system that visualizes patient-specific human mandibular movements. The system provides not only three-dimensional visual information of individual mandibular movements but also quantitative information of positions, velocities or accelerations at arbitral points of the mandible. This paper describes measurement results of mandibular movements of two subjects. The system indicates quite different mandibular motions between the subjects, and analysis of the information suggests an effective therapeutic strategy for the disease of the subject. The system has an enough potential ability to be an intelligible diagnostic system of tempolomandibular disorders (TMD) for both medical doctors and patients. It will be useful for informed consent for medical treatments of TMD.

2. INTRODUCTION

It is quite important to understand an exact motion of a mandibular condyle for proper diagnosis and treatment of temporomandibular disorders (TMD) because of the complicated motions of the human mandible. Hence, an intelligible diagnostic system of TMD is expected by both medical doctors and patients. There have been some devices for recording mandibular movements [1-2]. These devices with non-contacting motion measuring methods have an advantage with permitting a masticatory movement of a patient under almost natural conditions. However, there still remain problems that the systems can not treat geometrical relationship between motion-capturing devices and anatomical structures. It is impossible to compute the exact motion of the jaw bone without the geometrical relationship. Our display system proposed in this study focuses on this point. The original research of the authors aimed to indicate the mandibular movement using a cephalometric radio-graph or laminated layer image obtained from x-ray CT data [3]. In the successive studies, we developed a display system of individual mandibular movement using patient-specific finite element models [4]. The previous

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paper examined total performance of the system [5]. In this paper we firstly explain our display system of patient-specific mandibular movement in brief. Then, we describe measurement results of mandibular movements of two subjects.

3. MATERIALS AND METHODS

Our display system of individual mandibular movement integrates two engineering methods. One is an optical motion capture technique for measuring the mandibular movements. The other is a patient-specific finite element modeling method based on the x-ray CT images. The system provides not only three-dimensional visual information of individual mandibular movements but also quantitative information of positions, velocities or accelerations at arbitral points of the mandible. Figure 1 shows the measurement procedure of the mandibular movement using the system.

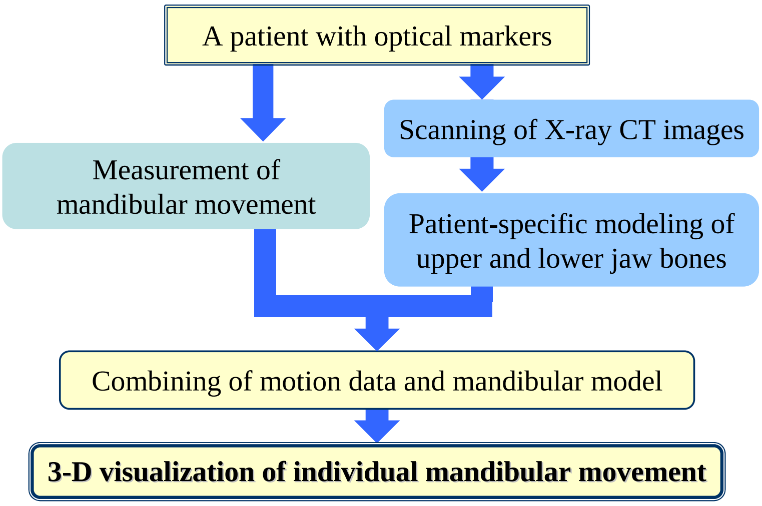


Fig. 1 Diagram of three-dimensional display system.

At the beginning, facebows with optical markers for the motion capture are attached to the labial surfaces of upper and lower incisors with cyanoacrylate adhesive. For the markers, we employ acrylic fluorescent balls that glow under UV-A lights often called “black lights.” Three-dimensional mandibular movements are measured by two CCD cameras. Motion data of the facebows are computed as the following procedures after the camera capturing. First, the positions of the markers are extracted as contours based on the brightness of each image. Next, best-fitting equation of a circle for each contour is solved by a least square method. Then, the direct linear transformation (DLT) method computes three-dimensional coordination of the markers. Finally, coordinate transform matrices of the skull and the mandible are computed using the coordinates of the three markers equipped to each facebow.

