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Determination of Mandibular Center of Rotation and Assessment of Association between Cephalometric Indices and Its Location

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Abstract

Aim: Following maxillary impaction, the mandible rotates around a center. Inaccurate determination of mandibular rotation can profoundly affect orthognathic surgical treatment planning and final surgical outcomes. The present study determined the relationship between the cephalometric characteristics of candidates for maxillary impaction surgery using sagittal and vertical locations of the center of rotation of the mandible.
Methods: In a descriptive and cross-sectional trial, 36 candidates were selected for LeFort I maxillary impaction surgery. Two lateral cephalograms were obtained in open and closed mouth positions. The center of rotation of the mandible was determined by the Reuleaux technique. Cephalometric measurements of the patients with the determined center of mandibular rotation locations (regions 1 and 4 of the coordinate axis) were made and the results were subjected to the Student's t-test.
Results: The center of mandibular rotation was located in region 1 of the coordinate axis in 17 (50%) and in the 4th region of the coordinate axis in 17 (50%). Statistically significant differences were observed regarding MP-SN ($P<0.006$), CO-GO ($P<0.006$), and CO-GN ($P<0.04$) at the two regions of 1 and 4 for the center of rotation of the mandible in the coordinate axis.
Conclusion: With the decreased length of the ramus and increased inclination of the plane, the center of rotation of the mandible tended to be situated in region 1 of the coordinate axis; with the increased length of the ramus and decreased inclination of the plane, the center of mandibular rotation tended to be located in region 4 of the coordinate axis.

Keywords: Center of rotation of the mandible, Cephalometry, Condyle, Maxillary impaction surgery, Surgical prediction.

Background

Class Treatment planning is pivotal in successfully managing patients with severe dentofacial deformities, requiring orthognathic surgery (1). Careful prediction is a critical step in treatment planning, and prediction methods vary from cephalometric tracing prediction to using recently introduced 3D software programs. The relationship between the predicted and postoperative results has been investigated in various studies, with the results revealing varying degrees of inaccuracy in prediction methods (2).

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Superior repositioning of the maxilla via LeFort I osteotomy and mandibular autorotation tends to correct maxillary excess, resulting in hard and soft tissue changes in the lower face (3). The radiographic center of the condyle has been assumed as the center of rotation for predicting mandibular autorotation in cases that need superior repositioning of the maxilla via LeFort I osteotomy. Furthermore, the mandibular movement has been considered a purely rotational movement around a single focal point along the entire path of autorotation (4). However, several studies have indicated that the true center of rotation is not located on the radiographic center of the condyle (5, 6) and is not fixed during movement. In contrast, an instantaneous center of rotation exists, and those changes for any slight movement of the mandible (7) result in a mandibular movement that combines a hinge and translation movement (8).

Determining the precise location of the center of rotation has been a matter of controversy in several studies, with ongoing disagreements about its clinical impacts on the postoperative soft tissue profile. Several studies evaluating the predicted soft tissue profiles have demonstrated that the most significant regions of error are the lower lip and chin (9), and it has been stated that inaccuracies in predicting mandibular autorotation during LeFort I surgery play an important role in reported errors of these regions (2, 3, 9). The drawbacks of using an inaccurate center of rotation in prediction are difficulty in positioning maxillary segments during surgery along with significant sagittal malpositioning of the maxilla, displacement of the mandible, increasing the finishing time of postoperative orthodontics due to occlusal discrepancies, inability to decide whether mandibular surgery or adjunctive surgeries are needed concomitant with LeFort I or not, the possibility of postoperative pain and dysfunction of the TMJ due to "disk squeezing" and unpredictability of the final soft tissue profile (10-14).

Considering the importance of accurate prediction of the mandibular autorotation path in orthognathic treatment planning, many studies have focused on evaluating the location of the mandibular center of rotation following maxillary impaction (15, 16). However, published data are inconclusive, with significant discrepancies in the applied methodology, landmarks, and results. Nadjmi et al. demonstrated that the location of the center of rotation using the Rouleux method has good accuracy, with no difference between the center of rotation that they determined using this method and its position after maxillary impaction (as a result of mandibular rotation). They reported that the mandible rotates around the same point during maxillary impaction surgery as during initial jaw opening (4).

Since the jaw and facial structures are in harmony, in addition to the condyle's morphology and its joints, there may be a relationship between the cephalometric properties, size, and position of the mandible with its rotational center. Due to the lack of investigation of this relationship, this study was conducted to determine the relationship between the cephalometric characteristics of patients undergoing surgery and the mandibular rotational position.

