Incidence and Effects of Posterior Cranial Vault Deformation in Adult Females With Skeletal Class III Malocclusion

Kouta Fujimoto (✉ k-fujimoto@dent.meikai.ac.jp)

Meikai University: Meikai Daigaku <https://orcid.org/0000-0003-2934-3691>

Au Sasaki

Meikai University: Meikai Daigaku

Akemi Kawajiri

Meikai University: Meikai Daigaku

Koji Yamaguchi

Meikai University: Meikai Daigaku

Takafumi Oshima

Meikai University: Meikai Daigaku

Yuri Togane

Meikai University: Meikai Daigaku

Yuichiro Otsuka

Meikai University: Meikai Daigaku

Naoto Suda

Meikai University: Meikai Daigaku

Research

Keywords: cranial vault, mandibular fossa, mandibular body length, masseter volume

Posted Date: November 22nd, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1064113/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Background

The precise characteristics of posterior cranial vault deformation are difficult to identify using a two-dimensional analysis. Recently, three-dimensional analysis using computed tomography (CT) data and software analysis has enabled us to examine the craniofacial structure precisely.

To identify the deformation in the cranial vaults by a three-dimensional analysis and examine its effects on other structures, CT data of skeletal mandibular protrusion cases without lateral deviation of pogonion (Pog) were examined.

Methods

Thirty-two adult female patients with skeletal mandibular protrusion who visited Meikai University Hospital were included in this study. CT images were taken before orthognathic surgeries, and the craniofacial structures were examined threedimensionally.

The lateral deviation of Pog was less than 3 mm in all cases.

Genetic/congenital anomaly cases, endocrine disorders, or cases with severe trauma or temporomandibular disorder were excluded.

Results

Many cases had three-dimensional deformations in the cranial vaults. The cranial vaults with unilateral posterior deformation had posteriorly positioned mandibular fossae on the same sides. Mandibular body lengths were related to the position of the mandibular fossae, and the posterior mandibular fossae tended to have longer mandibular body lengths on the same sides. Masseter muscles with larger volumes were related to longer mandibular body lengths.

Conclusions

Mandibular body lengths can compensate for the bilateral difference in the position of the mandibular fossae to avoid lateral deviation of the Pog. The masseter muscles are likely one of the factors related to the bilateral differences in the mandibular body length.

Background

Two-dimensional analysis has limitations in analyzing complicated and asymmetric structures.^{1,2} The cranial vault shape is known to present with an asymmetric appearance.³ In addition, there are variations in the shape and position of mandibular fossae among cases, which are difficult to analyze using two dimensional methods.⁴ Thus, three-dimensional (3D) analysis using computed tomography (CT) data is essential to examine these structures.

Previous studies have reported that skull shape is related to mandibular asymmetry.^{5,6} It has also been reported that asymmetric skull appearance is related to the displacement of the temporomandibular joint.⁷ This study aimed to clarify the relationship and arrangement of these craniofacial structures in cases with limited lateral deviation of the pogonion (Pog). We examined female cases with skeletal Class III malocclusion showing less than 3 mm of lateral deviation of the Pog. The findings demonstrated a wide variation in the cranial vault shape, position of the mandibular fossae, and mandibular body lengths. The characteristic arrangement of craniofacial structures, including masticatory muscles, are highlighted in this study.

Methods

The study protocol was reviewed and approved by the Ethics Committee of the Faculty of Dentistry, Meikai University (approval number: A1931, facility number: 11000689). Adult female patients with skeletal mandibular protrusion visited Meikai University Hospital from 2010 to 2018 were included in this study (Table 1). All patients underwent surgical mandibular setback after sagittal split ramus osteotomy, and lateral cephalograms and CT images were taken at the first visit or immediately before the orthognathic surgery. The lateral deviation of the Pog was less than 3 mm from the mid-sagittal reference plane on CT images in all cases. Genetic/congenital anomaly cases, endocrine disorders, or cases with severe trauma or temporomandibular disorder were excluded. All participants in this study met the following inclusion criteria: 1) SNA angle was within ± 1 standard deviation (SD) from the values of the Japanese adult female standard.⁸ 2) SNB angle was larger than the Japanese adult female standard and smaller than +3SD. 3) ANB angle was smaller than 0°. Thirty-two patients were selected as the participants in this study. CT images with 0.6 mm slices were obtained using SOMATOM Emotion 6 (Siemens Healthineers, Bayern) at 130 kVp and 63 mA. CT data were transferred in a Digital Imaging and Communication in Medicine format and 3D images were reconstructed.

