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# MOTION CHARACTERISTICS OF THE HUMAN TMJ DURING BORDER MOVEMENTS: A PRELIMINARY STUDY

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## Abstract

**Purpose.** Unambiguous evidence of pure rotation of a mandible put in CR position has never been provided in living subjects. The hypothesis of this investigation was that there are no significant differences, owing to the intervention of different operators, between acquisitions. The aim of this work was to validate our acquisition protocol to quantify the contribution of different operators to the CR movements.

**Methods.** Five male adults volunteered for this study. Mandibular movements of open-close, laterotrusion and protrusion were recorded via an optoelectronic device. Four acquisitions for each subject were made from an operator induced CR starting position, another four from ICP. Two different operators put the subjects in CR. For each subject, the mandibular motions were cleaned from external movements, the motions of the interincisor point were reconstructed and the rotational component was calculated in particular in the instants of maxima.

**Results.** For every considered movement, the influence of the operator in putting each subject in CR was negligible. Between CR and ICP movements no significant. differences in the points of maxima were found regarding the percentage contribution of rotation, this contribution in CR movements was never exhaustive.

**Clinical significance.** The protocol for the detection of mandibular movements may be considered repeatable and thus be used to perform deeper analysis on the considered movements in an attempt to find a scientific basis to the use of CR mounted models.

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## Introduction

The debate about centric relation (CR) is one of the most controversial, and it has been central in dental research and practice in the last decades. Even the definition of CR has changed many times. From a rearmost, uppermost and midmost (RUM) position [1], in the present day the term has come to define the most superior anterior position of the condyles in the glenoid fossae [1]. The Glossary of Prosthodontic Terms (GPT) [2, 3], in its latest edition, reports this definition: “a maxillomandibular relationship in which the condyles articulate with the thinnest avascular portion of their respective disks with the complex in the anterior-superior position against the slopes of the articular eminences”. Through this term is so indicated a position of the condyles in which the teeth may have no contacts whatsoever.

Some authors [1] maintained that, having the condyles in such a position, the mandibular movements are purely rotational in the first millimetres of opening since the condyles seem not to translate during the motion of the mandible thus identifying the terminal hinge axis. Granted this hypothesis, the clinical relevance of the CR position lies in the fact that plaster models are mounted on articulators only capable of rotational movements: putting a toothed patient in CR makes the dentist able to reproduce his movements on the articulator. In contrast, other authors [4] affirm that no pure rotational movements are made by the mandible, even in CR, in any instant. Actually, unambiguous evidences of pure rotation of a mandible put in CR position have never been provided in living subjects. Moreover no data are available about differences on percentage contribution of rotation and translation during mandibular movements between toothed living subjects and their plaster models mounted on an articulator. Therefore it is fundamental to have a better insight on the real gain of the use of models mounted in CR and the neuromuscular deprogramming associated with the CR position.

Nowadays technology permits the non invasive recording of human movements in a 3D space providing data for quantitative analysis and biomechanical modelling [5-9]. Still, without invasive methods, it is difficult, if not impossible, to trace the movements of the mandibular condyles, but it is becoming more and more possible to acquire the motion of the mandible as a whole. Through optoelectronic devices we are able to track the motion of several cranial and mandibular, oral and extraoral [10-12] landmarks without interfering with the natural movements of the subjects.

Using an optoelectronic system with passive markers, even less intrusive [12-14], and some original mathematical algorithms, we were able to confront the mandibular movements of subjects, both when put in the CR position, by operators through the Dawson method [15], and when free to perform the same movement from the intercuspal position (ICP).

In this contest, “CR” and “ICP” define two different relations of the mandible and the maxilla even if the first defines a condylar position and the second a dental one. Some authors suggest using “retruded cuspal position” (RCP) and ICP respectively [2].

The aim of this preliminary investigation was to validate our acquisition protocol to quantify the contribution of different operators to the CR movements. The hypothesis of this investigation was that, using our protocol, no significant differences, owing to the intervention of different operators in putting the subjects in CR, are measurable between acquisitions. Intersession variability was also assessed.

