

Three-dimensional Jarabak ratio measurement and vertical evaluation in adult patients based on CBCT

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Research Article

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Abstract

Objective

This study aimed to investigate the 3D Jarabak ratio and evaluate vertical skeletal patterns in adult patients using CBCT.

Materials and methods

CBCT scans of 97 pre-treatment adult patients were retrospectively selected and imported into MIMICS software. Following 3D model construction, the Jarabak ratio and FH-PP, FH-OP, and FH-MP angles were measured in three dimensions. All measurements were performed twice by two experienced examiners. Reliability and variable correlations were evaluated. Additionally, the 3D Jarabak ratio was compared among normodivergent, hyperdivergent, and hypodivergent groups, which were classified based on their 2D cephalometric FH-MP angles.

Results

High measurement reliability was confirmed, with all ICCs above 0.85 and the 3D Jarabak ratio ICCs exceeding 0.90. A significant positive correlation was observed between FH-MP and FH-OP. The 3D Jarabak ratio correlated negatively with both FH-OP and FH-MP. No significant correlation was found between FH-PP and the other variables. Group comparisons revealed a significantly larger 3D Jarabak ratio in the hypodivergent group compared to the normodivergent ($P < 0.001$) and hyperdivergent ($P = 0.001$) groups, with no significant difference between the latter two.

Conclusions

The CBCT-based 3D Jarabak ratio demonstrates sufficient reliability and effectively reflects the spatial divergence of the mandibular and occlusal planes. While this ratio effectively identifies hypodivergent skeletal patterns, it cannot clearly differentiate between normodivergent and hyperdivergent groups.

Clinical Relevance:

Integrating this 3D Jarabak ratio measurement into routine analysis provides valuable reference for vertical skeletal diagnosis, facilitating more comprehensive spatial evaluation and individualized treatment planning in adult orthodontics.

Introduction

Three-dimensional (3D) evaluation of patients' facial skeletal pattern has been recognized as an indispensable part of diagnosis and treatment planning in orthodontics and orthognathic surgery [1]. While all three spatial dimensions are important, the vertical dimension has consistently been a primary focus due to its influence on facial aesthetics, growth patterns [2], and treatment outcomes [3, 4].

Two-dimensional (2D) cephalometrics, initially introduced by Broadbent and Hofrath in 1931, has been a fundamental and routinely used assessment tool throughout the orthodontic treatment process [5]. Among the commonly used 2D quantitative measurements, the most widely used variables include FH-MP, FH-OP, and FH-PP. Previous studies have shown that angular measurements are easily affected by local bone modeling [6], whereas the Jarabak ratio (SGo/NMe) reflects a more fundamental and overall vertical growth trend [7]. The Jarabak ratio has been another important variable of vertical evaluation, and commonly applied in routine clinical diagnosis and orthodontic research [8].

With the advent and widespread clinical use of cone-beam computed tomography (CBCT) over the past two decades [9], an increasing number of studies have focused on 3D cephalometric analysis [10]. Studies have confirmed that linear and angular measurements derived from 3D CBCT models are more accurate and reliable than 2D cephalometric analysis [11, 12], and can be used as a supplementary option to support conventional cephalometric measurements [13]. Furthermore, quantitative comparisons between CBCT and reconstructed lateral cephalograms have shown that CBCT provides a more reliable representation of anatomical structures and reduces bias associated with planar projection [14].

Despite the advantages of 3D imaging, the lack of standardized and widely accepted protocols for 3D vertical assessment has limited its routine use in clinical research [15, 16]. Consequently, many contemporary studies continue to rely on traditional 2D cephalometric measurements for vertical evaluation, even when CBCT data are available [17, 18, 19]. Current studies of 3D vertical evaluation tend to rely on true 3D linear distances measurements [20] and angular measurements which are derived from the intersections of anatomical reference planes [21, 22]. Nevertheless, the 3D Jarabak ratio has not yet been evaluated. It remains essential to establish validated and standardized protocols for 3D vertical cephalometric analysis [23].