In parallel with this, the patient with facebows is subjected to x-ray CT scanning. Patient-specific finite element models of upper and lower jaw bones are generated based on the CT images using our modeling method [6]. The generated finite element models of jaw bones are usually applied to the stress analyses [7]. In this study, we extract a surface polygon model from the finite element model in order to display the mandibular movement as an animation. It is possible to build a new system that integrates stress and motion analyses in the future. The geometrical relationship between optical markers and anatomical structures are also computed by use of the CT images.

Then, coordinate transformation of the mandibular model is performed according to the three-dimensional motion data, and an animation of the mandibular movement is displayed. We have developed a user interface of the display system. As shown in Fig. 2, the interface consists of three information display windows, that is an animation window, a position display window, and a graph window. One of the most important feature of the system is the interface provides synchronized presentation of mandibular motion animation and the quantitative information with easy operations.

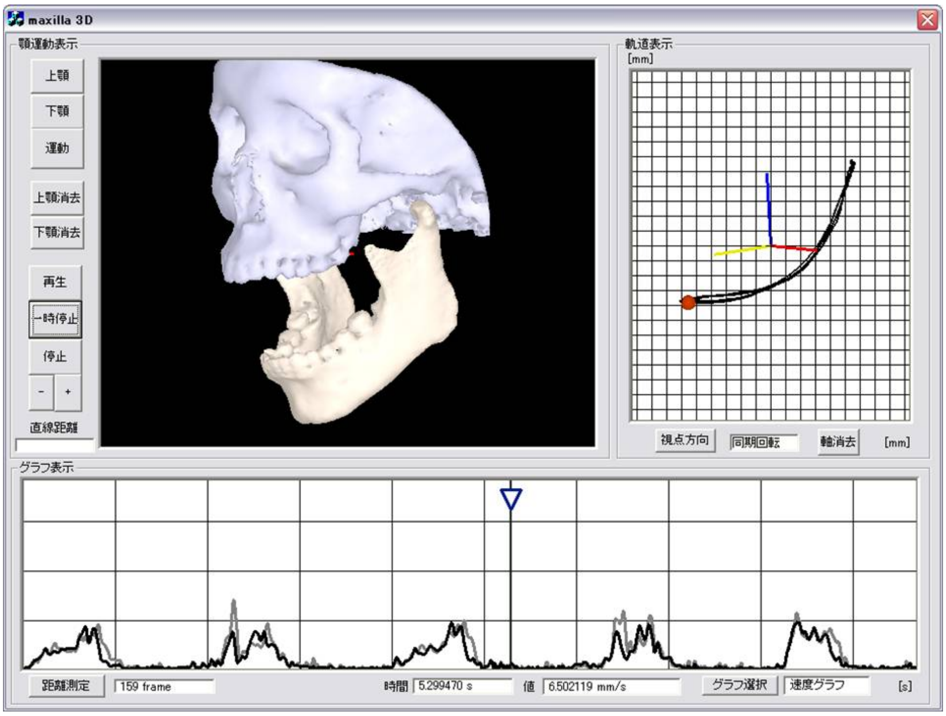
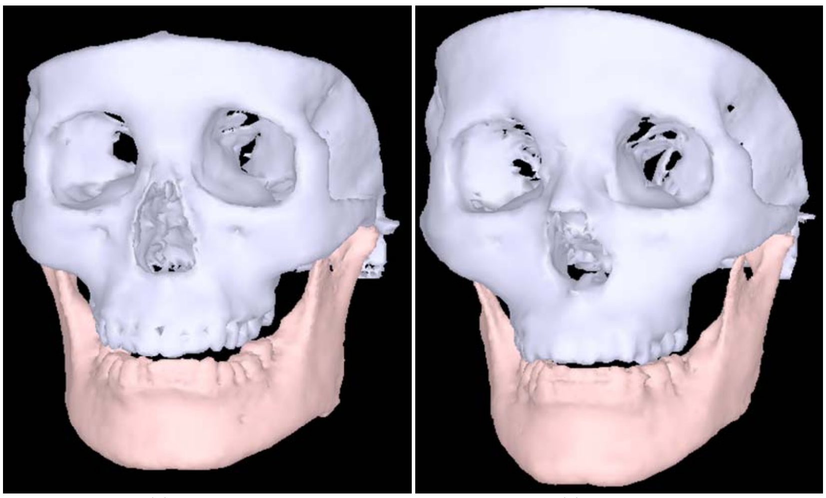