Methods

This descriptive cross-sectional study was conducted on 36 patients (6 males and 30 females, mean age: 29±9, age: 20–38 years). Orthognathic surgery treatment included maxillary impaction surgery. Inclusion criteria for patients were: undergoing maxillary impaction surgery with or without mandibular osteotomy or genioplasty (having an open oral radiograph), mature patients (end of growth spurt, CVM VI), and the ability to open their mouth at least 10 mm. Patients with a history of syndromes affecting the head and facial features, TMJ ankylosis, and low-quality radiographs with obscured landmarks were excluded.

Due to the lack of a similar study, the sample size was calculated using the following formula. It should be pointed out that the initial number of participants was 36, and two centers of mandibular rotations at region 3 of the coordinate axis were excluded.

$$N=\frac{\left(z_{(1-\frac{\alpha}{2})}+z_{(1-\beta)}\right)^2 (SD_1{}^2+SD_2{}^2)}{(X_1-X_2)^2} \rightarrow N=\frac{(1.96+0.84)^2(4+6)}{(5)^2} \rightarrow N=17$$

α=0.05
β=0.2
$\bar{X}_1-\bar{X}_2$=5
SD_1=4
SD_2=6

After selecting qualified patients and obtaining their informed consent, the following steps were performed for each patient individually.

Cephalometric radiography

Two lateral cephalometric radiographs were taken with the mouth closed and open before surgery. For open-mouth cephalometric radiographs, custom-made acrylic blocks with a thickness of 10 mm were prepared for each patient. Then, the patients were asked to place the blocks

between their posterior teeth and bite. All the radiographs were taken in the natural head position (NHP).

Determining the mandibular rotation center

The radiographs were traced onto acetate paper to determine the center of mandibular rotation and identify landmarks. The points of the incisal edge of the mandibular central incisors and gonion (Go) were marked on both tracings. Then, the radiographs were superimposed on the cranial base (Figure 1). The Reuleaux technique was used to determine the center of mandibular rotation, and regions 1, 2, 3, and 4 were defined in the coordinate axis (17). For this purpose, the bisector line perpendicular to the interconnected segments of the incisal edge of the central incisors in two tracings and sectional joints of the gonions in two tracings were marked. The extension of these two sections is the center of the mandibular rotation (Figure 2).

After determining the center of mandibular rotation, the distance between the vertical and horizontal reference lines was measured and recorded. The horizontal linear reference line is parallel to the Frankfurt plane, which runs from the center of the radiographic image of the condyle. The vertical reference line is perpendicular to the Frankfurt plane, passing through the center of the image of the condyle. To determine intra-examiner reliability in 10 patients, the center of rotation was calculated using the Reuleaux technique, and the measurements were repeated after two weeks. Intra-examiner reliability was calculated using the intra-class correlation (ICC) test.

Digital cephalometric tracing

Lateral cephalometric radiographs with a closed mouth were traced using Dolphin software, and landmarks were identified. The measurements were calculated, and to determine the intra-examiner reliability in 10 patients, the cephalometric analysis was performed with the points, intervals, and angles. Measurements were repeated after two weeks. Finally, intra-examiner reliability was calculated and reported using the ICC test.

Statistical analysis

Table 1 presents the results of assessing the normal distribution of the data using the Kolmogorov-Smirnov test for each landmark. Based on the results of this test, each landmark had a normal distribution. Therefore, the Student's t-test was used to compare them in the two regions of the center of mandibular rotation.

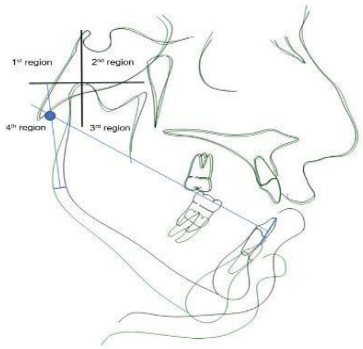


Figure 1. Superimposing radiographs and determining points of the mandibular incisor edge and gonion.