Based on these considerations, this study aimed to assess the reliability of the 3D Jarabak ratio measurement using CBCT, explore its correlations with other vertical parameters, and compare its differences among adult patients with different vertical skeletal patterns.

Material and Methods

This study was approved by the Research Ethics Committee of Qingdao Municipal Hospital (NO. 2026-KY-137-143) and complies with the Declaration of Helsinki. Initial CBCT scans were selected from the orthodontic patient database at the Department of Stomatology, Qingdao Municipal Hospital. The inclusion criteria were as follows: (1) Adult patients with permanent dentition (age > 18), (2) all teeth erupted to the occlusal plane with no teeth missing. The exclusion criteria were as follows: (1) any of the

first molars and the first bicuspid have large restoration or extensive wear; (2) acquired or inherited dentofacial deformities, including cleft, craniofacial syndrome, or posttraumatic deformity, (3) craniofacial asymmetry, including obvious mandibular deviation (the distance from Me to the midsagittal plane larger than 2 mm) [24], (4) previous orthodontic, orthopedic, or orthognathic treatment.

Power analysis was performed using Power Analysis and Sample Size (PASS, version 15.0; NCSS, LLC, Kaysville, Utah) software based on a Spearman rank correlation. Based on previously reported correlations among vertical cephalometric parameters, which typically range from weak to moderate strength ($r \approx 0.2-0.6$) [25], the assumed effect size ($\rho = 0.35$) was chosen to strike a balance between clinical relevance and statistical power [26]. Using this effect size, along with a two-sided significance level of 0.05 and a desired power of 0.90, the required sample size was calculated to be eighty-two. Ultimately, Ninety-seven patients (twenty-eight males and sixty-nine females, mean age 24.61 ± 6.16 years) were included in this study.

CBCT scans (i-CAT model 17–19; Imaging Sciences International, Hatfield, Pa) were retrospectively selected from the database of patients’ initial visit records. The scanning settings were as follows: 120 kV, 5 mA, exposure time of 10 s, voxel size of 0.25 mm, axial slice thickness of 0.3 mm, and scanning area of head and neck. The digital imaging and communications in medicine (DICOM) data were exported and transferred into Materialise’s interactive medical image control system (MIMICS, version21.0; Materialise, Leuven, Belgium) software. 3D virtual models of the skulls were reconstructed, and the head positions were reoriented. Subsequently, following the instruction of Swennen et al. [27], the points were located firstly and directly on the 3D models, then calibrated in axial, coronal, and sagittal views, respectively. The locations and definitions of the points were shown in Figure I and Table I. Since a plane is geometrically defined by three points in 3D space, the 3D measurement planes for this study were constructed and defined as shown in Figure II and Table II.

Figure I. The measuring points on 3D reconstructed models. A, frontal view. B, posterior view. C, right lateral view. D, left lateral view.

Figure II. The 3D measuring planes. A, FH, PP, OP, and MP. B, FH and MSP.

Table I. The definitions of three-dimensional landmarks.

Points	Definitions
Sella turcica (S)	The central point of the hypophyseal fossa
Left Gonion (GoL)	The point at left mandibular angle that is defined by dropping a perpendicular from the intersection point of the tangent lines to the posterior margin of the left mandibular vertical ramus and inferior margin of the left mandibular body
Right Gonion (GoR)	The point at right mandibular angle that is defined by dropping a perpendicular from the intersection point of the tangent lines to the posterior margin of the right mandibular vertical ramus and the inferior margin of the right mandibular body
Menton (Me)	The most inferior midpoint of the chin on the outline of the mandibular symphysis
Nasion (N)	The midpoint of the frontonasal suture
Anterior nasal spine (ANS)	The most anterior midpoint of the anterior nasal spine of the maxilla
Left posterior nasal spine point (LPNS)	The point of maximum concavity of the posterior border of the palatal bone in the horizontal plane at the left side
Right posterior nasal spine point (RPNS)	The point of maximum concavity of the posterior border of the palatal bone in the horizontal plane at the right side
Right first molar point (R6)	The occlusal point of the mandibular right first molar
Left first molar point (L6)	The occlusal point of the mandibular left first molar
Right first premolar point (R4)	The occlusal point of the mandibular right first premolar
Left Orbitale (LOR)	The most inferior point of the left infra-orbital rim
Right Orbitale (ROr)	The most inferior point of the right infra-orbital rim
Porion (Po)	The most superior point of left external acoustic meatus

Table II. The definitions of three-dimensional measuring planes.

