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RESEARCH AND EDUCATION

Positional influence of center of masticatory forces on occlusal contact forces using a digital occlusal analyzer

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ABSTRACT

Statement of problem. Digital occlusal analyzers allow the recording of dental contact forces. Some authors assume a unique location for the center of contact forces at the position of maximum intercuspation, while others indicate variations in dental contact forces when recorded at different times of the day. Which approach is more appropriate is unclear.

Purpose. The purpose of this in vitro study was to analyze whether a change in the balance of masticatory forces influences the location of the center of contact forces and its magnitude.

Material and methods. Three different dental casts, selected under dental criteria, were mounted in maximum intercuspation on a semiadjustable articulator equipped with a pattern indicating 9 different force application points (intersection point between 3 longitudinal rows and 3 transverse columns). A force of constant magnitude (169 N) was applied 10 times at each of the application points, and occlusal forces were recorded with a digital occlusal analyzer. Then, two variables were studied: the location of the center of contact forces and its magnitude. Each force application position (9 positions × 3 dental casts=27 in total) was repeated 10 times, and measured data were statistically analyzed with 2-way repeated measures ANOVA (α=.05) test.

Results. The repeatability of the method indicated that the coefficient of variation mean was 0.37% in the location of the center of contact forces and that its magnitude was 3.70%. The 2-way repeated measures ANOVA test revealed statistically significant variations in the location of the center of contact forces and its magnitude, revealing that longitudinal changes of the application point of masticatory forces affected the magnitude of contact forces and that longitudinal and transverse changes of the application point of masticatory forces affected the location of the center of contact forces.

Conclusions. The location of the center of contact force and its magnitude provided by a digital occlusal analyzer at the position of maximum intercuspation are not necessarily unique to each articulated dental cast. Even if the intensity of the masticatory force remains unchanged, changes in its lateral or longitudinal balance also influence the result of the occlusion forces. (J Prosthet Dent 2023;129:930.e1–e8)

Digital occlusal analyzers were developed to detect contacts between teeth and to measure the relative intensity of force at those contacts at each instant throughout occlusion.[1] The first to be marketed and the most studied device (T-Scan; Tekscan Inc) has a measurable area unit of 1.27×1.27 mm, which corresponds to the area of a sensel.[2] This device, with its own software program (Fig. 1), processes measured data and provides qualitative graphical information on the intensity of force on each sensel and shows the location of the center of contact forces (CO-CF) together with its trajectory during occlusion.[3,4]

Output data provided by the device, and especially the location of CO-CF regarding the mid-sagittal plane, are intended to help the dentist detect occlusal quality. These

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Clinical Implications

Transverse equilibrium changes in masticatory forces can change occlusion measured with a digital occlusal analyzer. Dentists should consider this circumstance in their diagnoses, as fatigue or pain could change the masticatory force balance.

data are also used for other clinical purposes, such as to detect and correct diseases of the temporomandibular joint,[5,6] to evaluate rehabilitations with or without implants,[4,7] to evaluate the outcome of orthodontic treatment,[8] and to address various dental problems such as bruxism,[9] severe tooth wear,[10] and muscle pain.[11]

Despite providing useful information for dentists, the use of these devices has not been as widespread as initially expected,[12] possibly because of doubts about the reliability of their measurements. The reliability of contact positions provided by such a device has been widely analyzed and compared in relation to other methods,[13-17] whereas the reliability of the contact force (CF) values it provides has been less studied.[18-20] Another difficulty with the clinical use of such a device has been the inability to interpret the data obtained. One such difficulty is the location of the CO-CF, which has been studied.[3,21,22] While some authors assumed that each individual's dentition has a unique location of CO-CF at maximum intercuspation position (MIP),[21-23] other authors concluded that occlusion cannot be considered static and unique in MIP and that intensities at contact points vary throughout the day.[24,25] This last statement has been considered in the past, pointing to the level of contraction of the masticatory muscles as a possible cause of this variation.[25]

Three forces act simultaneously in the MIP of occlusion (Fig. 2): the forces exerted voluntarily by masticatory muscles, CFs between teeth, and forces on the temporomandibular joint. The sum of these 3 forces should be in equilibrium. Masticatory force and CF are different from each other, and each has a resultant that intersects the occlusal plane at a point called the center of forces; they also have a different force magnitude (Table 1).

When masticatory muscles exert compressive force, the maxillary and mandibular dentition come together until they reach the MIP, and, in response, the CFs, which are the forces measured by a digital occlusal analyzer, rise at all dental contacts. Reaction forces also occur at the condyles of the temporomandibular joint, although these are not recorded with these devices.