# Materials and Methods

## Subjects

Five men aged 23–27 years volunteered for this study. The subjects were previously informed about all adopted procedures and gave their consent to the investigation. The local ethic committee stated there was no risk of harm to the subjects due to the procedures followed. All the subjects had sound, complete, permanent dentitions and bilateral canine and molar Angle Class I jaw relationships. The anterior teeth had vertical and horizontal overlap between 0 and 3 mm while the mandibular and maxillary inter-incisal lines had lateral deviations limited to less than 2 mm. Every subject had no previous history of craniofacial trauma or congenital anomalies.

## Data Collection

Three-dimensional coordinates of three cranial landmarks, one mandibular dental landmark and three extra-oral landmarks located on a frame fixed on the mandible at the midline level were collected through the use of optoelectronic infrared motion analysis.

Six high resolution infrared sensitive charge-coupled device video cameras (Smart system; BTS bioengineering, Garbagnate Milanese - Milan, Italy) provided the three-dimensional coordinates of each landmark's centre of gravity during mandibular movements.

The system, working at a frame rate of 60 Hz, acquired the positions of 6 mm hemispheric reflective markers fixed on the centre of each point with bi-adhesive plaster (Fotofix; Favorit, Milan, Italy).

The cameras were positioned to obtain a working volume of 77 (width) cm x 66 (height) cm x 77 (depth) cm. Metric calibration and correction of optical and electronic distortions were performed before each acquisition session, giving a static accuracy of 0.09 mm (x-coordinate, left to right), 0.06 mm (y-coordinate, cranio-caudal), 0.08 mm (z-coordinate, antero-posterior).

The Smart system has been described in detail elsewhere [12,13,16,17]. In brief, the system to work needs at least two cameras with non-parallel optical axes to see each marker in every moment, so the cameras are positioned at different angles of the working volume to film the subject from different points of view. An image analysis software recognizes the position of each marker for each camera during the execution of the movement. Afterward all the coordinates are converted to real metric data and a set of x-, y- z-coordinates is obtained for each landmark in each frame that constitutes the recorded movement.

The cranial landmarks were positioned on the glabella (identified by inspection) and the cutaneous projections of the left and right mandibular condyles (identified by palpation). These three markers defined a cranial plane of reference and the location of the hinge (inter-condylar) axis [12,16].

The three extra-oral markers were placed on equilateral triangular frame made of stainless steel wire with a 1 mm diameter. Each side of the frame measured 40 mm. Surgical adhesive (Stomahesive; Convetec Inc., Deeside, UK) was used to anchor the frame buccally on the mandibular anterior gingival line just out of dental contact. Through these markers we were able to define an extra-oral mandibular plane and to describe its movements relative to the cranial plane of reference.

The mandibular marker was adhered to the incisal edge of the midline (inter-incisal point). In this way we could identify a dental (occlusal) landmark relative to the cranial plane of reference and the extra-oral frame. This position was recorded by a static acquisition before each dynamic record (see below), and provided a reference frame for subsequent calculations.

The acquisitions were made by two distinct operators in two different days. On each session of acquisition, four sequences of four movements (open-close, right side laterotrusion, left side laterotrusion and protrusion) at free (habitual) velocity were recorded for each subject while he was sitting on a chair with the head in natural position [16]. To obtain this position, the subject was asked to look straight into a mirror positioned 2 m away. The mirror was mounted at eye level to permit subjects to see the reflected images of their eyes.

On the first two acquisitions of each session the subjects were asked to start the movement from ICP. In the latter sequences the operators put each subject in CR, using the Dawson method, thus making them start from a RCP. Overall we had eight dynamic acquisitions for each subject, four (two ICP and two CR) made by one operator on a certain day, and four (also two ICP and two CR) made by a different operator on another day.

## Data Analysis

In the first place the position of the dental (inter-incisor point) marker in each frame of the movement of the dynamic records was calculated starting from its relative position from the marker on the extra-oral frame (static acquisition). The module of the vector between the midpoint of the inter-condylar axis and the dental marker while the subject was in ICP was used as an estimate of the mandibular size [12,18].

Second, the subject's mandibular movement was cleaned from the influence of head and neck movements through an original mathematical algorithm that calculates a space of reference from the three cranial markers and finds the coordinates of the frame and intra-oral markers relative to that space in each frame of the acquisition. The origin of the cranial reference system was set in the midpoint of the hinge axis.