Planes	Definitions
Frankfort horizontal plane (FH)	Connecting the LOr, ROr, and Po
Palatal plane (PP)	Connecting ANS, LPNS, and RPNS
Functional occlusal plane (OP)	Connecting R6, R4, and L6 [28]
Mandibular plane (MP)	Connecting GoL, GoR and Me
Mid-sagittal plane (MSP)	A plane constructed through the S-N line and perpendicular to the Frankfort horizontal (FH) plane

The definitions of 3D linear and angular measurements were shown in Table III. An innovative 3D Jarabak ratio analysis protocol was introduced. Firstly, considering the mandibular transverse variations, the NMe should not be the direct 3D distance from point N to point Me, but the projected length of it on the MSP. Secondly, the SGo was calculated through three directly measured 3D distances: SGoL, SGoR, and GoLGoR; the distance between the point S and the midpoint of bilateral Go could be calculated to be the final variable SGo (The calculation protocol was shown in Table III and Figure III). Thirdly, the Jarabak ratio could be accurately calculated through SGo/NMe, despite the bias in the transverse dimension in this way.

Figure III. A and B, the 3D measurements and calculation of SGo (the blue line). C and D, the NMe (the green line) is the projected length of direct 3D N-Me distance on the MSP.

Table III. The definitions of three-dimensional linear and angular measurements

Measurements	Definitions
FH-PP	Three-dimensional angulation between the FH plane and the PP plane
FH-OP	Three-dimensional angulation between the FH plane and the OP plane
FH-MP	Three-dimensional angulation between the FH plane and the MP plane
SGoL	The three-dimensional distances from S to GoL
SGoR	The three-dimensional distances from S to GoR
GoLGoR	The three-dimensional distances from GoL to GoR
SGo	The distance from S to the midpoint of the bilateral gonion points (the blue line in Figure III), was subsequently calculated using SGoL, SGoR and GoLGoR, based on geometric relationships within a triangle.
NMe	Measure the direct 3D distance from N to Me, then measure the distance from Me to MSP, then the vertical component of the 3D N-Me distance was calculated using the Pythagorean theorem.
Jarabak ratio	Jarabak growth pattern evaluation, defined as the ratio of posterior facial height to anterior facial height (SGo/NMe)

Landmark identification and 3D measurements were performed by two practiced researches (examiner 1 Fangshuo Wang and examiner 2 Chunxi Zhang) two times, with a time interval of two weeks. The means of the measurements of two examiners and two times each were calculated for subsequent analysis.

The intraclass correlation coefficients (ICCs; 2-way random, single measurements) were used to assess the intra-examiner and inter-examiner reliability. The agreement was classified according to the following ICCs [29]: excellent (0.9), good (0.75–0.9), moderate (0.5–0.75), or poor (< 0.5).

The Shapiro-Wilk tests were performed to test the normal distribution. All of the measurements were all normally distributed. Therefore, Pearson correlation coefficient analyses were performed to assess the correlation among the six variables.

Based on the vertical facial growth pattern, the subjects were divided into three groups according to the 2D FH-MP angle (the angle formed by the intersection of the Frankfort horizontal plane and the mandibular plane) as originally described by Tweed [30]. The samples were classified into hypodivergent group (47 samples) with $\text{FH-MP} \leq 22^\circ$; normodivergent group (29 samples) with $22^\circ < \text{FH-MP} < 28^\circ$; and hyperdivergent group (21 samples) with $\text{FH-MP} \geq 28^\circ$ [31, 32]. The data for all three groups were normally distributed (Shapiro-Wilk test, $P > 0.05$). The means and standard deviations for the hypodivergent, normodivergent, and hyperdivergent groups were $17.66^\circ \pm 3.31^\circ$, $24.91^\circ \pm 1.75^\circ$, and $31.21^\circ \pm 3.28^\circ$, respectively. But the assumption of homogeneity of variances was violated according to Levene's test ($P < 0.05$). Considering the unequal variances and the unbalanced sample sizes among the groups, Welch's ANOVA was utilized to compare the means. Subsequently, the Games-Howell test was chosen for post hoc multiple comparisons.