Any physiological inequality, or any lack of lateral symmetry of the main masticatory muscles (masseter and temporalis muscle),[26,27] is considered to result in a noncoincidental location of the center of masticatory forces (CO-MF) in the mid-sagittal plane. In addition, each individual can voluntarily or involuntarily vary the intensity of muscle contraction.[28,29] As a consequence, the CO-MF position will move longitudinally in an anterior−posterior direction from the incisors (Y-coordinate) and also transversely from left to right from the mid-sagittal plane (X-coordinate).

The activity of masticatory muscles, measured with electromyography, and CFs, measured with a digital occlusal analyzer, have been studied together.[6,30,31] However, the authors are unaware of in vitro studies evaluating the consequence of the lack of masticatory force symmetry.

The purpose of this study was to analyze whether articulated dental casts have a unique resulting CF at MIP, which could only be changed by modifying the geometry of the dentition, or, alternatively, if there is an influence of CO-MF even if the magnitude of the masticatory forces are kept constant. The null hypotheses were that, for any articulated dental cast, no relationship would be found between CO-MF and CO-CF when the magnitude of the masticatory forces was constant and that, for any articulated dental cast, no relationship would be found between CO-MF and the contact force magnitude (CF-M) when the magnitude of the masticatory forces was constant.

MATERIAL AND METHODS

The influence of the CO-MF position in the location of the CO-CF and the CF-M was studied by applying an input force (equivalent to masticatory force) of constant magnitude at 9 different positions on articulated dental casts (equivalent to different CO-MF or balances of masticatory force). Once approval had been obtained from the university ethical committee (M10_2019_254), 3 different dental casts (CASE GSR, CASE GSL, and CASE BSL) were mounted in maximum intercuspation on a semiadjustable articulator (Artex CN; Amann Girrbach AG). The articulator was calibrated by using a magnetic plate system, which obtained a precision where deviations were reduced to below 10 µm. An investigator made an impression of both arches (3M ESPE Express 2 Putty Soft and 3M Express 2 Light Body Standard; 3M), recorded the occlusion at MIP with silicone (3M Imprint 4 Bite; 3M), and determined the position of the maxilla and its orientation relative to the cranium axis by using a facebow (Artex facebow; Amann Girrbach AG). That position was transferred to the articulator in the laboratory by using a transfer table (Artex Transfer Table; Amann Girrbach AG). Dental casts were mounted using the transferred position and the occlusal registry at MIP. This standardized procedure ensured the correct positioning of the dental cast in relation to the Frankfurt plane on the semiadjustable articulator.

