Iran J Orthod. 2023 June; 18(1): e1112. doi: 10.22034/IJO.2023.2001885.1112.
Published online 2023 June 1 Research Article

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

Azita Tehranchi[1], Setareh Sohrabi[2], Farnaz Younessian[3] , Fatemeh Zahedipour [4]*

[1] Professor of Orthodontics, Dentofacial Deformities Research Center, Research Institute for Dental Sciences, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[2] Postgraduate student, Department of Orthodontics, Dental School, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[3] Department of Orthodontics, Nova Southeastern University, College of Dental Medicine, Fort Lauderdale, Florida, USA
[4] Department of Orthodontics, Dental School Shahid-Beheshti University of Medical Sciences, Daneshjoo Street, Shahid-Chamran Highway, Tehran, Iran

***Corresponding author:** Fatemeh Zahedipour, Department of Orthodontics, Dental School Shahid-Beheshti University of Medical Sciences, Daneshjoo Street, Shahid-Chamran Highway, Tehran, Iran

Email: Fatemezahedipour29@gmail.com

Received: 2023 May 08; **Revised:** 2023 May 24; **Accepted:** 2023 May 30

Abstract

Aim: Following maxillary impaction, the mandible rotates around a center. Inaccurate determination of mandibular rotation can have profound effects on orthognathic surgical treatment planning and final surgical outcome. 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 for LeFort I maxillary impaction surgery were selected. 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 done and the results were subjected to the student t-test.

Results: The center of mandibular rotation was located in region 1 of the coordinate axis in 17 (50%) and in 17 (50%) in the 4th region of the coordinate axis. Statistically significant differences existed regarding the MP-SN ($p<0.006$), CO-GO ($p<0.006$), and CO-GN ($p<0.04$) at 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 at region 1 of the coordinate axis, and together with the increased length of the ramus and decreased plane inclination, the center of mandibular rotation tended to be located at region 4 of the coordinate axis.

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

1. Background

Treatment planning plays a pivotal role in the successful management of patients with severe dentofacial deformities who need 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. The relationship between the predicted and post-surgical results has been investigated in various studies and published results have revealed varying degrees of inaccuracy in prediction methods (2).

Superior repositioning of the maxilla via LeFort I osteotomy along with mandibular autorotation is used to correct maxillary excess, which results in hard and soft tissue changes of 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. Also, the mandibular movement has been considered a purely rotational movement around a

Copyright © 2023, Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/) which permits copy and redistribute the material just in noncommercial usages, provided the original work is properly cited.

single focal point during the entire path of autorotation (4). However, several studies have stated 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 small movement of the mandible (7) result in a mandibular movement that is a combination of a hinge and translation movement (8).

Determining the precise location of the center of rotation has been a matter of controversy among several studies, and there are still disagreements on its clinical impacts on the post-operative soft tissue profile. Several studies evaluating the predicted soft tissue profiles have demonstrated that the most significant regions of error were the lower lip and chin (9), and it has been stated that inaccuracies in the prediction of 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 of maxillary segments during surgery along with significant sagittal malpositioning of the maxilla, displacement of the mandible, increasing the finishing time of post-surgical orthodontics due to occlusal discrepancies, inability to decide whether mandibular surgery or adjunctive surgeries are needed concomitant with LeFort I or not, possibility of post-operative 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. However, published data are not conclusive and there are 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. There was 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), and they stated 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 cephalometric characteristics of patients undergoing surgery and the mandibular rotational position.

2. Methods

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

Due to the lack of a similar study, sample size was calculated through the following formula and it should be mentioned that the initial number of participants was 36, and two center of mandibular rotations at region 3 of the coordinate axis were excluded.

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

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

After selecting qualified patients and obtaining their informed consent, the following steps were performed on each of them individually.

2.1Cephalometric 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, and then patients were asked to place the blocks between their posterior teeth and bite. All radiographs were taken in the natural head position.

2.2Determining the mandibular rotation center

To determine the center of mandibular rotation, the radiographs were traced onto acetate paper and landmarks were identified. The points of the incisal edge of the mandibular central incisors and gonion were marked on both tracings. Then radiographs were superimposed on the cranial base (Fig. 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 perpendicular bisector line 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 (Fig. 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 a perpendicular line 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 again after two weeks. Intra-examiner reliability was calculated using the intra-class correlation (ICC) test.