Fig. 2 Snapshot of the display system.

The system was applied to two subjects (volunteers of male adults.) One of the subjects (subject A) has no clinical history of TMD. On the other hand, the other (subject B) has some symptoms of TMD. The patient-specific models of the subjects based on their x-ray CT images are shown in Fig. 3.



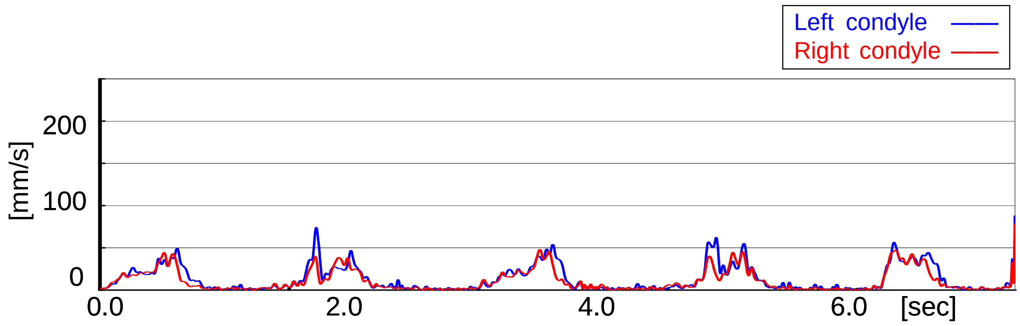
(a) Subject A
(healthy person)

(b) Subject B
(with TMD)

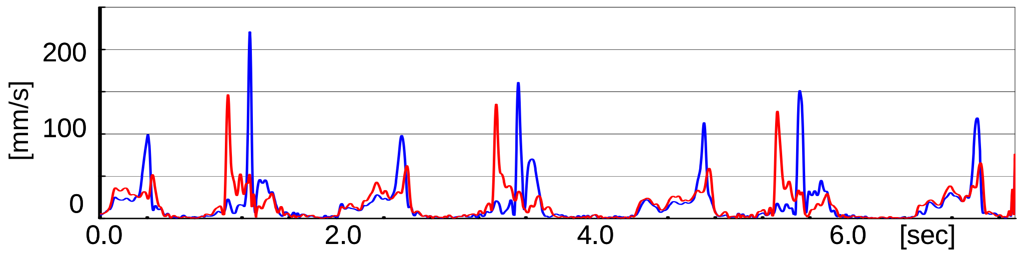
Fig. 3 Patient-specific models of upper and lower jaw bones of the subjects.

4. RESULTS AND DISCUSSIONS

We firstly investigated mandibular border movements of the two subjects. The animation of mandibular movements of the TMD patient obviously displayed irregular opening-closing motion. In order to perform quantitative analyses of the movements, we calculated velocity profiles of left and right mandibular condyles of the two subjects as shown in Fig. 4. The velocities were calculated using three-dimensional interpolated trajectories of condyles with a cubic spline. Figure 4(a) shows velocity profiles of the healthy person (subject A.) The velocities of left and right condyles are nearly equal and the maximum velocity indicates about 50mm/s. On the other hand, the velocities of the TMD patient's condyles sometimes increase abruptly as shown in Fig. 4(b). In particular, there are some time-lags between highest velocities of left and right condyle in closing motion and the highest velocity exceeds 150mm/s.



(a) The case of the healthy person.