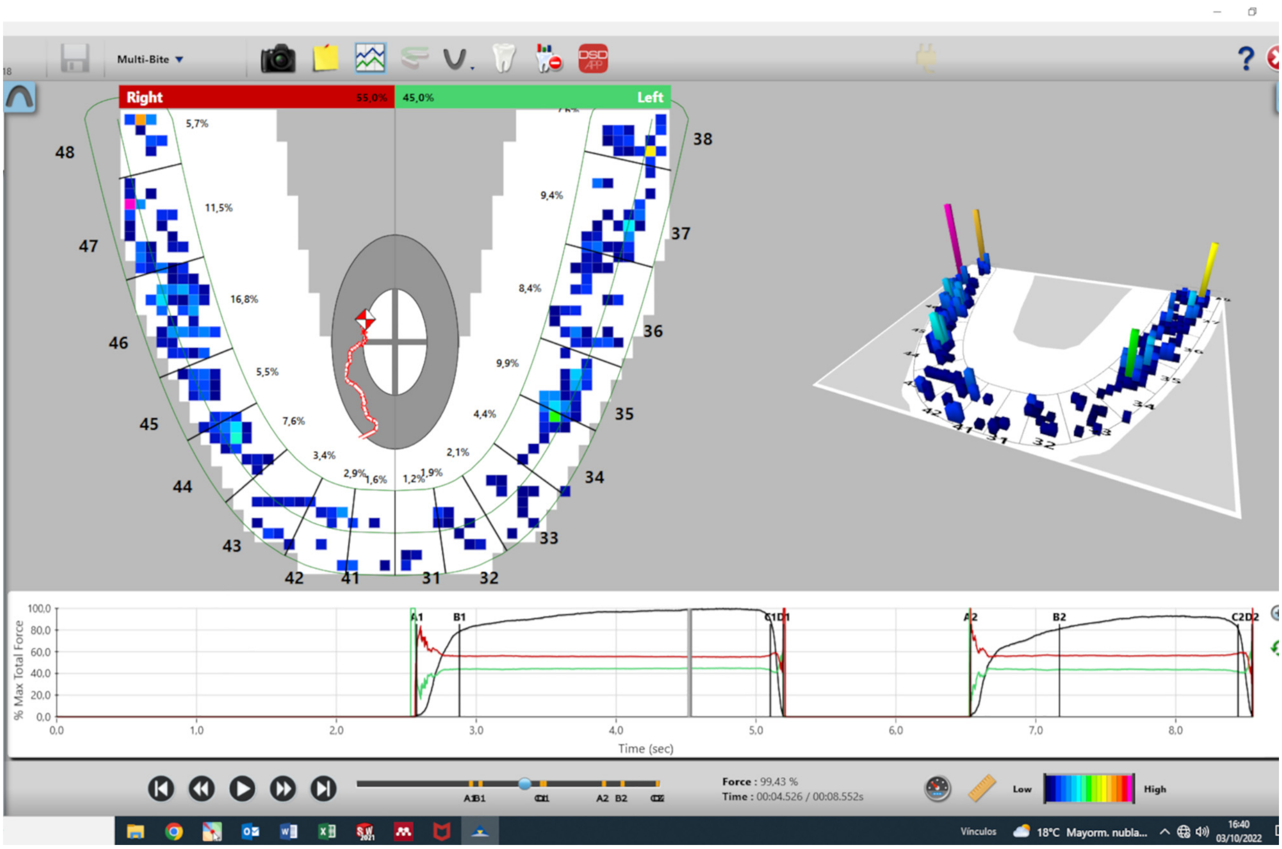


Figure 1. Digital occlusal analyzer (T-Scan; Tekscan Inc) results screen with *red* and *white* rhombus indicating location of center of forces in maximum intercuspation position together with its trajectory during occlusion.

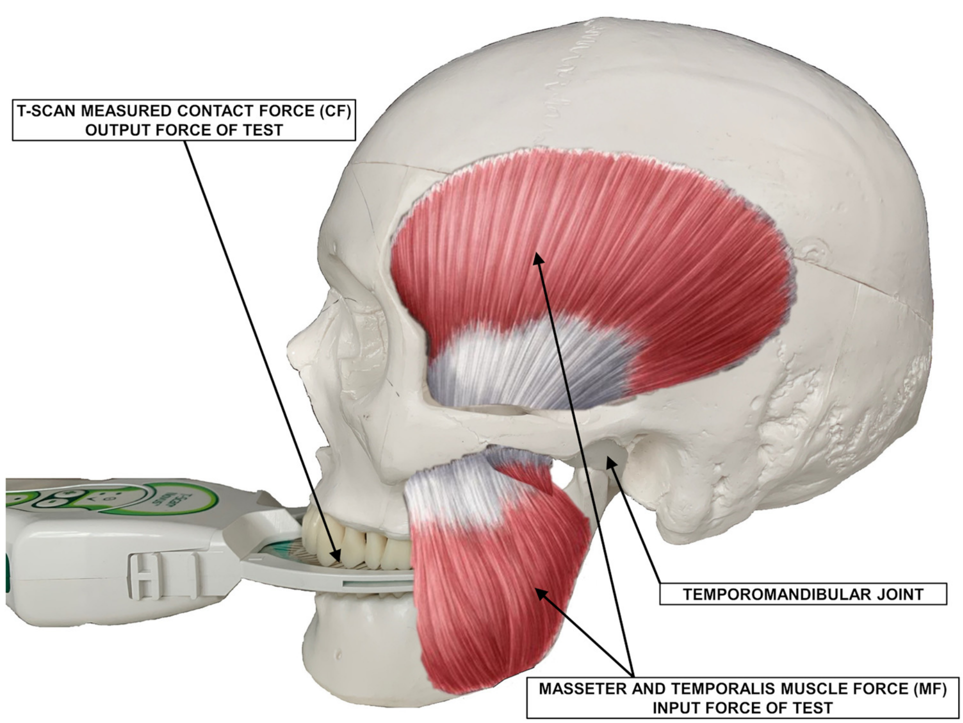


Figure 2. Force type that appears in occlusion when maximum intercuspation position has been reached.

Table 1. Abbreviations related to forces when maximum intercuspation position has been reached

Occlusion Force Type	Resultant	Magnitude	Center of Force
Masticatory force: input force of test	(MF)	(MF-M)	(CO-MF)
Device-measured contact forces: output force of test	(CF)	(CF-M)	(CO-CF)
Temporomandibular joint force	Not used	Not used	Not used

CF, contact force; CF-M, contact force magnitude; CO-CF, center of contact force; CO-MF, center of masticatory forces; MF, masticatory force; MF-M, magnitude of masticatory forces.