On CT images, the reference planes and reference points were set using ProPlan CMF software (Materialize, Leuven, Belgium) (Figure 1). The shape of the cranial vault and the position of the mandibular fossa were evaluated according to a previous study (Figure 2).^{9,10} Mimics software (Materialize) was used to measure the length of the mandibular bodies and the volume of the masseter and medial pterygoid muscles (Figure 3). Mimics software automatically identified CT values in any range of the CT images, and CT values between 40-90 HU were used to extract the muscles.¹¹

Statistical analysis

The normality of the data was verified using the Shapiro–Wilk test. Some data didn't show normality. Thus, a nonparametric test was performed, and Spearman's rank correlation coefficient was examined. The Mann–Whitney U test was performed to examine the difference between two groups. The significance level was set to 5%.

Results

Interclass correlation coefficients were 0.93–0.99 for intraobserver reliability on 5 different days, and 0.91–0.99 for interobserver reliability by five examiners, indicating high reliability of measurements for hard and soft tissues. A previous study that examined the relationship between the muscle and skeletal measurements showed a correlation coefficient as 0.5.¹² The error probability was set at 0.05, and the power (1-b error probability) was set at 0.80. Using G-power, the minimum required sample size was estimated to be 26, which is smaller than that in this study.

The mean age of the participants was 24.2 ± 8.4 years (Table 1). The SNA angle ($82.4 \pm 1.9^\circ$) was comparable to the Japanese female standard. However, the ANB angle ($-2.5 \pm 1.9^\circ$) was much smaller than the Japanese female standard, owing to the large SNB angle ($84.9 \pm 2.4^\circ$).

The bilateral differences in the sagittal lengths of the cranial vaults are shown in Table 2. There was a significantly high negative correlation between SF and S20 ($r=-0.73$, $p<.001$), SF and S40 ($r=-0.73$, $p<.001$), and SF and S60 ($r=-0.71$, $p<.001$) (Figure 4).

The bilateral differences in the vertical lengths of the cranial vaults are shown in Table 3. Unlike the relationship between the bilateral difference in sagittal lengths of the cranial vaults and the bilateral difference in sagittal position of mandibular fossae, there was no significant correlation between VF and V20, VF and V40, or VF and V60 (Figure 5).

The bilateral difference in the transverse lengths of the cranial vaults and the bilateral difference in the transverse position of the mandibular fossae (TF) are shown in Table 4. There was no significant correlation between TF and T20, TF and T40, or TF and T60 (Figure 6).

Next, linear and arc lengths of the mandibular bodies were measured on both sides, and the bilateral differences were represented as lengths of D sides minus those of ND sides (Table 5). The linear and arc lengths were ranged from -3.6 to 6.2 mm and -6.1 to 6.0 mm, respectively. The relationship between the bilateral difference in mandibular body lengths and the bilateral difference in the sagittal position of mandibular fossae is shown in Figure 7. There were significant negative correlations between the bilateral difference in the mandibular body lengths and the bilateral difference in the sagittal position of the mandibular fossae ($r=-0.41$, $p<.05$, in both linear and arc lengths).

Finally, volumes of the medial pterygoid muscles and masseter muscles, attached to the mandibular bodies, were measured on both sides (Table 6). There was no significant correlation between the volumes of the medial pterygoid muscles and mandibular body lengths (Figure 8). However, there was a significant positive correlation between the masseter muscle volume and mandibular body length ($r=0.51$, $p<.01$ in linear lengths, and $r=0.46$, $p<.01$ in arc lengths).