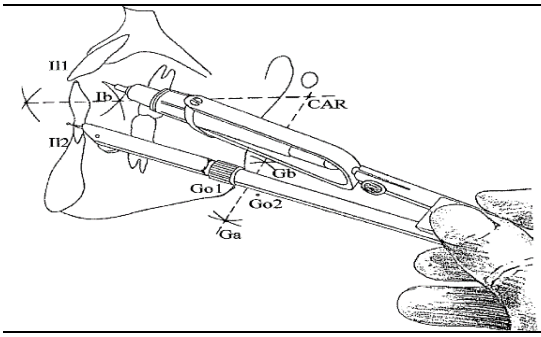


Figure 2. Determining the center of mandibular rotation.

Results

Thirty-six candidates for maxillary impaction surgery were evaluated. Of these subjects, the center of mandibular rotation was located in region 1 of the coordinate axis in 17 (50.0%) and in 17 (50.0%) in region 4 of the coordinate axis. Two samples were eliminated because they were located in region 3. Furthermore, the average coordinates of the center of rotation were the point [x = -28.1, y = -2.08].

The highest magnitude of the difference in means between the first and second tracing was 0.003 mm or 0.03º. The IC and 95% CI for the level of agreement between T1 and T2 indicated no significant differences. All the results of the ICC test were above 0.90 (strong correlation), indicating excellent intra-rater reliability.

The mean ± SD of the MP-SN in regions 1 and 4 of the mandibular rotation center was 39.53±4.42 and 34.24±6.05, respectively. The mean ± SD of the CO-GO in regions 1 and 4 was 51.88±5.83 and 58.13±5.18, respectively. The mean ± SD of the gonial angle in regions 1 and 4 was 129.76±8.02 and 130.91±8.77, respectively. The mean ± SD of the Occ-SN in regions 1 and 4 of the mandibular rotation center was 17.44±3.83 and 15.25±4.39, respectively. The mean ± SD of the face height in regions 1 and 4 of the center of mandibular rotation was 91.94±4.44, 60, and 63.61±4.76, and the mean±SD of CO-GN in regions 1 and 4 was 111.09±11.85 and 119.4±10.28, respectively (Table 1).

Student's t-test showed significant differences between the values of MP-SN (P<0.006), CO-GO (P<0.006), and CO-GN (P<0.04) in the two regions 1 and 4 for the position of the center of mandibular rotation. However, there were no significant differences between the gonial angle (P=0.69), Occ-SN (P=0.13), and face height (P=0.09) in the two regions 1 and 4 for the position of the center of mandibular rotation (Table 2).

Table 1. Results of the analysis of data with normal distribution using the Kolmogorov-Smirnov test, separately for each landmark

Landmarks	Statistical magnitude of the Kolmogorov-Smirnov test	The rotational center of the mandible	Degree of freedom	P-value
MP-SN	0.136	1	17	0.2
	0.163	4	17	0.2
CO-GO	0.176	1	17	0.169
	0.179	4	17	0.149
Gonial angle	0.164	1	17	0.2
	0.143	4	17	0.2
Occ-SN	0.133	1	17	0.2
	0.156	4	17	0.2
Face height	0.174	1	17	0.18
	0.129	4	17	0.2
CO-GN	0.135	1	17	0.2
	0.203	4	17	0.061

Table 2. Indices of the central distribution of cephalometric landmarks of regions 1 and 4, placing the center of the mandibular rotation

Landmarks	Center of mandibular rotation	No	Mean	SD	Standard error	Mean difference	P-value
MP-SN	1	17	39.53	4.42	1.07	5.29	0.006
	4	17	34.24	6.05	1.47		
CO-GO	1	17	51.88	5.83	1.41	6.25	0.002
	4	17	58.13	5.18	1.26		
Gonial angle	1	17	129.76	8.02	1.95	1.15	0.69
	4	17	130.91	8.77	2.13		
Occ-SN	1	17	17.44	3.83	0.93	2.18	0.13
	4	17	15.25	4.39	1.06		
Face Height	1	17	60.91	4.44	1.08	2.7	0.09
	4	17	63.61	4.76	1.15		
CO-GN	1	17	111.09	11.85	2.87	3.8	0.04
	4	17	119.4	10.28	2.49		

Discussion

Traditionally, orthognathic surgery is based on face-bow registrations, and the models are articulated, and surgical procedures are performed on the model. Barbenel et al. reviewed the probable problems associated with surgical intervention on the model at the condyle as the center of mandibular rotation in the articulator (11). Clinical studies related to these cases also showed significant differences between the predicted and actual positions of the maxilla after LeFort I osteotomy surgery (15, 16). With this in mind, the accuracy of the kinematic method for determining the mandibular rotational center has been questioned (17, 18).