The dental casts were selected under dental criteria: CASE GSR (good symmetry and right displaced) presented many contact points, a good left–right symmetry in its contact points, and a CO-CF slightly shifted to the right; CASE GSL (good symmetry and left displaced) also presented many symmetrical contact points, but its CO-CF was slightly shifted to the left; and finally, CASE BSL (bad symmetry and left displaced) presented few nonsymmetrical contact points, and its CO-CF was clearly displaced to the left from the mid-sagittal plane.

A pattern with an XY coordinate system (X=transverse axis and Y=longitudinal axis) and 9 points for application of input force was attached to the upper arm of the semiadjustable articulator (Fig. 3). The points for application of the input force were established by using a grid with 3 rows and 3 columns: an anterior row, placed 6-mm distally from the incisors; a middle row, at a distance of 28 mm from the incisors; a posterior row, at a distance of 50 mm; a first column, placed 18 mm to the right from the mid-sagittal plane; a second column exactly in the mid-sagittal plane; and a third column, placed 18 mm to the left from the mid-sagittal plane. Furthermore, the 9 points for application of input force were grouped in 3 positional groups according to the row in which they were situated: anterior positions, the 3 situated in the anterior row; middle points, the 3 situated in the middle row; and posterior positions, the 3 situated in the posterior row.

For each articulator mounting, a digital occlusal analyzer (T-Scan; Tekscan Inc) was positioned with the aid of a fixed structure that had been custom designed and manufactured (Fig. 4). The structure was then placed on the table of a vertical drill (OPTI F30; Optimum), and an input force equivalent to a masticatory force of constant magnitude of 169 N—previously measured with a digital dynamometer (Beslands Push-pull Force Gauge, SF-500; beslandstool)—was applied perpendicular to the Frankfurt plane with a Ø12.5-mm spherical tip 10 times on each application point identified in the pattern (Fig. 3).

Each time an input force was applied, the occlusion was measured with the digital occlusal analyzer, as per the manufacturer's protocol.[20] All measurements were recorded in the software program of the digital occlusal analyzer, and, from each of them, 3 values were

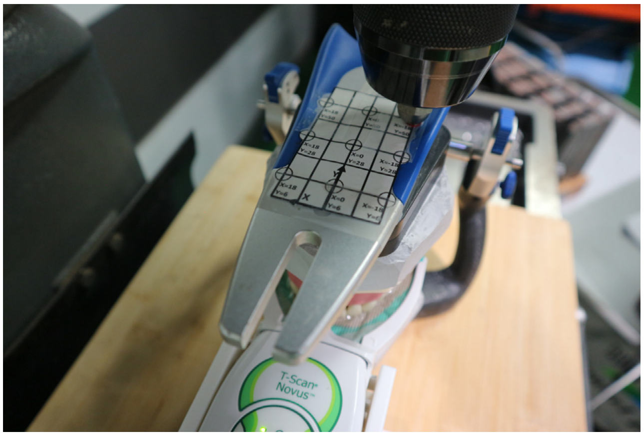


Figure 3. Pattern to control position of input force application point.

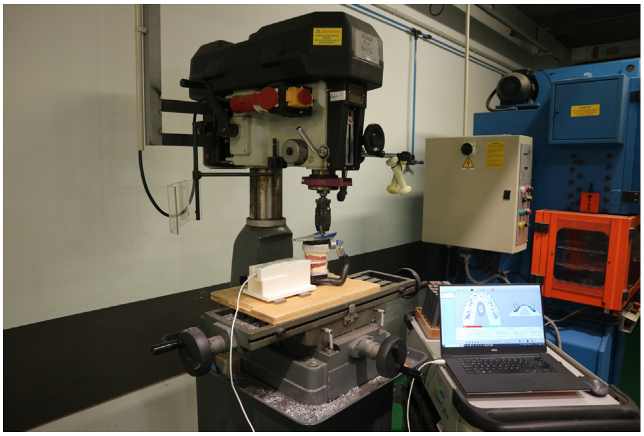


Figure 4. Assembly of elements used for tests.

subtracted from the American Standard Code for Information Interchange (ASCII) format file: CF-M and 2 coordinates of CO-CF (X and Y, in millimeters and with the same reference system as the pattern). The X-coordinate corresponded to the transverse location of the CO-CF from the mid-sagittal plane, and the Y-coordinate to the longitudinal location in the anterior–posterior direction measured from the incisors. In total, in each mounting, 10 CF-M and X and Y coordinates of CO-CF were obtained for each input force application point.

