BOLUS PROCESSING - 3D MOTION ANALYSIS OF MASTICATION

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Abstract: Mastication is complicated motion, which individually reacts on changes in chewing apparatus and which is able to cause its changes. A process duration and trajectory of mandible movement affect the direction and size of all components of acting chewing force. The aim of this study was a detection of the trajectory, mastication movement amplitude and direction of lower jaw movement. The three dimensional human mandible movement during masticating of hard and soft aliment was analyzed by use of motion analysis method. All recorded data were statistically evaluated at the scope of each patient and at the scope of 50 patients statistical set. The ratio of amplitudes and duration of masticatory movements in three different directions are results of this research.

Introduction

The range and pattern of human masticatory system movements during bolus processing are of considerable interest. The trajectory of lower jaw motions affects a direction and magnitude of masticatory force. This trajectory is among others markedly influenced by patient's chewing habits [1].

Mastication consists of several particular periodic movements. During mastication, a food is primarily bitted, detached bolus is transported distally towards the pharynx during fine crushing, mixed with saliva and finally swallowed [2, 3]. Bolus is transported distally towards the pharynx during fine crushing and mixing. Center of lower jaw motions moves along a curve of approximately elliptical shape [4].The magnitude and shape of this curve oscillate depending on stadium of bolus processing (bite, fine crush) and bolus character (soft, hard, fibrous, etc.) [4, 5].

Masticatory movements during function are technically a typical example of kinematically and mechanically indeterminate system. Jaw movements are realized by a large count of masticatory muscles. While these muscles are activated heterogeneously [6] each muscle is able to influence more than one degree oh freedom [7]. All muscles act together and generate a resultant force and torque (six degrees of freedom) with respect to the lower jaw [8]. The distribution of forces and torques necessary to perform any movement over the different parts is not established. Consequently, the system is mechanically redundant.

Two segments, the mandible and the skull, are able to move with respect to each other. All movements are guided by two temporomandibular joints. Mandibular condyle articulates incongruently with the articular fossa of the temporal bone in each joint. The articular capsule is slack. Due to this construction both joints allow for movements with six degrees of freedom (rotation - depression and elevation, side to side movements - sinistro and dextropulsion and translation - propulsion and retropulsion). If the joint surfaces are assumed to be undeformable and maintain contact all the time, the mandible is still able to move with four degrees of freedom [9]. Jaw movements in particular anatomical directions can be defined by the three dimensional path of point, that is rigidly connected with lower jaw. Movement of this point can be scanned and its path can be reconstructed by motion analysis technique [10].

Figure 1: Specially developed and individualized sensor

The aim of this experiment was detection of path of lower jaw movement during mastication, duration of processing of one bite depending on its character (hard and soft aliment) and peak amplitude of this motion. The knowledge of lower jaw movement in population is very important for dominant anatomical direction assessment during adduction and for bite force direction specification.

Materials and Methods

The motion analysis method was used for recording of three-dimensional (3D) mandible movements in this study [10]. Specially developed and individualized sensor was made for tracing the movements of mandibula. This sensor made of dental wire was rigidly fastened by

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dental silicon impression material to lower frontal teeth of each volunteer. The central part of sensor ringed round lip and methylmethacrylate resin marker at the end served as mandible position reading instrument (Figure 1). Additional black paper skin markers were put on patient face, particularly above eyebrows, on nose dorsum and above upper lip. These markers were made for definition of local coordinated system, where the motion of sensor was observed. local coordinated system, where the motion of sensor was observed. The **x**, **y**, **z** coordinates (Figure 2) represents mandibular movement in mesio-distal (propulsion, retropulsion), cranio-caudal (abduction, adduction) and vestibulo-oral direction (lateropulsion, mediopulsion) respectively. The origin of local (non-stationary) coordinated system was placed on nose dorsum marker. Kinematical transformation relations between primary (stationary) coordinated system and local (non-stationary) coordinated system were determined by means of kinematical transformations matrix technique.