Results

The ICCs were all above 0.85, with the Jarabak ratio ICCs all above 0.9, indicating sufficient reliability. The descriptive statistics and ICCs were shown in Table IV.

Table IV. Descriptive statistics and reliability of three-dimensional cephalometric measurements

Variables	Descriptive statistics	Intra-examiner 1 ICC (95%CI)	Intra-examiner 2 ICC (95%CI)	Inter-examiner ICC (95%CI)
FH-OP (°)	3.07 ± 4.58	0.897 (0.850–0.930)	0.906 (0.863–0.936)	0.926 (0.892–0.950)
FH-PP (°)	-6.45 ± 3.49	0.854 (0.752–0.910)	0.919 (0.879–0.945)	0.889 (0.816–0.930)
FH-MP (°)	19.62 ± 5.27	0.955 (0.933–0.970)	0.966 (0.949–0.977)	0.953 (0.920–0.971)
Jarabak ratio	0.67 ± 0.04	0.929 (0.895–0.952)	0.909 (0.866–0.938)	0.958 (0.936–0.972)

As for the results of Pearson correlation coefficient analyses, correlations with $P < 0.01$ were considered statistically significant. The FH-MP and FH-OP were significantly and positively related. The significant and negative correlations were found between Jarabak ratio and FH-OP, Jarabak ratio and FH-MP. No significant correlation was found between FH-PP and any other variables. The correlation coefficients were presented in Table V.

Table V. Correlation coefficients among six variables

variable	1	2	3	4
1.FH-OP	-			
2.FH-PP	0.088	-		
3.FH-MP	0.542*	0.107	-	
4.Jaraback	-0.416*	0.007	-0.781*	-

*:Indicates a statistical significance at $P < 0.01$

Welch's ANOVA revealed a highly significant difference in the 3D Jarabak ratio among the three groups ($P < 0.001$). Further post hoc pairwise comparisons using the Games-Howell test demonstrated that the 3D Jarabak ratio in the hypodivergent group was significantly greater than those in both the normodivergent group ($P < 0.001$) and the hyperdivergent group ($P = 0.001$). However, no statistically significant difference was observed between the normodivergent and hyperdivergent groups ($P = 0.392$) (Table VI).

Table VI. Pairwise comparisons of the 3D Jarabak ratio among the three vertical relationship groups (Games-Howell post hoc test).

Comparison	Difference	95% Confidence Interval (CI)	P value
Hypodivergent vs. Normodivergent	0.0367 ± 0.0073	0.0192–0.0543	< 0.001*
Hypodivergent vs. Hyperdivergent	0.0541 ± 0.0131	0.0217–0.0864	0.001*
Normodivergent vs. Hyperdivergent	0.0173 ± 0.0131	-0.0150-0.0497	0.392

* Statistically significant difference ($P < 0.05$). Overall comparison was performed using Welch’s ANOVA ($P < 0.001$).

Discussion

Reliability is fundamental before any diagnostic tool is clinically applied. In the present study, both intra-examiner and inter-examiner ICCs demonstrated excellent reproducibility for all evaluated variables. Notably, the newly proposed 3D Jarabak ratio measurements exhibited exceptional stability, with intra-examiner and inter-examiner ICCs all exceeding 0.90. This high level of agreement indicates that the landmark identification required for our 3D method is straightforward and highly consistent. The FH-PP showed slightly lower ICCs (ranging from 0.854 to 0.919) compared to FH-MP and the Jarabak ratio. This minor variation can be attributed to the anatomical characteristics and technical challenges associated with defining the bilateral posterior nasal spines (PNS). Due to the inherently thin structure of the palatine bone horizontal plate, software masking and 3D reconstruction often yield an incomplete rendering of its posterior border. Although multi-planar 2D views (sagittal, coronal, and axial) were used to manually correct and verify the PNS localization, the reproducibility remained slightly affected. Future studies could use AI-driven algorithms for automated landmarking to reduce subjective errors and improve localization accuracy.

