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Quantitative evaluation of symmetric alignment of the mandible with the mid-sagittal plane using a new 3D cephalometric approach

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1. Introduction

Three-dimensional (3D) computed tomography (CT) or cone beam CT (CBCT) scans are now routinely used for the planning of computer-assisted orthognathic surgery procedures. One key element of this planning is the assessment of the symmetric alignment of the mandible with respect to the mid-sagittal plane.

The first steps of this virtual planning usually consist in the segmentation of the facial units to obtain 3D models which are then annotated with cephalometric landmarks. Those annotations are used to reorient the models and perform a quantitative evaluation of facial symmetry.

One way to assess the position of each facial unit is to build local coordinate system (LCS) for each unit and compare its orientation to the world coordinate system (WCS) of the cranial base (Gateno et al. 2011).

Several reports demonstrated that the 3D landmarks manually localized on curved structures with no clear boundaries should be used clinically with caution (Lagravère et al. 2010; Dot et al. 2022). On the contrary, recent reports showed that both manual and automatic localization of landmarks on bilateral craniofacial foramens exhibited an excellent reliability

(Dot et al. 2022). To our knowledge, the use of foraminal landmarks for the quantitative evaluation of symmetric mid-sagittal alignment of the mandible has not been proposed yet.

The main goal of this study was to measure the reliability and relevance of the assessment of symmetric alignment of the mandible along the mid-sagittal plane, using both classical and foraminal landmarks in healthy volunteers and orthognathic surgery patients.

2. Materials and Methods

2.1 Database characteristics

Our database was comprised of two groups of subjects: (1) 80 asymptomatic volunteers (54 F / 36 M) - age range 17-67 and (2) 452 presurgical patients exhibiting dento-maxillo-facial deformities (208 F / 244 M) - age range 14 – 66. CT scans of the whole head were acquired for each subject. The level of asymmetry of the mandible with regards to the skull mid-sagittal plane was evaluated qualitatively for each orthognathic surgery subject by an experienced orthodontist as none (n=289), moderate (n=108), or severe (n=39).

2.2 Manual and automatic landmarking

Landmarking of 33 anatomical points on the preoperative subjects was performed manually twice by 3 experienced operators on 20 randomly selected CT scans and once by one experienced operator on 178 other scans. Landmarking of the remaining 254 presurgical subjects and the 80 asymptomatic subjects was performed automatically (Dot et al. 2022).

2.3 Quantitative measurements

The landmarks were used to define an upper skull WCS based on the following landmarks: right/left porions; left orbitale, sella and nasion. The first 3 landmarks were used to construct the Frankfurt plane, from which we obtained the z-axis. The x-axis was calculated as the normalized vector from the projection of the sella (P1) to the projection of the nasion (P2) on the Frankfurt plane. Then, the y-axis was calculated by using the cross product between x and z. Finally, the origin of this coordinate system was chosen as P1. The mid-sagittal plane is computed by rotating the Frankfurt plane by 90° twice, once around y-axis then around z-axis. The mandibular LCS was defined using both mental foramens, the B point, the pogonion, the gnathion, and the menton. The origin of this coordinate system was the barycenter of these 6 points. The z-axis was defined by the normed vector between the barycenter of the pogonion, gnathion, and menton landmarks and the B point. A temporary y-axis was

constructed thanks to the normalized vector between the right and left foramen. The x-axis was calculated thanks to the cross product of the latter two vectors. Finally, the orientation of the y-axis was refined by taking the cross product of the x- and z-axis, ensuring orthogonality and proper alignment within the coordinate system.

The mediolateral translation (-Y axis) of the mandible, as well as the rotations (-X axis and -Z axis) were computed and reported as measurements of the asymmetry.

2.4 Evaluation

The repeatability and reproducibility (R&R) of these measurements was evaluated on the 20 CT annotated by the three experts following the guidelines of the ISO norm 5725-2. The measurements of asymmetry were compared between the symmetric, moderate and severe asymmetric group using an appropriate ANOVA method followed by pairwise comparison.

3. Results and discussion

3.1 Repeatability and reproducibility of measurements

Translation measurements along the y-axis had a 95% confidence interval (CI) of R&R inferior to 1.5mm and rotation measurements along the x and z-axes had a 95% CI of R&R limited to under 4° (Table 1).

Table 1. 95% confidence interval (2*SD) of R&R of the asymmetry measures.

	Repeat. 2*SD	Repro. 2*SD
Translation -Y (mm)	0.5	1.3
Rotation -X (°)	2.7	3.7
Rotation -Z (°)	0.8	1.3

SD: standard deviation; Repeat.: repeatability; Repro.: reproducibility

3.2 Variability between asymmetry groups

Considering the non-normality of some of our samples, we performed a Kruskal-Wallis test. Significant differences between at least 2 groups ($p < 0.01$) were found for each measure: y-axis translation, x- and z-axis rotation. As shown on Figure 1, almost all groups were significantly different from one another for y-axis translation.

3.3 Discussion

In addition to classical landmarks, we used reliable foramina landmarks to construct the mandibular LCS, which was then used to calculate the symmetric alignment of the mandible with the mid-sagittal plane. Our measures were limited to translation along the y-

axis and rotation along the x-axis and z-axis. These measures seem consistent with the expertly assessed levels of asymmetry.

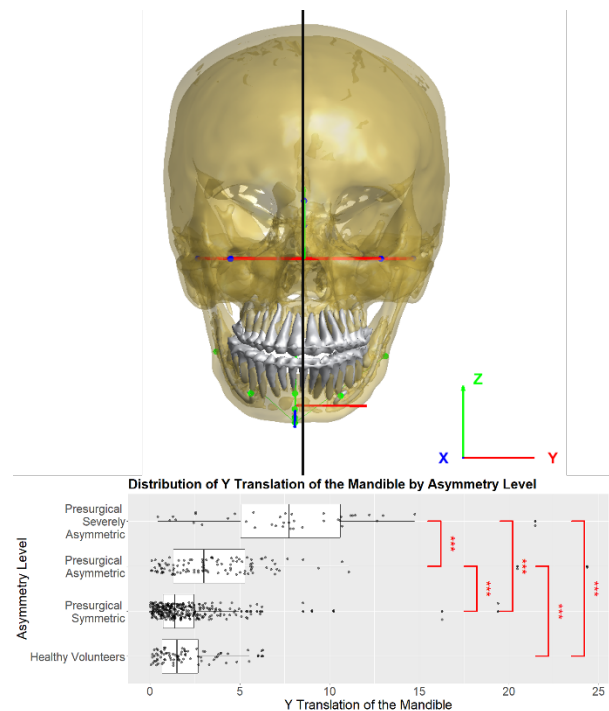


Figure 1. Mid-Sagittal Plane and XYZ Axis (Upper) - Distribution of Translation -Y measures according to asymmetry level and ANOVA significant groups (Lower)

4. Conclusions

The benefits of using local coordinate systems were demonstrated previously by Gateno et al. (2011), who did not evaluate the reliability of these constructions. Our study showed that translation along the y-axis and rotation along the x-axis and z-axis are clinically significant measures in discriminating degrees of asymmetry while having satisfying R&R results. This study is a first step, as we plan to assess more 3D clinical measurements (e.g. antero-posterior, vertical and transverse) in the future.

Conflict of Interest

The authors have nothing to declare.

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