All measurements were entered into a statistical software program (IBM SPSS Statistics, v26; IBM Corp) to test the null hypotheses. To test the first null hypothesis, the influence of the input force application position in the X and Y coordinates of the CO-CF was analyzed with a 2-way repeated measures ANOVA test (α=.05) for each of the coordinates. Each coordinate was considered a repeated measures factor with 9 levels, and the articulated dental casts an independent factor with 3 levels (given that 10 repeated coordinates were measured for each of the 9 force application positions for each of the 3 articulated dental casts). Similarly, to test the

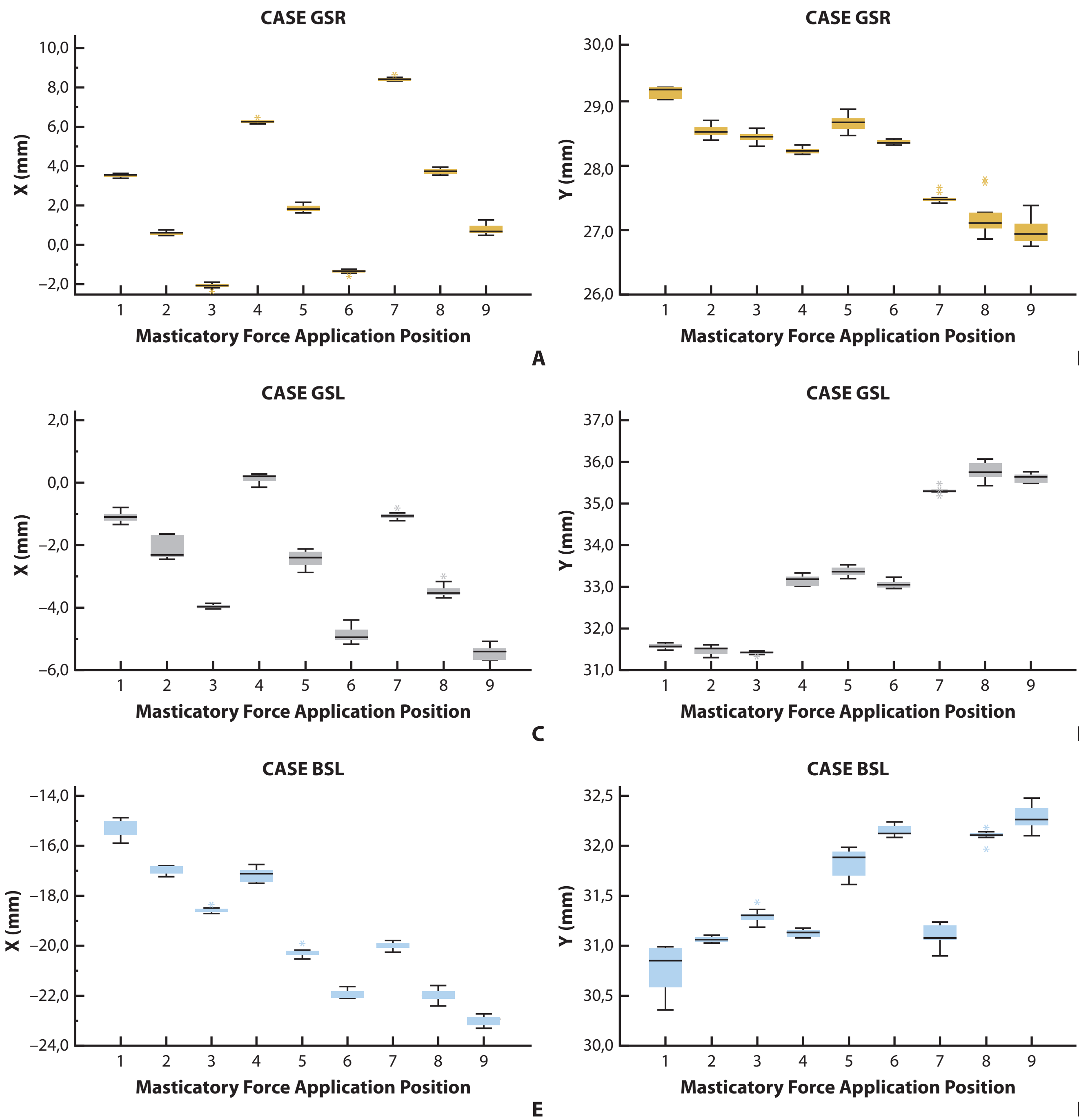
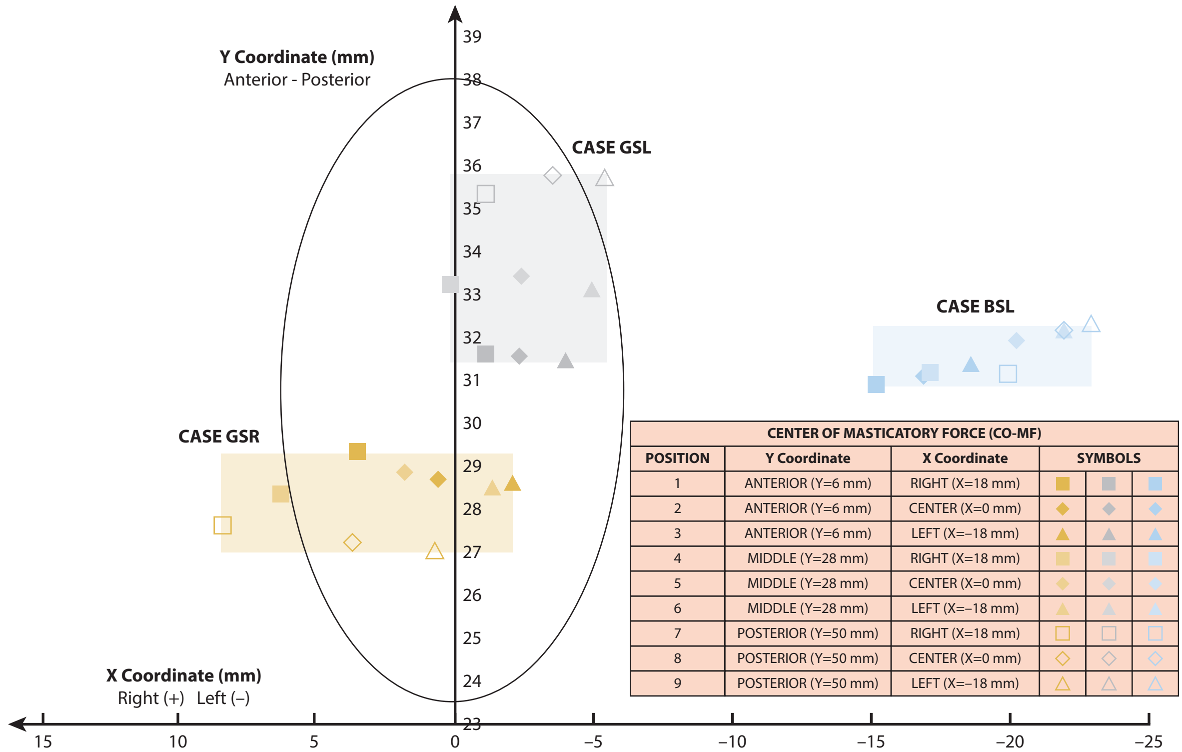