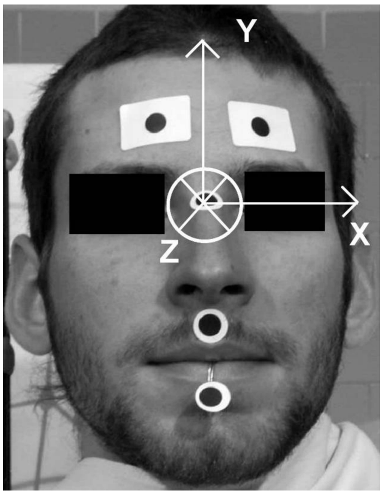

Figure 2: Definition of local coordinated system, skin markers and sensor

The motion of markers and sensor was mark-scanned by three digital video camera recorders SONY DCR-TRV900E. Recorders were set out so that all markers and sensor were visible. The shutter was used for the synchronization. Recorders calibration of was achieved by specially constructed calibrating cage. Video records, 3D motion reconstruction by direct linear transformation and results processing was performed by APAS system. Results and kinematical transformations between coordinated systems were evaluated by the MATLAB system.

The chewing of 50 volunteers with natural dentition was evaluated (examined). At the beginning of new patient experiment the record of marginal movements (maximal opening, maximal dextro- and sinistropulsion) was performed. Then one bite of soft aliment (pastry) was inserted into the mouth by patient and started to masticate. The same process was repeated with the hard aliment (nuts). Duration of hard (t1) and soft (t2) bolus masticating and peak amplitude of masticating movement (in percent) in x, y and z axis related to peak amplitude of marginal movements (Amp 1 - hard aliment, Amp 2 - soft aliment) were evaluated for each patient. The path of sensor was graphically expressed for each patient and for each measured motion (marginal movements Figure 3 hard bite (A) and soft bite (B) Figure 4). All measured quantities were averaged; median, maximal, minimal and standard deviation values were set and they are shown in Table 1.

Results

Trajectories recorded in this study showed that chewing movements are markedly individual (Figures 5 and 6). Many of curves can be separated up to parts of bolus chopping, crushing and final grinding (Figure 5). Also aliment character influence the trajectory of jaw movements (Figure 6).

Computed results (average, median, peak magnitudes and standard deviations) of particular quantities are shown in Table 1.

Average duration (median) of A bite processing was 28.01 s (25.63 s), average duration of B bite was 22.14 s (19.77 s). Minimal duration of bite processing was 7.76 s for A and 6.58 s for B, maximal duration was 78.28 s for bite A and 52.28 s for bite B. Standard deviation for bite A (B) duration was 15.04 s (10.97 s) respectively.

Average (median) value of Amp1 of A bite was 56.79 % (55.69 %) in x direction, 35.94 % (33.48 %) in y direction and 66.18 % (55.63 %) in z direction. In the case of 8 patients peak values of marginal movements were exceeded (Amp1 $>$ 100 %). Removing of these exceeded peak values of 2 patients in x direction, 1 patient in y direction and 8 patients in z direction led to reduction of average (median) value to 54.90 % (54.35 %), 34.61 % (33.41 %) and 53.87 % (50.32 %) in x, y and z coordinate.

Average (median) value of Amp2 of B bite was 58.04 % (54.51 %) in x, 41.53 % (35.87 %) in y and 69.43 % (62.45 %) in z direction. The peak values of marginal movements were exceeded (Amp2 $>$ 100 %) in the case of 1 patient in x direction, 1 patient in y direction and in the case of 9 patients in z direction; therefore average (median) value was reduced to 57.04 % (54.26 %), 38.98 % (35.86 %) and 56.41 % (52.04 %) in x, y and z direction.