2.3Digital cephalometric tracing

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

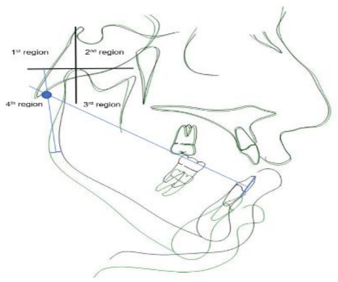

Fig 1. Superimposing images in radiography and determination of points of the mandibular incisor edge and gonion

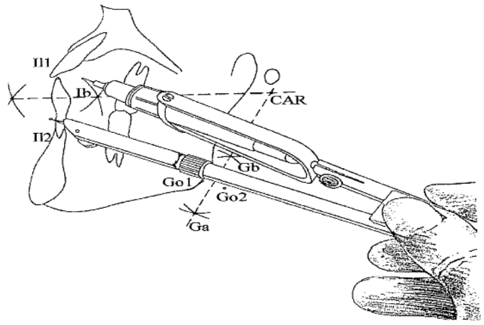

Fig 2. Determining the center of mandibular rotation

2.4Statistical analysis

In Table 1, the results of the assessment of the compliance of the data from the normal distribution using the Kolmogorov-Smirnov test are presented for each landmark. Based on the results of this test, each landmark was found to have a normal distribution. Therefore, the student t-test was used to compare them in the dual regions of the center of mandibular rotation.

3. Results

Thirty-six subjects who were 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. Also, the average coordinates of the center of rotation was 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 0.03 degree. 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) and there was excellent intra-rater reliability).

Table 1. Results of the evaluation of data following normal distribution using the Kolmogorov-Smirnov test separately for each landmark

Landmarks	Statistical magnitude of the Kolmogorov-Smirnov test	The rotational center of 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**

Mean±SD of the MP-SNL in regions 1 and 4 of the mandibular rotation center was 39.53 ± 4.42 and 34.24 ± 6.05 respectively. Mean±SD of the CO-GO in regions 1 and 4 was 51.88±5.83 and 58.13±5.18. 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. 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 Mean±SD of CO-GN in regions 1 and 4 was 111.09±11.85 and 119.4±10.28, respectively (Table 1).

According to the results of the student t-test, there were 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 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. Indices of the central distribution of cephalometric landmarks of regions 1 and 4, placing the center of 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		

4. Discussion

Traditionally, orthognathic surgery is based on face-bow registrations, and the models are articulated and surgical procedures are performed on the model. In a review by Barbenel et al., probable problems associated with surgical intervention on the model were assessed 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, the need to use more precise methods to determine the mandibular rotational center in maxillary impaction surgery was felt. 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 was 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 body move relative to another body or to another fixed coordinate system, at least three independent computations are needed: two perpendiculars coordinate axes and a rotation angle in the center of rotation (5). 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 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 in order 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 of the maxilla is particularly noticeable. The most significant outcomes were reported when the center of rotation was close to the line that is 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 alone have a significant influence on the position of the maxilla. 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 has 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 as possible to 90° (20). Also, these two markers should be located as far as possible from the center of rotation. Rekow et al. stated that the Reuleaux technique is reliable when the rotation angle is at least 6° (17).

In the present study, two cephalograms in 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, 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-SNs (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, but there was no difference between the gonial angle, Occ-SN and face height in regions 1 and 4. Mean value of MP-SN for the position of center of mandibular rotation in region 1 was greater than corresponding values for the position of center of rotation of the mandible in region 4 (39.53 vs. 34.24), and CO-GO mean value for the position of mandibular rotational center in region 1 was smaller than region (51.88 vs. 58.13). Also, CO-GN mean value in region 1 was less than region 4 (11.09 versus 119.41). Therefore, as the ramus length decreases and the slope of 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 the region 4 of the coordinate axes. Also, in contrast to the x axis, the location of center of mandibular rotation was correlated to the Y axis. Even though, some studies determined the center of mandibular rotation in orthognathic surgery, no study has been conducted on the correlation between 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, and consistent with the present study, they found that, due to individuals' specific craniofacial morphology, the center of mandibular rotation is not similar in patients. In the current study, sella-nasion, occlusal, palatal and mandibular planes were used as reference lines for superimpositions of pre- and post-surgical 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, and 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).

Lou et al. also used the Reuleaux technique to detect the mandibular auto rotational center in 25 patients with LeFort I (impaction) maxillary excision without mandibular osteotomy. It was set at 15.64 mm below and 0.82 mm behind the center of the condyle vertex (19). Consistently in some other studies, the center of rotation of the mandibular was not located at the condyle (20).

Lindauer et al. investigated mandible rotation during jaw opening in normal individuals using the Dolphin software. They stated that in neither of the studied cases, the center of mandibular rotation was in the condyle head. 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 and Vedtofte, the results of a new application method to determine the position of the mandibular rotation center and its effects on orthognathic surgery outcomes were reported (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. The method they used 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 differential amount of impaction of the posterior and anterior regions, positional changes in sagittal direction after maxillary surgery as well as some other factors all contribute to mandibular rotation. Also, the amount of the rotation is another factor for the occurrence of 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, due to the fact that the rotational angle cannot be increased to achieve optimal math results, any prediction of the center of mandibular rotation using the Reuleaux technique should be carried out precisely and with sufficient assurance that the landmarks are separated from each other by adequate distances. In spite of 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 in relation 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 the results of the 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 terms of craniofacial morphology and condyle displacement were observed to be effective in the actual position of the mandibular rotation center (28).