Figure 5. Box plot for XY coordinates for location of CO-CF. A, X-coordinate for CASE GSR (*yellow*). B, Y-coordinate for CASE GSR. C, X-coordinate for CASE GSL (*gray*). D, Y-coordinate CASE GSL. E, X-coordinate for CASE BSL (*blue*). F, Y-coordinate for CASE BSL. BSL, bad symmetry and left displaced; CO-CF, center of contact force; GSL, good symmetry and left displaced; GSR, good symmetry and right displaced.

second null hypothesis, the influence of the input force application position on the CF-M was analyzed by comparing the magnitudes for each group of input force application positions (anterior, middle, and posterior). In addition, to perform the comparisons, the means of the 10 CF-Ms measured for each of the 9 input force application positions were calculated for each of the articulated dental casts. Then, the CF-Ms measured for each of the articulated dental casts were divided by the highest mean value and expressed as percentages. A 2-way repeated measures ANOVA test (α=.05) was then performed, considering CF-M (expressed in percentages) a repeated measures factor with 3 levels and the articulated dental casts an independent factor with 3 levels



CENTER OF MASTICATORY FORCE (CO-MF)					
POSITION	Y Coordinate	X Coordinate	SYMBOLS		
1	ANTERIOR (Y=6 mm)	RIGHT (X=18 mm)	■	■	■
2	ANTERIOR (Y=6 mm)	CENTER (X=0 mm)	◆	◆	◆
3	ANTERIOR (Y=6 mm)	LEFT (X=–18 mm)	▲	▲	▲
4	MIDDLE (Y=28 mm)	RIGHT (X=18 mm)	■	■	■
5	MIDDLE (Y=28 mm)	CENTER (X=0 mm)	◆	◆	◆
6	MIDDLE (Y=28 mm)	LEFT (X=–18 mm)	▲	▲	▲
7	POSTERIOR (Y=50 mm)	RIGHT (X=18 mm)	□	□	□
8	POSTERIOR (Y=50 mm)	CENTER (X=0 mm)	◇	◇	◇
9	POSTERIOR (Y=50 mm)	LEFT (X=–18 mm)	△	△	△