Therefore, more precise methods are necessary to determine the mandibular rotational center in maxillary impaction surgery. Panjabi et al. designed an algorithm to determine the center of rotation and the angle of rotation of the human body joints, in which the axis coordinates of the two points on the bone were used in two different positions based on a reference point (19). This algorithm was developed based on the location of the center of rotation using the Reuleaux technique (20). Based on Panjabi's research, to record a bodily movement relative to another body or another fixed coordinate system, at least three independent computations are needed: two perpendicular coordinate axes and a rotation angle in the center of rotation (19). In this situation, the center of rotation will be the point of intersection of the vertical bisectors of the two lines connecting the initial and final positions of the two points in the plane, as in the Reuleaux technique (17, 19).

Failure to determine the position of a landmark on radiographs after mandibular rotation due to incorrect landmark identification and error in the calculation of the coordinate axes will cause an error in determining the original and rotated positions of the landmark (21, 22). Moreover, an error in the reconstruction or calculation of perpendicular bisectors leads to more errors (23). In our study, the Reuleaux technique was used to determine the mandibular rotational center, and all possible parameters were considered in this field to minimize the associated errors. According to a study by Nattestad et al., the unfavorable impact of some errors in determining the actual rotational center on mispositioning the maxilla is particularly noticeable. The most significant outcomes were reported when the center of rotation was close to the line perpendicular to another line connecting the center of the condyle to the mandibular incisors at the center of the condyle. The distance between the true center of rotation and the center of the condyle did not significantly influence the position of the maxilla alone. In addition, they stated that open-bite size has been proportionally effective in erroneous estimation of the horizontal position of the rotational center (24).

Panjabi suggested that two-point markers should be placed on a moving body to determine the center of mandibular rotation in research protocols, and the approximate rotational angle should be as close to 90° as possible (19). Also, these two markers should be located as far from the center of rotation as possible. Rekow et al. reported that the Reuleaux technique is reliable when the rotation angle is at least 6° (17).

In the present study, two cephalograms with open and closed mouths were traced. The incisal edge of the mandibular central incisors and gonion points were marked on both tracings, and radiographs were superimposed on the anterior cranial base. Then, the perpendicular bisector of the interconnecting segment of the central teeth and sectional joints of the gonions was drawn in superimposed tracings. The intersection of these two lines represented the mandibular rotational center. Afterward, the coordinate of the obtained point was determined based on the vertical and horizontal reference lines.

According to the results of this study, there were significant differences in the amounts of MP-SN (mandibular plane angles), CO-GO (ramus length), and CO-GN (mandibular length) between regions 1 and 4 of the coordinate axes for the position of the rotational center. However, no difference was noted between the gonial angle, Occ-SN, and face height in regions 1 and 4. The mean value of MP-SN for the position of the center of mandibular rotation in region 1 was greater than the corresponding values for the position of the center of rotation of the mandible in region 4 (39.53 vs. 34.24). CO-GO mean value for the position of the mandibular rotational center in region 1 was smaller than in region 4 (51.88 vs. 58.13). Also, the CO-GN mean value in region 1 was less than that in region 4 (11.09 versus 119.41). Therefore, as the ramus length decreases and the slope of the mandibular plane increases, the mandible rotational center with a greater probability would be in the first region, and with increasing the length of the ramus and decreasing the plane slope, the mandibular center of rotation would be more likely to be located in region 4 of the coordinate axes. Also, in contrast to the x-axis, the location of the center of mandibular rotation was correlated to the y-axis. Although some studies have determined the center of mandibular rotation in orthognathic

surgery, no study has evaluated the correlation between the locations of the center of rotation and cephalometric measurements.

Shahbodaghi et al. investigated the cephalometric location of the mandibular rotational center after LeFort I superior repositioning osteotomy. Consistent with the present study, they found that the center of mandibular rotation is not similar in patients due to individuals' specific craniofacial morphology. In the current study, sella-nasion, occlusal, palatal, and mandibular planes were used as reference lines for superimpositions of pre- and postoperative cephalometric tracings (25).

In a study by Kim et al. on 21 patients with anterior open bite undergoing the molar intrusion treatment approach, the center of mandibular rotation was determined by measuring the displacement of gonions and pogonions. The center of rotation was 7.4 mm behind and 16.9 mm below the condyle. Similar to this study, it was found in a location other than the condyle itself and was associated with the mastoid region (region 1 of coordinate axes based on the current study) (26).