Clear Correlations were found among the measured parameters: FH-MP, FH-OP and Jarabak ratio were all significantly correlated with one another, with the Jarabak ratio negatively correlated with FH-OP and FH-MP, which is in agreement with the results of previous 2D studies [33]. Nevertheless, the FH-PP angle showed no significant correlation with any of the other variables, suggesting that the FH-PP angle may be less appropriate for evaluating the overall cranial vertical relationship, acting instead as an isolated reflection of local maxillary morphology. Therefore, to achieve a precise 3D vertical diagnosis, clinicians should evaluate overall skeletal divergence independently from isolated local variations, ensuring each parameter is interpreted within its specific diagnostic scope.

In this study, subjects were classified into hypodivergent, normodivergent, and hyperdivergent vertical skeletal pattern based on the 2D FH-MP, which remains the most universally adopted standard for vertical skeletal classification in both routine clinical practice and orthodontic literature [30, 34]. Utilizing a 2D angular measurement as the grouping criterion and a 3D spatial linear proportion as the evaluation

metric ensures methodological independence and effectively precludes the risk of circular reasoning. The results revealed that the 3D Jarabak ratio significantly differentiated the hypodivergent group from the remaining subjects, not only demonstrating its diagnostic sensitivity for vertical discrepancies, but also reflecting the true skeletal framework by minimizing local morphological variations [8]. Nevertheless, no significant statistical difference was observed between the normodivergent and hyperdivergent group. The unique pattern of differences revealed among the three groups warrants a deeper exploration. Although hyperdivergent patients typically present a steep mandibular plane in 2D images, their actual 3D morphology often involves compensatory transverse flaring or twisting of the gonial region. These anatomical compensations mask the vertical differences, resulting in similar S-Go distances [20]. Conversely, it is well documented that hypodivergent individuals typically exhibit increased masticatory muscle mass and higher bite forces than normodivergent and hyperdivergent patients [35]. This heavy muscular loading induces marked bone apposition, creating a broader and more squared ramus and gonial angle [36]. This strong muscle-bone interaction explains why the 3D morphology of the hypodivergent group differs so significantly from the others, whereas the anatomical transition between normodivergent and hyperdivergent profiles is relatively gradual.

Furthermore, a relatively unbalanced sample size among the groups were presented in this study, with the hypodivergent group comprising the largest number of subjects ($n = 47$) and the hyperdivergent group the smallest ($n = 21$). This might have reduced the statistical power, which could partially explain the lack of a significant difference in the 3D Jarabak ratio between the normodivergent and hyperdivergent groups. Future studies with larger and more balanced sample cohorts are recommended to verify these findings.

To ensure that all measurements strictly reflected true vertical discrepancies, the confounding influence of transverse deviation was systematically minimized. Methodologically, patients with evident craniofacial asymmetry were excluded to avoid the coronal canting of the MP, OP, and PP [37], which would distort true sagittal inclinations into a combination of anteroposterior tilt and coronal canting. Furthermore, to account for the natural, minor transverse variations present even in symmetric individuals, anterior facial height (N-Me) was not measured as a direct 3D point-to-point distance, as done by Sahlsten et al. [38]. Instead, N-Me was calculated as a projection onto the mid-sagittal plane. This approach helps to better isolate the vertical dimension, thereby minimizing the confounding effect of minor lateral deviations.

There are some limitations of our study. First of all, the samples were selected from the database of patients with malocclusion; consequently, the findings of this study do not allow for the establishment of normative ranges. Second, ethnically diverse populations should be incorporated, and multi-center researches and larger sample size should be carried on to enhance generalizability. In the future, artificial intelligence can assist with 3D landmarking and vertical assessment, facilitating more efficient measurement and diagnosis in clinical practice.

Conclusions

The CBCT-based 3D Jarabak ratio demonstrates sufficient reliability and effectively reflects the spatial divergence of the mandibular and occlusal planes. While this ratio effectively identifies hypodivergent skeletal patterns, it cannot clearly differentiate between normodivergent and hyperdivergent groups.