(b) The case of the TMD patient.

Fig. 4 Velocity profiles of condyles.

Then, we performed a comprehensive investigation of the mandibular motion of the TMD patient using the synchronized presentation of motion animation and the quantitative information provided by the system. Figure 5 presents relative positions of upper and lower jaw bones and positions of an incisor when the velocities of each condyle indicate maximum values. The position of the incisor becomes irregular when the velocity of the right condyle indicates highest value. On the contrary, both condyles locate almost same position when their velocities indicate maximum values. Hence, the system points out concrete disease sites in left and right mandibular fossae of the subject B, and suggests therapeutic strategy for the patient.

Next, the system was applied to the measurement of masticatory motions of foods. Our light and compact motion capture device enables the observation of the masticatory motions. Figure 6 compares velocity profiles of the two subjects in mastications of a peanut. In the case of the healthy person (subject A), there are higher velocities at the opposite biting side as shown in Fig. 6(a). That is, when a peanut is bitten at right side, velocity of left condyle is higher than that of right one. On the contrary, the system

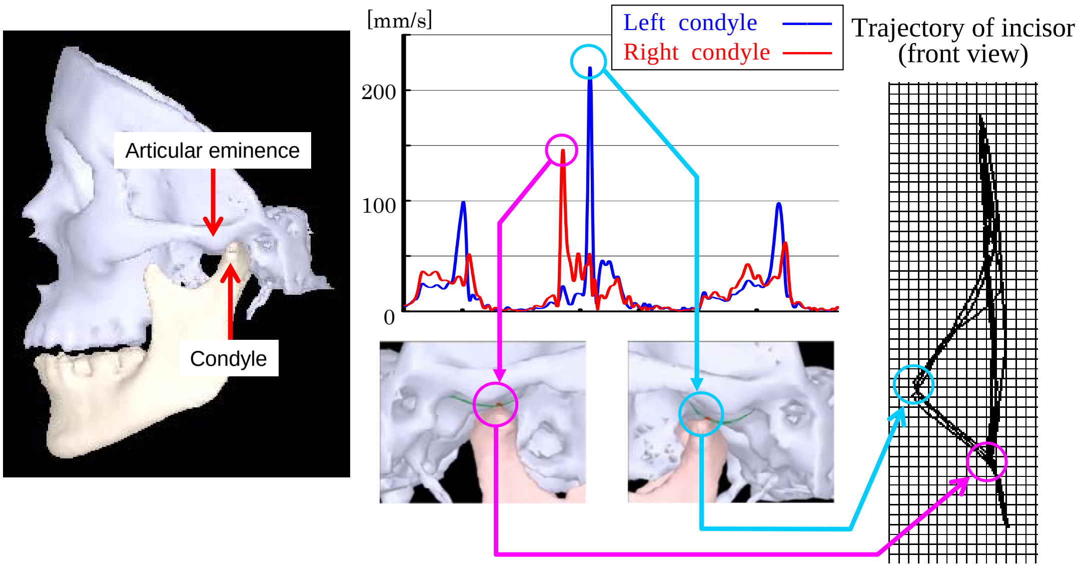


Fig. 5 Diagnosis based on the synchronized information.