Using the Dolphin software, Lindauer et al. investigated mandibular rotation during jaw opening in normal individuals. They reported that the center of mandibular rotation was in the condyle head in neither of the studied cases. In the present study, the central position of the condyle vertex in the inter-cuspal position was assigned as the center of the Cartesian coordinate system, and the anterior values and higher values based on the center of the condyle vertex were considered positive x and y values, respectively (27). Also, Rekow et al. showed significant differences in the position of the center of mandibular rotation in maxillary impaction surgery patients, and this center was not within the condyle trunk region (17). These findings were confirmed in the current study.

In a study by Nattestad et al., the results of a new application method were reported to determine the position of the mandibular rotational center and its effects on orthognathic surgery outcomes (24). According to their findings, considering the condylar center as the center of mandibular rotation while designing upward maxillary movements may lead to remarkable errors in the maxillary horizontal position in most patients. Their method was designed by computer analysis and from two lateral cephalograms with different degrees of opening.

In previous studies, the center of mandibular rotation after maxillary impaction surgery has been determined in different ways, and it should be kept in mind that different amounts of impaction of the posterior and anterior regions, positional changes in sagittal direction after maxillary surgery, and some other factors contribute to mandibular rotation. Also, the amount of rotation is another factor that might cause an error (3, 6, 14, 15). By increasing the angle of rotation, the error associated with the determination of the mandibular rotational center is likely to decrease (19).

In clinical conditions, there is, of course, limited freedom to manipulate mandibular rotation.

Therefore, since the rotational angle cannot be increased to achieve optimal mathematical results, any prediction of the center of mandibular rotation using the Reuleaux technique should be carried out precisely and with sufficient assurance that adequate distances separate the landmarks. Despite some probable errors, the Reuleaux technique is a simple method for determining the position of the center of rotation, and its reliability to determine the position of the center of rotation has been confirmed by Rekow et al. (17). Furthermore, the position of landmarks relative to each other and relative to the center of mandibular rotation can have significant effects in determining the actual rotational center. On the other hand, mismatches in determining the center of mandibular rotation using the Reuleaux technique or determining the mandibular condyle center from radiographs show that the mandibular movements are not just rotational but rather a combination of movement, rotation, and translation.

Based on a systematic review by Reddy et al., no permanent rotational center was detected in patients; also, the center was affected by muscle, ligament, and cartilage compounds (3). Furthermore, interpersonal differences in craniofacial morphology and condyle displacement were effective in the actual position of the mandibular rotational center (28).

The prediction of surgical results from cephalometric landmarks requires landmark detection, tracing, superimposition, and some computations, all of which have the possibility of error (29). On the other hand, photo cephalometry and video imaging techniques are also prone to be faulty (30, 31). Therefore, changes in hard tissues should be interpreted, considering the possible above-mentioned errors. Also, traditional cephalometric landmarks in the maxilla tend to be related to the dental system rather than basal bony structures. In addition, surgical procedures usually affect cephalometric landmarks, especially in the maxilla and gonion, and post-surgical fixation usually results in landmark changes. Furthermore, cephalometric prediction using tracings is a two-

dimensional technique with limitations. Optimal surgical movements are determined by combining predictive tracing and surgical prediction from the model, and these conditions can be used only if a valid and reliable technique is available. In addition to inherent errors in the process, orthognathic surgeries and predictions are susceptible to some errors due to differences in the individuals' responses.

Notably, each condylar center of rotation is an individualized measurement as the condyles and their fossa in the same individual are not anatomically identical. This means two different centers of rotation per individual exist, and their association leads to the final movement performed by the mandible. Thus, 3D images are the gold-

standard for planning orthognathic surgery as they provide individual condyle analyses without overlapping left and right condyles, which occurs in 2D images (10). According to the results of this study, the error in determining the actual position of the mandibular rotational center is probably one of the reasons associated with the lack of accuracy in orthognathic surgeries, especially in maxilla impaction surgeries.

Conclusion

With decreasing ramus length and increasing plane slope, the center of mandibular rotation with greater probability was in region 1 of the coordinate axes, and with increasing ramus length and decreasing plane slope, the center of mandibular rotation was more likely to be in region 4 of the coordinate axes. Furthermore, the center of mandibular rotation was related to the y-axis, although it had no relation to the x-axis.

Conflicts of Interest: None to declare.

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