Discussion and Conclusion

Definition of lower jaw movement by 3D path of point rigidly attached with lower jaw appears as one of suitable possibilities. Results obtained in this motion analysis comfirm data from similar study [1] concerning the influence of individual chewing habits. Overall motion of point in defined coordinated system is possible to take from path versus time charts and subsequently reconstruct 3D motion. The design of experiment using a one marker as a mandible position reading instrument served

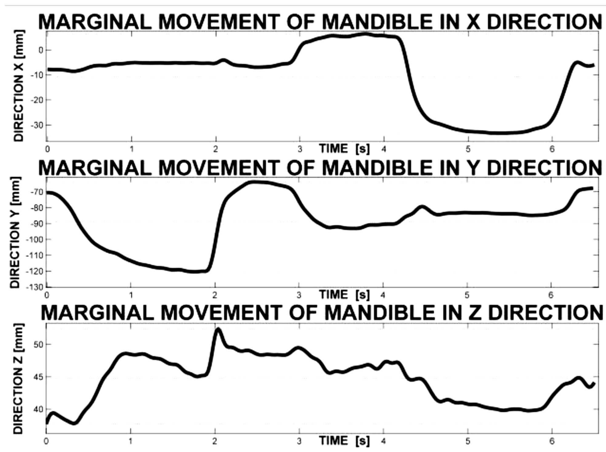

Figure 3: Example of marginal movements of lower jaw of one patient in local coordinated system

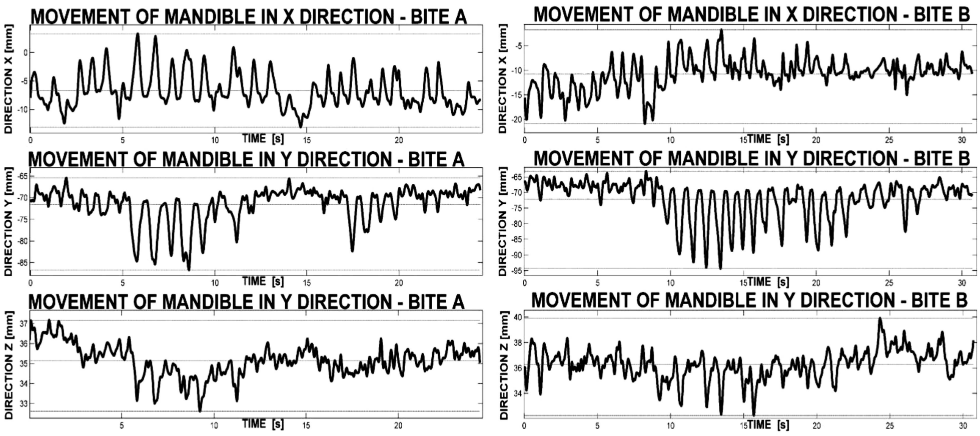

Figure 4: Example of lower jaw motion during A and B bites processing in local coordinated system

Table 1: Table of measured quantities.
t1 [s], t2 [s], Amp1 [%], Amp2 [%]; Average - arithmetical average of measured quantity; Median - median value of measured quantity; Max, Min - maximal and minimal value of measured quantity; Standard deviation - standard deviation of measured quantity; x, y, z- value of Amp1 and Amp 2 in local coordinated system; values in parenthesis - eliminated values of Amp1 and Amp2 after elimination of values overlapping 100 %

	t1[s]	t2[s]	Amp1[%]			Amp2[%]		
			x	y	z	x	y	z
Average	28.01	22.14	56.79 (54.90)	35.94 (34.61)	66.18 (53.87)	58.04 (57.04)	41.53 (38.98)	69.43 (56.41)
Median	25.63	19.77	55.69 (54.35)	33.48 (33.41)	55.63 (50.32)	54.51 (54.26)	35.87 (35.86)	62.45 (52.04)
Max	78.28	52.28	102.44 (98.54)	100.95 (78.92)	175.93 (98.93)	107.02 (92.81)	166.75 (97.14)	156.10 97.02
Min	7.76	6.58	21.79	16.67	12.05	30.87	17.41	11.4
Standard deviation	15.04	10.97	19.71 (17.78)	15.01 (11.91)	36.29 (21.82)	16.22 (14.78)	22.93 14.49	36.38 24.31