To find the contribution of rotation and translation to the mandibular movement, the trajectory of the inter-incisor point was modeled through the use of vectors.

The vector (Figure 1 vector $\bar{a}$) whose module had been taken as the mandibular size was considered as the starting vector. During each frame of the acquisition, while the mandible (i.e. the inter-incisor point) moved, the same vector ($\bar{b}$) going from the midpoint of the hinge axis to the inter-incisor point was recalculated. Using the director cosines of this vector and the module of the first one ($\bar{a}$), a vector ($\bar{c}$) having the same direction of the current vector ($\bar{b}$) and the module of the starting one ($\bar{a}$) was calculated. This vector represented the (hypothetical) pure rotation around the inter-condylar axis. Subtracting the vector representing the pure rotation ($\bar{c}$) from the vector representing the actual position of the inter-incisor point ($\bar{b}$) it was possible to find the contribution (in mm) of the pure translation. The relative, percentage contribution of the two components to the total movement was calculated for each frame of the motion. In particular, the situation at each maxima (opening, laterality, protrusion) was assessed.

For each movement, the degree of rotation (in degrees) and the three-dimensional displacement of the mandibular inter-incisor point (in mm) were also calculated for descriptive reasons. The displacement of the inter-incisor point was also computed on the main plane of each movement (two-dimensional projection).

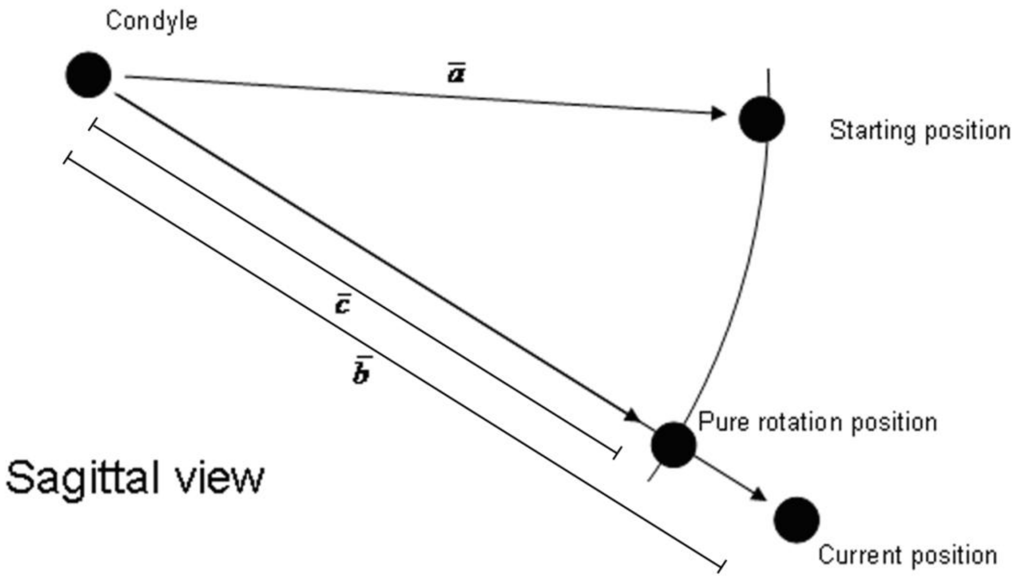


Figure 1. Calculation of rotation and translation contributes.

## Statistical Calculations

To assess the differences between the two operators, percentages of rotation from each acquisition from each operator were compared using a 2-way factorial analysis of variance (ANOVA).

Furthermore, 1-way ANOVAs were used to assess the differences in the percentages of rotation, degree of rotation and three dimensional displacement of the mandibular inter-incisor point between movements starting from ICP position and movements beginning in CR position.

Assumptions of ANOVAs were checked through a Hartley F-Max test. For all the ANOVAs, the level of significance was set to 5% ($p < 0.05$).

Variability between sessions was assessed by calculating the technical error of measurement (TEM):

$$TEM = \sqrt{\frac{\sum_{i=1}^{n}(x_{i,1} - x_{i,2})^2}{2n}}$$

where, $x_{i,1}$, $x_{i,2}$: mean of the two populations to be compared for each subject; n: number of subjects.