The prediction of surgical results from cephalometric landmarks requires landmark detection, tracings, superimpositions, and some computations, which all have the possibility of error (29). On the other hand, photo cephalometry and video imaging techniques are prone to be faulty as well (30, 31). Therefore, changes of hard tissues should be interpreted, considering the possible errors aforementioned. 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 and has its own 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.

It is noteworthy that 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 exists, and their association leads to the final movement performed by the mandible. Thus, 3D images are the gold standard to planning orthognathic surgery as it provides 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 rotation center is probably one of the reasons associated with the lack of accuracy in orthognathic surgeries, and this is especially evident 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, 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.

References

1. Chen Z, Mo S, Fan X, You Y, Ye G, Zhou N. A Meta-analysis and Systematic Review Comparing the Effectiveness of Traditional and Virtual Surgical Planning for Orthognathic Surgery: Based on Randomized Clinical Trials. J Oral Maxillofac Surg. 2021;79(2):471.e1-.e19. doi:10.1016/j.joms.2020.09.005.
2. Philip MR, AlFotawi R. The accuracy of soft tissue movement using virtual planning for non-syndromic facial asymmetry cases-a systematic review. Oral Maxillofac Surg. 2022. doi:10.1007/s10006-022-01059-w.
3. Reddy SGK, Ibrahim HM, Bhardwaj S, Potdar S, Kumar A, Uppal A, et al. Autorotation of the Mandible as Sequelae to Maxillary Intrusion: A Systematic Review. J Pharm Bioallied Sci. 2021;13(Suppl 2):S947-s51. doi:10.4103/jpbs.jpbs_389_21.
4. Nadjmi N, Mommaerts MY, Abeloos JV, De Clercq CA. Prediction of mandibular autorotation. J Oral Maxillofac Surg. 1998;56(11):1241-7; discussion 7-8. doi:10.1016/s0278-2391(98)90599-7.
5. Wang YC, Ko EW, Huang CS, Chen YR. The inter-relationship between mandibular autorotation and maxillary LeFort I impaction osteotomies. J Craniofac Surg. 2006;17(5):898-904. doi:10.1097/01.scs.0000234985.99863.97.
6. Peleg O, Mijiritsky E, Manor Y, Inchingolo F, Blinder D, Mortellaro C, et al. Predictability of Mandibular Autorotation After Le Fort I Maxillary Impaction in Case of Vertical Maxillary Excess. J Craniofac Surg. 2019;30(4):1102-4. doi:10.1097/scs.0000000000005544.
7. Mehl A. Hinge axis determination of the temporomandibular joint and its interpretation: what do we really measure? Int J Comput Dent. 2018;21(4):295-303.
8. Chang CL, Wang DH, Yang MC, Hsu WE, Hsu ML. Functional disorders of the temporomandibular

joints: Internal derangement of the temporomandibular joint. Kaohsiung J Med Sci. 2018;34(4):223-30. doi:10.1016/j.kjms.2018.01.004.