Discussion

To evaluate head shape, cephalic index (CI)¹³ and cranial vault asymmetry index (CVAI)¹⁴ have been used. CI is calculated from measurements of head breadth and length. CVAI is calculated from the dual

cranial diagonal diameters, and represented as the difference between the longer and shorter diagonals at 30 degree from the center of the face. However, both of them can't evaluate the 3D deformation of cranial vaults. Moreover, to highlight the deformation in the posterior part of the cranial vaults, three reference planes were defined on the CT images. In determining the midsagittal plane for evaluating an asymmetric craniofacial structure, the use of a sagittal plane perpendicular to FH plane was recommended.¹⁵ The midsagittal plane passing through the Na and Ba and perpendicular to the FH plane is known to show the smallest difference among examiners in the measurement of menton deviation.¹⁵ Therefore, we took advantage of using the midpoint of the bilateral ends in the nasomaxillary suture (point M) and Ba. Regarding the frontal reference plane, we selected PoL as the reference point, which is located more posteriorly than the sella, and convenient for evaluating the posterior part of cranial vaults.

There was a significantly high correlation between the bilateral difference in the sagittal position of the mandibular fossae and the bilateral difference in the sagittal lengths of the cranial vaults. Thus, the position of the mandibular fossae was related to the deformation of the cranial vaults in the antero-posterior (A-P) dimension. The mandibular fossae are included in the temporal bones that form sphenoquamosal sutures with the sphenoid bones, squamous sutures with the parietal bones, and occipitomastoid suture with the occipital bones.^{4,516} All these sutures promote the posterior growth of cranial vaults and can be related to the A-P position of the mandibular fossae.¹⁷ However, a significant correlation between the bilateral difference in the position of the mandibular fossae and the bilateral difference in the cranial vault lengths was only observed in the A-P dimension but not in other dimensions. As shown in Tables 3 and 4, the range of the bilateral differences in the cranial vault lengths in the vertical and transverse dimensions was smaller than those in the A-P dimension. This less variety in the bilateral differences of the cranial vault shape would account for the insignificant relationship in vertical and transverse dimensions.

As shown in Figure 7, there were significant negative correlations between the bilateral difference in the mandibular body lengths and the bilateral difference in the sagittal position of the mandibular fossae. However, it has been reported that the mandibular ramus shape can affect the lateral deviation and asymmetry of mandibles.¹⁸ In this study, precise bilateral differences in ramus shape were not examined. Examination of each side of the ramus shape might provide a more precise explanation of the relationship between the position of the mandibular fossae and the mandibular shape.

There was a significant positive correlation between the masseter muscle volume and mandibular body length (Figure 8). It has been reported that there is a significant correlation between muscle volume and muscle force.¹⁹ Considering the direction and attachment of the masseter muscles, it is possible to speculate that larger masseter muscles can serve as more effective mechanical stimulators to promote mandibular growth (Figure 9). In contrast, there was no significant correlation between the volumes of the medial pterygoid muscles and mandibular body lengths. The mean volume of the medial pterygoid muscles was only 41.4% of that of the masseter muscles (Table 6). Smaller volumes of the medial pterygoid muscles might likely be less effective in promoting the growth of the mandibular body length.

This study has some limitations. First, the skeletal female mandibular protrusion patients who underwent orthognathic treatment were examined. This was because CT data were only available from present orthognathic cases. Thus, it is unknown whether the present findings can be applied to Angle Class I or Class II cases. Second, cone-beam CT was frequently used to obtain 3D images of hard tissues by a lower dose of radiation.²⁰ It is known that cone beam CT can provide accurate hard tissue images; however, it is inaccurate for soft tissues.²⁰ In this study, muscles, together with cranial and facial bones, were examined, and multislice CT was used to obtain images of both hard and soft tissues. Use of a 0.6 mm slice of CT data would provide some errors in the measurements. Third, it is still known that larger volumes of masseter muscles are the cause or effect of longer mandibular body lengths. It is difficult to deny that longer mandibular body lengths are accompanied by larger volumes of masseter muscles.