The four repetitions of each kind (ICP and CR) each subject made were then averaged, and the mean values of the percentage of rotation, the degree of rotation (compared using circular statistics) and the three-dimensional, and on the main plane of each movement, displacement of the mandibular inter-incisor point at each maxima were calculated.

## Results

The Hartley's F-Max test ($\alpha = 0.05$, distribution $F_{max} = s^2_{max}/s^2_{min}$; subjects: F = 60.7, k = 5, df = 3; operators: F = 4.03, k = 2, df = 9), made on the percentages of rotation, pointed out that the homoscedasticity hypotheses were valid for each analyzed movement.

The 2-ways ANOVA applied on the percentages of rotation found no differences between acquisitions made by different operators in both ICP and CR. Significant differences were instead found between subjects for all analyzed movements in ICP acquisitions, while in CR acquisitions differences between subjects were found only for the open-close movement (Table 1).

**Table 1. Influence of different operators. F values of 2-way ANOVAs on the percentages of rotation at maximum mandibular displacement.**

| | Open (%) | R Lat (%) | L Lat (%) | Protr (%) |
|---|---|---|---|---|
| ICP | | | | |
| Operators (A) | 0.02 | 0.37 | 0.02 | 0.85 |
| Subjects (C) | 16.43* | 8.35* | 4.56* | 6.41* |
| A X C | 0.36 | 1.92 | 1.38 | 1.32 |
| CR | | | | |
| Operators (A) | 0.05 | 1.09 | 1.76 | 0.35 |
| Subjects (C) | 21.94* | 2.13 | 1.01 | 0.82 |
| A X C | 0.42 | 1.36 | 0.66 | 2.64 |

* significant difference, $p < 0.05$ (Limit values: operators, F (1,10) = 4.96; subjects, F (4,10) = 3.48, A X C, F (4,10) = 3.48).

**Table 2. Considered movements. Relevant data at maximum mandibular displacement.**

| | Open-close | | | | Protrusion | | | |
|---|---|---|---|---|---|---|---|---|
| | Max Open (mm) | Max Open Y (mm) | Rotation Angle (°) | % Rot (%) | Max Protr (mm) | Max Protr Z (mm) | Rotation Angle (°) | % Rot (%) |
| ICP | | | | | | | | |
| Mean | 52.06 | 50.00 | 30.64 | 77.69 | 10.34 | 9.67 | 1.28 | 16.13 |
| S.D. | 2.35 | 2.20 | 1.96 | 4.51 | 2.90 | 2.98 | 0.66 | 6.32 |
| TEM | 2.49 | 3.07 | 1.43 | 0.85 | 2.40 | 2.18 | 0.39 | 3.91 |
| CR | | | | | | | | |
| Mean | 48.84 | 47.13 | 28.91 | 77.69 | 9.59 | 9.09 | 1.71 | 22.69 |
| S.D. | 2.59 | 2.51 | 3.23 | 4.96 | 2.37 | 2.54 | 0.63 | 4.75 |
| TEM | 0.94 | 1.59 | 0.94 | 0.86 | 1.40 | 1.32 | 0.55 | 8.89 |
| | **Left-side laterotrusion** | | | | **Right-side laterotrusion** | | | |
| | Max Left Lat (mm) | Max Left Lat X (mm) | Rotation Angle (°) | % Rot (%) | Max Right Lat (mm) | Max Right Lat X (mm) | Rotation Angle (°) | % Rot (%) |
| ICP | | | | | | | | |
| Mean | 8.30 | 6.53 | 4.41 | 62.80 | 9.01 | 6.94 | 4.90 | 63.86 |
| S.D. | 2.56 | 2.37 | 1.14 | 4.74 | 2.49 | 2.03 | 1.18 | 4.81 |
| TEM | 0.90 | 0.42 | 0.29 | 3.30 | 1.15 | 0.87 | 0.52 | 2.99 |
| CR | | | | | | | | |
| Mean | 8.05 | 6.97 | 4.31 | 64.05 | 8.95 | 6.73 | 4.96 | 65.81 |
| S.D. | 2.90 | 2.83 | 1.45 | 3.36 | 1.78 | 2.20 | 0.80 | 3.88 |
| TEM | 1.10 | 1.05 | 0.58 | 3.94 | 1.63 | 1.06 | 1.10 | 4.24 |

All values refer to the mandibular interincisor point. Descriptive statistics of the angle of rotation were calculated with angular statistics.