9. Kaklamanos EG, Kolokitha OE. Relation between soft tissue and skeletal changes after mandibular setback surgery: A systematic review and meta-analysis. J Craniomaxillofac Surg. 2016;44(4):427-35. doi:10.1016/j.jcms.2016.01.005.
10. Quast A, Santander P, Kahlmeier T, Moser N, Schliephake H, Meyer-Marcotty P. Predictability of maxillary positioning: a 3D comparison of virtual and conventional orthognathic surgery planning. Head Face Med. 2021;17(1):27. doi:10.1186/s13005-021-00279-x.
11. Barbenel JC, Paul PE, Khambay BS, Walker FS, Moos KF, Ayoub AF. Errors in orthognathic surgery planning: the effect of inaccurate study model orientation. Int J Oral Maxillofac Surg. 2010;39(11):1103-8. doi:10.1016/j.ijom.2010.07.004.
12. Robin O, Coste A. [Orthognathic surgery and joint dysfunctions: benefits or risks?]. Orthod Fr. 2021;92(4):381-90. doi:10.1684/orthodfr.2021.63.
13. Wolford LM. Comprehensive Post Orthognathic Surgery Orthodontics: Complications, Misconceptions, and Management. Oral Maxillofac Surg Clin North Am. 2020;32(1):135-51. doi:10.1016/j.coms.2019.09.003.
14. Eshghpour M, Shooshtari Z, Labafchi A, Radvar N, Tohidi E, Samieirad S. Does Mandibular Advancement Orthognathic Surgery Lead to TMJ Dysfunction in Skeletal Class 2 Patients? A Quasi-Experimental Trial in an Iranian Population. World J Plast Surg. 2022;11(1):51-8. doi:10.52547/wjps.11.1.51.
15. Jacobson R, Sarver DM. The predictability of maxillary repositioning in LeFort I orthognathic surgery. Am J Orthod Dentofacial Orthop. 2002;122(2):142-54. doi:10.1067/mod.2002.125576.
16. Kim J-W, Kim J-C, Jeong C-G, Cheon K-J, Cho S-W, Park I-Y, et al. The accuracy and stability of the maxillary position after orthognathic surgery using a novel computer-aided surgical simulation system. BMC Oral Health. 2019;19. doi:10.1186/s12903-019-0711-y.
17. Rekow ED, Speidel TM, Koenig RA. Location of the mandibular center of autorotation in maxillary impaction surgery. Am J Orthod Dentofacial Orthop. 1993;103(6):530-6. doi:10.1016/0889-5406(93)70093-4.
18. Ahn SJ, Tsou L, Antonio Sánchez C, Fels S, Kwon HB. Analyzing center of rotation during opening and closing movements of the mandible using computer simulations. J Biomech. 2015;48(4):666-71. doi:10.1016/j.jbiomech.2014.12.041.
19. Lou XT, Shen GF, Feng YM, Fang B, Wu Y, Zhu M. [Inter-relationship between mandibular rotation center and maxillary Le Fort I impaction osteotomies]. Shanghai Kou Qiang Yi Xue. 2014;23(6):704-7.
20. Moorehead JD, Montgomery SC, Harvey DM. Instant center of rotation estimation using the Reuleaux technique and a Lateral Extrapolation technique. J Biomech. 2003;36(9):1301-7. doi:10.1016/s0021-9290(03)00156-8.
21. Mehl A. Is it possible to detect a true rotation axis of the temporomandibular joint with common pantographic methods? A fundamental kinematic analysis. Comput Methods Biomech Biomed Engin. 2020;23(9):445-55. doi:10.1080/10255842.2020.1724975.
22. Naeije M, Huddleston Slater JJ, Lobbezoo F. Variation in movement traces of the kinematic center of the temporomandibular joint. J Orofac Pain. 1999;13(2):121-7.
23. Ferrario VF, Sforza C, Lovecchio N, Mian F. Quantification of translational and gliding components in human temporomandibular joint during mouth opening. Arch Oral Biol. 2005;50(5):507-15. doi:10.1016/j.archoralbio.2004.10.002.
24. Nattestad A, Vedtofte P, Mosekilde E. The significance of an erroneous recording of the centre of mandibular rotation in orthognathic surgery. J Craniomaxillofac Surg. 1991;19(6):254-9. doi:10.1016/s1010-5182(05)80066-6.
25. Shahbodaghi D, Hosseinzadeh Nik T, Akhundi M, Kavoosinejad S, Saffar a. Cephalometric Evaluation of Maxillary and Mandibular Centers of Rotation Subsequent to Maxillary and Mandibular Surgery. Iranian Journal of Orthodontics. 2020;In Press. doi:10.5812/ijo.102222.
26. Kim K, Choy K, Park YC, Han SY, Jung H, Choi YJ. Prediction of mandibular movement and its center of rotation for nonsurgical correction of anterior open bite via maxillary molar intrusion. Angle Orthod. 2018;88(5):538-44. doi:10.2319/102317-714.1.
27. Lindauer SJ, Sabol G, Isaacson RJ, Davidovitch M. Condylar movement and mandibular rotation during jaw opening. Am J Orthod Dentofacial Orthop. 1995;107(6):573-7. doi:10.1016/s0889-5406(95)70099-4.
28. Sanz PM, Reyes MG, Torras AB, Castillo JAC, Vich MOL. Craniofacial morphology/phenotypes influence on mandibular range of movement in the design of a mandibular advancement device. BMC Oral Health. 2021;21(1):19. doi:10.1186/s12903-020-01369-z.
29. Grogger P, Sacher C, Weber S, Millesi G, Seemann R. Identification of 'Point A' as the prevalent source of error in cephalometric analysis of lateral radiographs. Int J Oral Maxillofac Surg. 2018;47(10):1322-9. doi:10.1016/j.ijom.2018.03.019.
30. Leonardi R, Annunziata A, Caltabiano M. Landmark identification error in posteroanterior cephalometric radiography. A systematic review. Angle Orthod. 2008;78(4):761-5. doi:10.2319/0003-3219(2008)078[0761:Lieipc]2.0.Co;2.
31. 31.Muradin MS, Rosenberg A, van der Bilt A, Stoelinga PJ, Koole R. The reliability of frontal facial photographs to assess changes in nasolabial soft tissues. Int J Oral Maxillofac Surg. 2007;36(8):728-34. doi:10.1016/j.ijom.2007.05.010