Conclusion

To clarify the 3D deformation in cranial vaults and examine its effect on other craniofacial structures, CT data of 32 skeletal mandibular protrusive females were examined. Many cases had 3D deformation in the cranial vaults. Cranial vaults with unilateral posterior deformation had posteriorly positioned mandibular fossae on the same side. Patients with posteriorly located mandibular fossae tended to have longer mandibular body lengths on the same side. The mechanical stress provided from the masseter muscles to the mandibular bodies possibly serves as a mechanical regulator to prevent lateral deviation of the Pog.

Declarations

Ethics approval and consent to participate

This retrospective case-control study was approved by the Ethics Committee of the Faculty of Dentistry, Meikai University (approval number: A1931, facility number: 11000689), and the requirement to obtain informed consent for participating in this study from the patients was waived.

Consent for publication

Not applicable

Availability of data and materials

The datasets analyzed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was supported by Grants-in-Aid for Scientific Research (18K09843 and 21K10194), from Japan Society for the Promotion of Science.

Authors' contributions

Conceptualization, K.F., A.S., Y.O. and N.S.; Investigation, K.F., A.K., K.Y., T.O and Y.T.; Data Curation, K.F., A.K. and K.Y.; Writing-Original Draft Preparation, K.F. and N.S.; Visualization, K.F., A.K. and K.Y.; Supervision, N.S.; Project Administration, K.F. and N.S.; Funding Acquisition, N.S.

Acknowledgements

Authors are grateful to Professor Shinji Kito (MUSD) for his valuable suggestions.

Authors' information

Not Applicable

References

Vig PS, Hewitt AB. Asymmetry of the human facial skeleton: *Angle Orthod.* 1975;45:125-129.

Grummons DC, Kappeyne van de Coppello MA. A frontal asymmetry analysis: *J Clin Orthod.* 1987;21:448-465.

Sasaki J, Hasegawa S, Yamamoto S, Watanabe S, et al. Relationship between facial asymmetry and positional plagiocephaly analyzed by three-dimensional computed tomography. *J Craniomaxillofac Surg.* 2020;48:193-198.

doi: <https://doi.org/10.1016/j.jcms.2019.12.011>

Jain A, Thenmozhi M. A study on morphology and morphometry of mandibular fossa. *Drug invention today.* 2018;10:2289-2292.

St John D, Mulliken JB, Kaban LB, et al. Anthropometric analysis of mandibular asymmetry in infants with deformational posterior plagiocephaly. *J Oral Maxillo fac Surg* . 2002 ; 60 : 873 - 877.

doi: <https://doi.org/10.1053/joms.2002.33855>

Moon IY, Lim SY, Oh KS. Analysis of facial asymmetry in deformational plagiocephaly using three-dimensional computed tomographic review. *Arch Craniofac Surg.* 2014;15:109-116.

doi: <https://doi.org/10.7181/acfs.2014.15.3.109>

Pirttiniemi P, Kantomaa T. Relation of glenoid fossa morphology to mandibulofacial asymmetry, studied in dry human Lapp skulls. *Acta Odontol Scand.* 1992;50:235-243.

doi: <https://doi.org/10.3109/00016359209012768>

Izuka T, Ishikawa F. Normal standards for various cephalometric analysis in Japanese adults. *J Jpn Orthod Soc*. 1957;16:4-12.

Kawajiri A, Sasaki A, Uesato T, et al. Three-dimensional analysis of cranial vault and position of mandibular fossa Part 1: Analysis of mandibular protrusion cases without asymmetry. *Jpn J Jaw Deform*. 2019;29:31-41.

doi: <https://doi.org/10.5927/jjdd.29.31>

Yamaguchi K, Sasaki A, Kawajiri A, et al. Three-dimensional analysis of cranial vault and position of mandibular fossa -Part 2. Analysis of asymmetric mandibular protrusion cases-. *Jpn J Jaw Deform*. 2020;30: 267–280.

doi: <https://doi.org/10.5927/jjdd.30.267>

Aubrey J, Esfandiari N, Baracos VE, et al. Measurement of skeletal muscle radiation attenuation and basis of its biological variation. *Acta Physiol (Oxf)*. 2014;210:489-497.