Results pointed out a similarity at maxima between movements executed from both starting positions. The percentages of rotation, the displacement of the interincisor point and the degrees of rotation calculated at maximum displacement were not significantly different between CR and ICP (1-way ANOVAs, $p < 0.05$ in all occasions; the homoscedasticity hypotheses were valid for all comparisons).

The TEM of the percentage of mandibular rotation calculated on the two different acquisition sessions varied between 0.85% (open-close in ICP) and 8.89% (protrusion in CR). Pooled values for each kind of acquisition (ICP, CR independently from operator) were then computed (Table 2).

## Discussion

Along this study different data regarding the mandibular trajectories during mouth opening, laterotrusion and protrusion were collected on a group of young adults with complete, sound and permanent dentitions.

In both ICP and CR acquisitions, no differences were reported between movements acquired by different operators: the protocol was therefore valid and repeatable even if made by different operators.

The search for a temporo-mandibular joint optimal position that may permit a generalization of the procedures to make prosthesis and other orthodontic treatment brought to the concept of CR. Sutcher [19] brought forth the idea that CR is an obsolete concept which applicability's not been proved, reporting a clinical study. Cordray [20,21], on the other hand, consider the use of mounted models in CR and neuromuscular deprogramming of the utmost importance in making accurate diagnosis. Other authors, such as Christensen [22], suggests the idea that CR has to be used, thanks to its reproducibility, just when "the original natural occlusion had caused overt pathosis, or when all teeth or one arch of the teeth is being restored at one time". Foglio-Bonda et al. [23] showed that there is a posterior mandibular movement far from ICP even if in older subjects it is smaller, proposing to use models made from CR just in the case of older patients. Simply stated, as Rinchuse and Kandasamy [2] point out, "The benefit of using gnathologic CR records and articulators in orthodontics has not been substantiated by scientific evidence".

Celenza [24] affirms that in CR position pure rotational movement can be demonstrated. Our data may not contradict that statement nor give evidence to it. As of now we pointed out that our protocol is repeatable and may bring an insight to this subject gathering information from more subjects and focalizing not on maxima but on the first millimetres of each movement: the key ones. Regarding the maxima openings we found out that they were somewhat smaller than in the ICP acquisitions but not significantly, nor it resulted any difference from the contribution of rotation and translation or from the angles of rotation in the movements made starting from a natural ICP or an operator induced CR position. Thus the contribution of translation to the mandibular movements in the points of maximum starting from a CR position resulted to be not null as we would expect: the differences in rotation between ICP and CR starting movements are to be found, if any, just in the first millimetres of opening.

Regarding the ICP movements of laterotrusion, current results are smaller than those found by other authors while protrusion results are similar. Buschang et al. [15] reported a 11.45 mm laterotrusion to the right, 10.98 mm to the left and 9.58 mm protrusion in 25–35 years old adult females. However it is to be noted how their research focused on a different sex, and in the current investigation, we assessed only a handful of subjects, without looking for reference values.

The linear displacement during mouth opening movements (also from ICP) resulted to be larger than what reported by other authors [25,26] but similar to what found out by Ferrario et al. [16]. Considering the opening angle reported by the same authors, we found a slightly smaller angle in maximum mouth opening.

In conclusion, in a convenience sample of five healthy subjects, significant differences were not found among different operators, and no significant differences came out in the characteristics of the maxima of standardized mandibular movements (percentage contribution of rotation and translation, displacement of the interincisor point, degrees of rotation) started from either ICP or CR position.

Through this study, we proved that our protocol regarding mandibular border movements of open-close, laterotrusion and protrusion is repeatable regardless of the influence of different operators. Non-invasive optoelectronic techniques may be used in vivo to investigate the differences between ICP and CR and to have an insight into the differences between articulator movements and real ones.

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