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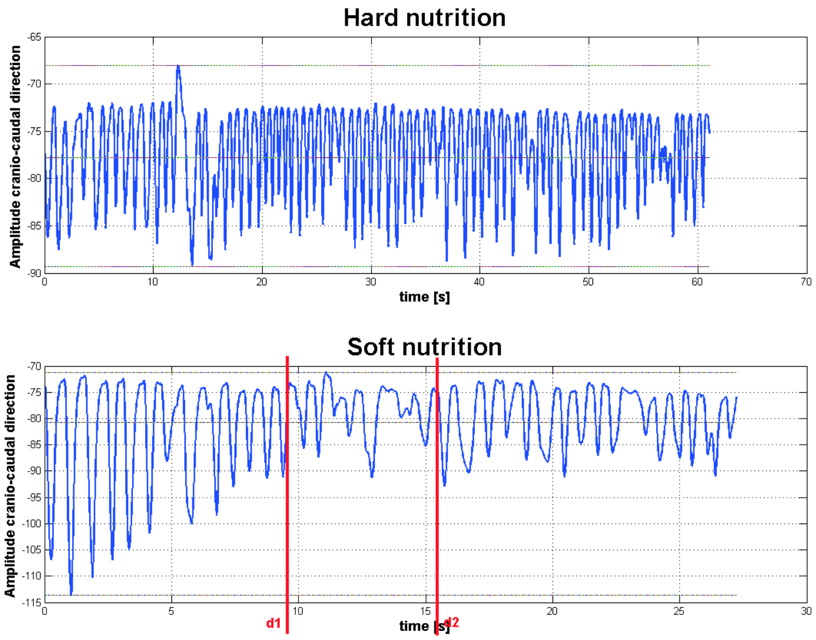

Figure 5: Example of chewing movements individuality and dividing the bolus process into three parts

Figure 6: Example of chewing movements individuality and dividing the bolus process into three parts

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sufficiently for detection of translational degrees of freedom. The three markers were used in comparative research [1] in order to detect rotational and translational degrees of freedom, but the rotational movements were not useful for evaluation of jaw movement parameters.

Exceeding of marginal movements values (Amp1, Amp2 $>$ 100 %) could be explained by 2 ways. First, the maximal limited position of marginal movements during recording was not achieved by some patients. Second, the quite abnormal mandible movement during mastication was used, because of sensor placement. Both, sensor placement and unusual movements to the maximal limited positions could be actions altering nautrally occurred motions [1]. Different numbers of patients exceeding marginal movement's values for different chewing patterns support both hypotheses.

Logical presumptions that bolus character affects processing duration were statistically significant, because count of patients with longer duration of soft bite processing was approximately one third of researched set of patients. This conduces to finding, that the mastication is highly individual process influenced not only by anatomical conditions, but also by specific manner acquired during life. Similar findings was performed by Gerstner [1]. Decrease of amplitude in cranio-caudal (abduction, adduction) movements observed in the study support the statement, that stadium of bolus processing influence the shape of curve describing a movements of mandibula and thus direction of acting chewing force. Computed trajectories agree with observations examined by Bhatka [4] that center of lower jaw motions moves along a curves of approximately elliptical shape.

Understanding of mastication development and knowledge of some physiological relationships is very important for principal anatomical direction assignment during adduction and for statement of resultant direction of loading within mastication. These results can be used for ideal reconstruction of defected dentition from mastication point of view, planning treatment of some masticatory apparatus disorders and/or treatment procedure validation. Results can also affect design and usage of materials for dental implants, their position in jaws and shape of occlusal surface of bridgeworks and dentures.

Values measured in this pilot study suggest, that masticatory movements are very individual and that their relationships to directions and magnitudes of acting chewing force should be more precisely examined.

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