doi: <https://doi.org/10.1111/apha.12224>

Imamura K, Terajima M, Nakashima A, et al. A three-dimensional analysis of masticatory muscles in laterognathism. *Orthod Waves*. 2019;78:143-150.

doi : <https://doi.org/10.1016/j.odw.2019.09.010>

Loveday BP, de Chalain TB. Active counterpositioning or orthotic device to treat positional plagiocephaly?. *J Craniofac Surg*. 2001;12:308-313.

doi: 10.1097/00001665-200107000-00003

Kunz F, Schweitzer T, Große S, et al. Head orthosis therapy in positional plagiocephaly: longitudinal 3D-investigation of long-term outcomes, compared with untreated infants and with a control group. *Eur J Orthod*. 2019;41:29-37.

doi: <https://doi.org/10.1093/ejo/cjy012>

An S, Lee JY, Chung CJ, et al. Comparison of different midsagittal plane configurations for evaluating craniofacial asymmetry by expert preference. *Am J Orthod Dentofacial Orthop*. 2017;152:788-797.

doi: <https://doi.org/10.1016/j.ajodo.2017.04.024>

Pirttiniemi P, Kantomaa T, Tuominen M. Associations between the location of the glenoid fossa and its remodeling. An experimental study in the rabbit. *Acta Odontol Scand*. 1991;49:255-259.

doi: <https://doi.org/10.3109/00016359109005916>

Buschang PH, Santos-Pinto A. Condylar growth and glenoid fossa displacement during childhood and adolescence. *Am J Orthod Dentofacial Orthop*. 1998 ;113:437-442.

doi: <https://doi.org/10.3109/00016359109005916>

Hwang HS, Hwang CH, Lee KH, et al. Maxillofacial 3-dimensional image analysis for the diagnosis of facial asymmetry. *Am J Orthod Dentofacial Orthop*. 2006 ;130:779-785.

doi: <https://doi.org/10.1016/j.ajodo.2005.02.021>

Maughan RJ, Watson JS, Weir J. Strength and cross-sectional area of human skeletal muscle. *J Physiol*. 1983;338:37-49.

doi: <https://doi.org/10.1113/jphysiol.1983.sp014658>

van Vlijmen OJ, Maal T, Bergé SJ, et al. A comparison between 2D and 3D cephalometry on CBCT scans of human skulls. *Int J Oral Maxillofac Surg*. 2010;39:156-160.

doi: <https://doi.org/10.1016/j.ijom.2009.11.017>

Tables

Due to technical limitations, table 1, 2, 3, 4, 5 and 6 is only available as a download in the Supplemental Files section.

Figures

Fig 1

Figure 1

Reference points and planes on the CT image. A, Three reference planes. The horizontal reference plane was defined by the plane running through the right (PoR) and left Porion (PoL) and the left Orbitale (Or). The frontal reference plane was defined by the plane running through PoL, and perpendicular to the horizontal reference plane and the mid-sagittal reference plane. Or was defined as the most inferior point of the left orbit. The mid-sagittal reference plane was defined by the plane running through the M point (midpoint of bilateral ends denoted by black circles in nasomaxillary suture) and Basion, and perpendicular to the horizontal reference plane. B, Po was defined as the most superior point of the external ear. C, Basion (Ba) was the most anterior and inferior point of the foramen magnum.