Abbreviations

CBCT

Cone-beam computed tomography

3D

three-dimensional

2D

Two-dimensional

DICOM

digital imaging and communications in medicine

PASS

Power Analysis and Sample Size

ICCs

intraclass correlation coefficients. The abbreviations of the measured variables were shown in Table I and II.

Declarations

Preprint Declaration

A prior version of this manuscript was deposited as a preprint on Research Square. DOI: <https://doi.org/10.21203/rs.3.rs-8984975/v1>. The current submission has been substantially revised and updated.

Preprint Statement

An earlier version of this manuscript was posted as a preprint on Research Square and can be accessed via DOI: <https://doi.org/10.21203/rs.3.rs-8984975/v1>. The current submission has been substantially revised and updated.

Ethics approval and consent to participate

This study was approved and registered as a project by the Shandong Provincial Health Commission (Shandong Provincial Medical and Health Science and Technology Youth Project, No. 202308030346), ethical review had already been conducted by the Ethics Committee of Qingdao Municipal Hospital prior to project application. In 2026, the ethics committee issue a separate approval reference number (NO. 2026-KY-137-143) for this study. This study complies with the Declaration of Helsinki, and the written informed consents were received from the patients.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Fangshuo Wang contributed to methodology, investigation, repeat measurements, and original draft preparation; Liying Chen contributed to investigation and statistical analysis; Xiao Xu contributed to data acquisition and supervision. Rongtao Yuan contributed to the original draft, figures, and tables preparation; Chunxi Zhang contributed to conceptualization, methodology, project administration, manuscript review, and editing.