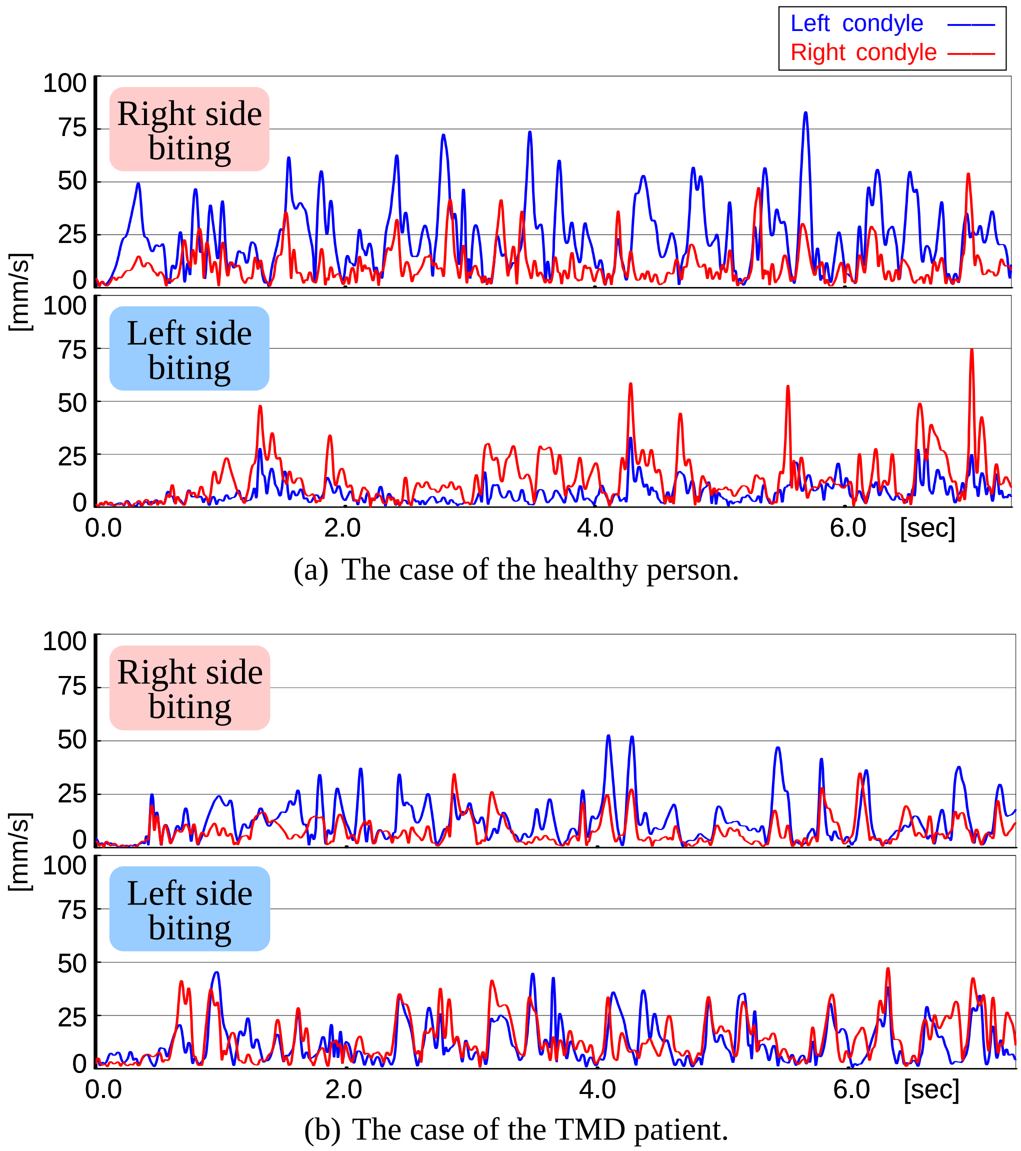


Fig. 6 Velocity profiles of condyles in mastication of a peanuts.

shows different trends according to biting sides in the case of the TMD patient (subject B) as shown in Fig. 6(b). That is, there is no obvious difference in velocity in left side biting. The measured masticatory motion of the subject B also suggests that such uncoordinated motion is caused by dislocation of articular disc at both condyles. Furthermore, it is possible to obtain new physiological knowledge about mastication by further analyses of the data.

5. CONCLUSION

This paper described the display system of mandibular movement using a patient-specific model. The system was applied to human subjects, and we measured mandibular border movements and mastication of foods. The measurement indicated quite different mandibular motions between the subjects, and analysis of the synchronized information suggests an effective therapeutic strategy for the disease of the subject. The system has an enough potential ability to be an intelligible diagnostic system of TMD, and it will be useful for informed consent for medical treatments of TMD.

6. ACKNOWLEDGEMENT

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