Fig 2

Figure 2

Cranial vault length and position of the mandibular fossa. All D and ND denoted the pogonion (Pog) deviated side and Pog non-deviated side, respectively. A, Sagittal measures. s20 (D) and s20 (ND) denoted the intersections of the posterior end of cranial vault and sagittal planes having 20 mm distance from the mid-sagittal reference plane. s40 (D) and s40 (ND) denoted the intersections having 40 mm distance from the mid-sagittal reference plane. s60 (D) and s60 (ND) denoted the intersections having 60 mm distance from the mid-sagittal reference plane. S20 (D), S40 (D), S60 (D), S20 (ND), S40 (ND), and S60 (ND) represented the distances from s20 (D), s40 (D), s60 (D), s20 (ND), s40 (ND), and s60 (ND) to the frontal reference plane, respectively. B, Vertical measures. v20 (D) and v20 (ND) denoted the intersections of the posterior end of the cranial vault and sagittal planes having 20 mm distance from the mid-sagittal reference plane. v40 (D) and v40 (ND) denoted the intersections having 40 mm distance from the mid-sagittal reference plane. v60 (D) and v60 (ND) denoted the intersections having 60 mm distance from the mid-sagittal reference plane. V20 (D), V40 (D), V60 (D), V20 (ND), V40 (ND), and V60 (ND) represented the distances from v20 (D), v40 (D), v60 (D), v20 (ND), v40 (ND), and v60 (ND) to the horizontal reference plane, respectively. C, Transverse measures. t20 (D) and t20 (ND) denoted the

intersections of the posterior end of the cranial vault and sagittal planes having 20 mm distance from the frontal reference plane. t40 (D) and t40 (ND) denoted the intersections having 40 mm distance from the frontal reference plane. t60 (D) and t60 (ND) denoted the intersections having 60 mm distance from the frontal reference plane. T20 (D), T40 (D), T60 (D), T20 (ND), T40 (ND), and T60 (ND) represented the distances from t20 (D), t40 (D), t60 (D), t20 (ND), t40 (ND), and t60 (ND) to the mid-sagittal reference plane, respectively. D and E, F (ND) and F (D) were defined as the most superior points in the mandibular fossae in the frontal (D) and sagittal (E) CT images. SF (D) and SF (ND) represented the distances from F (D) and F (ND) to the frontal reference plane, respectively. VF (D) and VF (ND) represented the distances from F (D) and F (ND) to the horizontal reference plane, respectively. TF (D) and TF (ND) represented the distances from F (D) and F (ND) to the mid-sagittal reference plane, respectively.

Fig 3

Figure 3

Linear and arc lengths of the mandibular body. A and B, Pog was defined as the most protruded point of the mental protuberance in the horizontal (A) and sagittal (B) CT images. C, Go was defined as the intersection of the mandibular angle and the bisector of the ramus plane (white solid line) and the mandibular plane (white solid line). D and E, Linear distance between the Pog and Go was the direct length of these two points (linear length). Curve distance between the Pog and Go was the shortest length of these two points on the mandibular body surface (arc length). Both linear and arc lengths were measured on the Pog deviated (Pog-Go (D)) and non-deviated sides (Pog-Go (ND)).

Fig 4

Figure 4

Correlation between the bilateral difference in sagittal lengths of the cranial vaults (S20, S40, and S60) and the bilateral difference in the sagittal positions of the mandibular fossae (SF).

Fig 5

Figure 5

Correlation between the bilateral difference in vertical lengths of the cranial vaults (V20, V40, and V60) and the bilateral difference in the vertical positions of the mandibular fossae (VF).

Fig 6

Figure 6

Correlation between the bilateral difference in transverse lengths of the cranial vaults (T20, T40, and T60) and the bilateral difference in the transverse positions of the mandibular fossae (TF).

Bilateral difference in sagittal position of mandibular fossae (mm)

Bilateral difference in linear lengths of mandibular bodies (mm)

Bilateral difference in arc lengths of mandibular bodies (mm)

Fig 7

Figure 7

Correlation between the bilateral difference in the mandibular body lengths and bilateral difference in the sagittal positions of the mandibular fossae.

Fig 8

Figure 8

Correlation between the mandibular body lengths (linear and arc lengths in left and right, respectively) and masticatory muscle volumes.

Fig 9

Figure 9

Summary of findings A, Deformation of the posterior cranial vault. The cranial vault with larger deformation is associated with a more posteriorly located mandibular fossa on the same side. B: Masseter muscle attached to the mandibular body. To prevent lateral deviation of the pogonion (Pog), the posteriorly located mandibular fossa is associated with a longer mandibular body and larger masseter muscle, which can evoke a larger mechanical stimulation.

Fig 10

Figure 10

Please see the Manuscript file for the complete figure caption.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Tables.pptx](#)