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Not applicable

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Figures

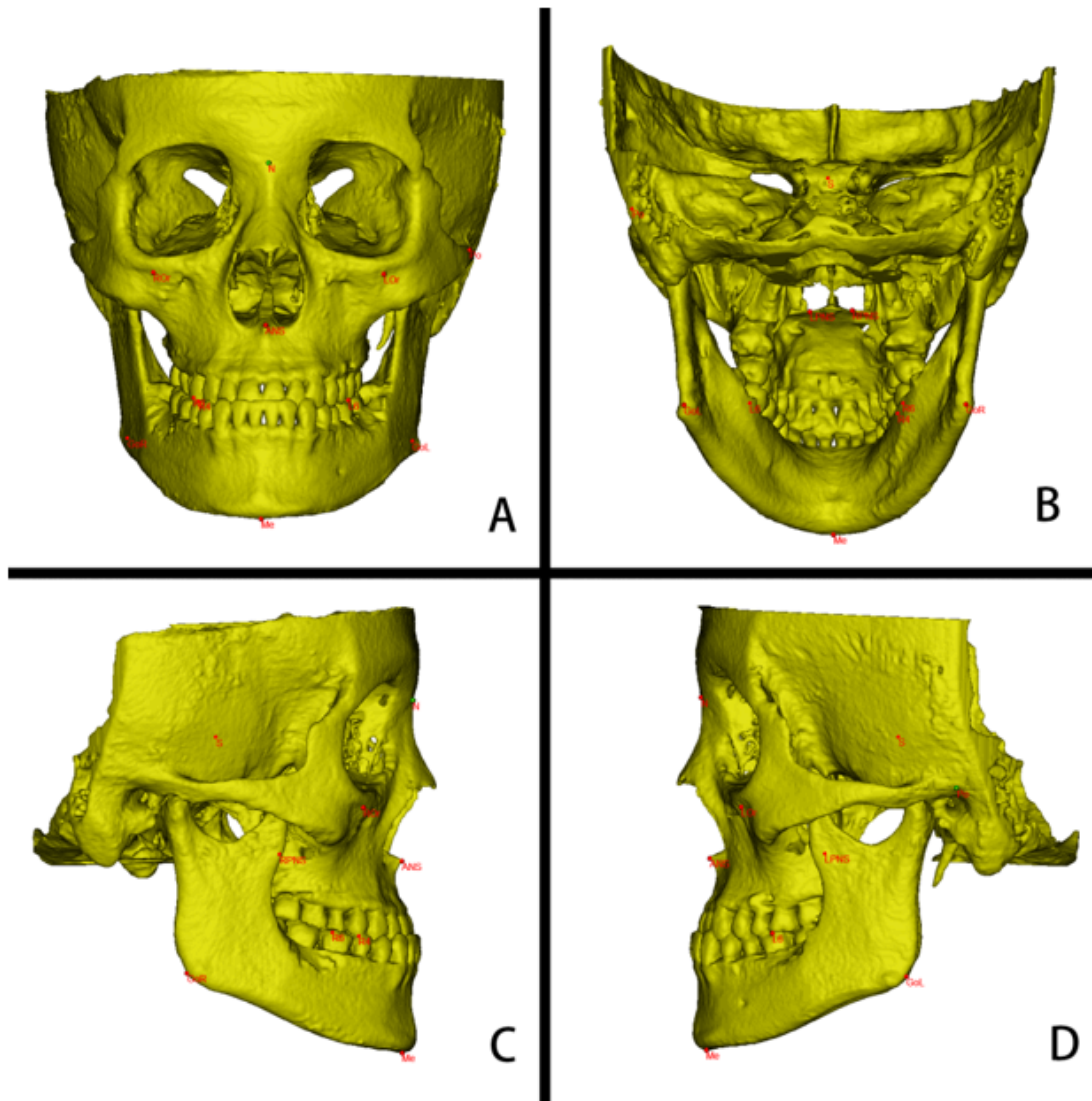


Figure 1

The measuring points on 3D reconstructed models. A, frontal view. B, posterior view. C, right lateral view. D, left lateral view.