Figure 6. Graph for medians of locations for CO-CF in 3 dental cast situations. Each symbol corresponds to a different position of CO-MF. CO-CF, center of contact force; CO-MF, center of masticatory forces.

(given that 10 repeated CF-M values were obtained for each of the 3 input force application positions belonging to each of the 3 groups of input force application positions for each of the 3 articulated dental casts).

RESULTS

The influence of the input force application point on the X and Y coordinates of CO-CF is presented in Figure 5. The 2-way repeated measures ANOVA test revealed significant differences in the X (F_{G-G} [9.32, 125.85] =1204.70; P<.001; η2=0.989) and Y (F_{G-G} [7.75, 104.66] =1149.69; P<.001; η2=0.988) coordinates among the groups for the 3 articulated dental casts, demonstrating that the point of application of the input force had an influence on their value. Furthermore, a coefficient of variation mean of 0.37% was obtained in the X and Y coordinate values obtained in the 10 repetitions for the 27 groups. In Figure 6, the median of the CO-CF location for each group of repetitions of the test variable CO-MF has been positioned with a symbol; that is, 9 symbols for each dental cast. A reference ellipse has also been drawn, within which is what is considered to be a normal location in MIP for 68% of the population, according to Maness et al[21] and Mizui et al.[22]

Regarding the influence of the input force application point in the magnitude data of CF (Fig. 7), a 2-way repeated measures ANOVA test (F_{G-G} [3.37, 146.71] =73.08; P<.001; η2=0.627) revealed statistically significant differences in CF magnitude percentages among the 3 groups in each articulated dental cast, demonstrating that even when testing with the same

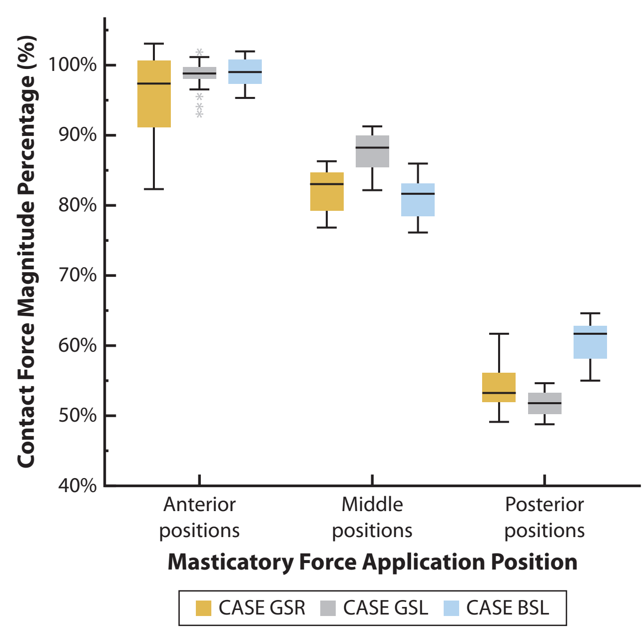


Figure 7. Box plot of CF magnitudes percentages for 3 dental cast cases. Each group corresponds to anterior, middle, and posterior positions of CO-MF. BSL, bad symmetry and left displaced; CF, contact force; CO-MF, center of masticatory forces; GSL, good symmetry and left displaced; GSR, good symmetry and right displaced.

magnitude of input force (169 N), the values of CF-M varied significantly for the 3 groups. In the CF-M percentages, a coefficient of variation mean of 3.70% was obtained for 30 repetitions for the 3 groups in each of the 3 articulated dental casts.

DISCUSSION

The purpose of this study was to analyze whether a change in the masticatory force balance influenced the location of the CO-CF and its CF-M. Statistically significant differences were found on the measured CO-CF and CF-M values when changing the masticatory force balances (application points). Therefore, the hypothesis that each articulated dental cast had a unique location of the CO-CF at the MIP was rejected as was the hypothesis that if the intensity of the masticatory force remained constant, the magnitude of the tooth CF would also always remain constant. Furthermore, the obtained average coefficient of variation (0.37% in location of CO-CF and 3.70% in CF-M) revealed that the test method designed and used to measure both parameters of dental CFs was highly repeatable.