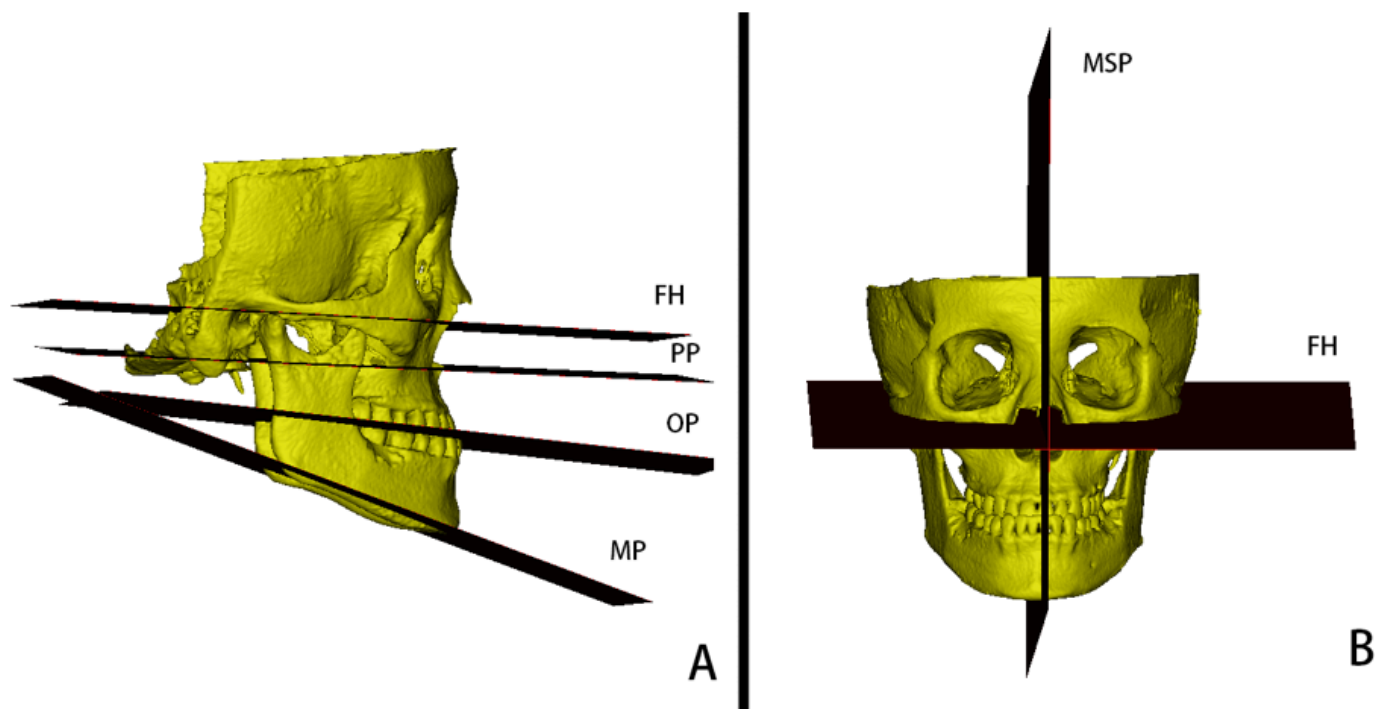


Figure 2

The 3D measuring planes. A, FH, PP, OP, and MP. B, FH and MSP.

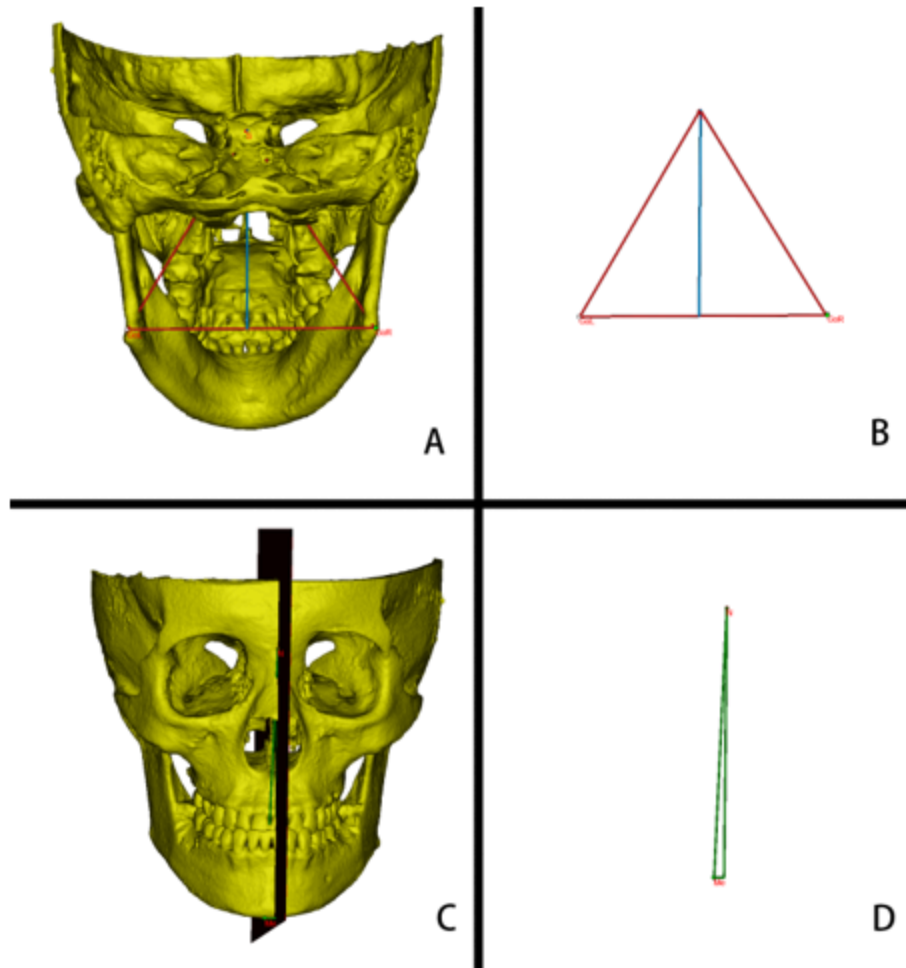


Figure 3

A and B, the 3D measurements and calculation of SGo (the blue line). C and D, the NMe (the green line) is the projected length of direct 3D N-Me distance on the MSP.