To analyze the location of CO-MF, 27 groups (9 positions of CO-MF in 3 dentures) were used, with excellent repeatability. However, to analyze the magnitude of CFs, 9 groups (anterior, middle, and posterior positions of CO-MF in 3 dentures) were used; these were less homogeneous and therefore had reduced repeatability.

Cerna et al[18] concluded that the digital occlusal analyzer used in the present study was a reliable device if the total force value was measured with sensors of the same manufacturing series, as used in the present study. Kerstein et al[20] also concluded that this digital occlusal analyzer was a reliable device if the percentage of left and right side force were measured; this information is consistent with good repeatability of the X coordinate of the CO-CF in the present study.

Lee et al[19] also concluded that the digital occlusal analyzer was a reliable device if absolute force value is measured. In their in vitro test, a denture was mounted in a semiadjustable articulator and was compressed with a force applied always at the same point of the articulator. This conclusion was consistent with the results of the present study (Fig. 6).

ANOVA tests performed on 2 coordinates of the CO-CF for 3 dental modes led to the rejection of the first null hypothesis (*P*<.05). Graphically (Fig. 6), it could be clearly distinguished that medians of the CO-CF varied when the CO-MF changed. Examining the graph also led to the rejection of the first null hypothesis because each articulated dental cast did not have a unique location for the CO-CF in MIP. By using electromyography, Wiechens et al[24] concluded that symmetrical masticatory forces do not imply a centered and balanced CO-CF, consistent with the results of the present study (Fig. 6).

In the present study, the quality of the occlusion of articulated dental casts did not significantly influence variations in the location of the CO-CF. However, the poorest quality dental cast, CASE BSL, presented less variation in the CO-CF than better quality casts, possibly because there were fewer contact points and the redistribution of forces was more limited.

Although longitudinal position changes made in the CO-MF were greater than transverse changes, variations in the longitudinal location of the CO-CF were smaller. Furthermore, the transverse location variation of the CO-CF directly correlated with the transverse position changes of CO-MF. However, the longitudinal CO-CF location variation did not directly correlate with the longitudinal CO-MF changes. This effect may have been because transverse stability was achieved with 2 supports on the condyles located at each transverse end, but longitudinal stability was only achieved with the 2 condyles located at the same longitudinal end.

ANOVA tests for the percentages of the CF-M also rejected the second null hypothesis (*P*<.05). When the same value of masticatory force (value 169 N) was applied in positions closer to condyles, the magnitude of CFs was lower (Fig. 7), because condyles bear a larger part of the masticatory force.

Among the studies simultaneously analyzing muscle force and dental CF,[28-31] none have focused on the influence of the first force with respect to the second. Wiechens et al[24] and Berry and Singh[25] concluded that the location and intensity of CF changes throughout the day and pointed to variation in muscle contraction as the likely cause, a finding that was consistent with the present study.

Limitations of the present study include the use of in vitro tests. Future research could measure the variability in the CO-CF in vivo by monitoring muscle contraction with surface electromyography measurements. To do this, once the point of maximum intercuspation is reached, patients could voluntarily vary muscle contraction from left to right to determine the effect on the location of the CO-CF.

Although an imbalance was introduced by shifting the CO-MF from the mid-sagittal plane, another limitation was the impossibility of quantifying muscle force on each side. In order to quantify it, it would be necessary to know the exact lateral position of muscles, and this aspect was beyond the scope of the present study.

The null hypotheses were established for any existing dental cast, and they must be satisfied for all situations. Three dental casts were analyzed, and the statistics determined that the null hypotheses were not satisfied; as a result, they are not satisfied in any situation. It might be thought that the null hypotheses will not be satisfied in any dental cast, but, with only 3 examples tested, the statistical evidence was insufficient to confirm this.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The location of the CFs offered by a digital occlusal analyzer at the maximum intercuspation position was not necessarily unique for each articulated dental cast. Even if the intensity of the masticatory force remains unchanged, changes in its lateral or longitudinal balance also influence this location.
2. Even if the intensity of the masticatory force remains constant, the magnitude of the absolute force measured with a digital occlusal analyzer can vary significantly. Changes in the longitudinal position of the CO-MF cause this variation.

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Mikel Jauregi: Conceptualization, Methodology, Software, Investigation, Writing – original draft. **Xabier Amezua:** Investigation, Writing – original draft, Visualization. **Angel P. Manso:** Formal analysis, Data curation, Visualization. **Eneko Solaberrieta:** Validation, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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