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Three-Dimensional Analysis of the Articular Space in Patients with Complete Unilateral Cleft lip and Palate

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ABSTRACT

Introduction: *Cleft lip and palate is among the most common congenital craniofacial malformations and is associated with functional, esthetic, and psychosocial morbidity. Its origin is multifactorial and involves genetic, environmental, and sociodemographic factors. These alterations can affect maxillofacial growth and temporomandibular joint function.*

Aim: *To perform a comprehensive three-dimensional Cone Beam computed Tomography-based evaluation of condylar morphology and TMJ joint space characteristics in patients with complete unilateral cleft lip and palate during the growth phase.*

Materials and Methods: *A cross-sectional observational study was conducted among 15 patients with unilateral cleft lip and palate aged 12–18 years. CBCT images were analyzed using OnDemand3D software following previously described criteria for the three-dimensional evaluation of joint space and condylar morphology.*

Results: *There were no statistically significant differences between the affected side and the normal side of the TMJ in most measurements, except for the roof of the glenoid fossa. Additionally, 73% of the patients presented with a more anterior condylar position on the affected side, and 86% showed condylar morphological alterations characterized by greater width and shorter height.*

Conclusions: *CBCT plays a critical role in detecting dimensional changes in the TMJ in unilateral cleft lip and palate, offering superior diagnostic precision and improving clinical decision-making regarding significant condylar asymmetry.*

Keywords
CBCT, Growth, TMJ, Unilateral cleft lip and palate.

Introduction

Cleft lip and palate (CLP) is among the most prevalent congenital craniofacial anomalies worldwide and is associated with significant functional, esthetic, and psychosocial morbidity. Its pathogenesis is multifactorial, and involves complex gene environment interactions that disrupt normal embryologic fusion of the maxillary and medial nasal processes, thereby altering craniofacial morphogenesis and postnatal orofacial growth patterns [1]. These developmental disturbances frequently result in maxillary hypoplasia, transverse discrepancies, sagittal skeletal disharmony, and compensatory mandibular adaptations Patients with CLP-particularly those with complete unilateral cleft lip and palate (CUCL)-commonly exhibit structural asymmetries of the nasomaxillary complex that may extend to the temporomandibular joint (TMJ) [2-4]. Given that mandibular growth is closely coupled to condylar cartilage proliferation and functional loading, persistent craniofacial asymmetry may influence condylar modeling, glenoid fossa remodeling, and joint space distribution from early developmental stages. Such alterations may modify condyle-fossa spatial relationships, joint biomechanics, and mandibular kinematics, potentially predisposing affected individuals to temporomandibular dysfunction. Recent investigations have reported associations between craniofacial growth patterns and condylar morphology in patients with CLP, including variations in condylar volume, mediolateral and anteroposterior dimensions, positional asymmetry, and altered condyle-fossa relationships [4-7]. Three-dimensional assessment using cone-beam computed tomography (CBCT) has significantly improved the accuracy and reproducibility of TMJ morphometric analyses by enabling volumetric evaluation, spatial orientation measurements, and precise quantification of joint spaces without the superimposition limitations inherent to two-dimensional imaging [5,6,8]. Despite these advances, the literature remains limited and heterogeneous regarding the three-dimensional characterization of joint space distribution and condylar morphological parameters, specifically in growing patients with CUCL. Existing studies often aggregate different cleft phenotypes, lack standardized morphometric protocols, or do not adequately control for growth stage and skeletal pattern, thereby limiting the ability to delineate phenotype-specific TMJ adaptations. Consequently, the extent to which unilateral cleft-related craniofacial asymmetry translates into quantifiable alterations in condylar morphology and joint space symmetry remains insufficiently defined. Therefore, the aim of the present study was to perform a comprehensive three-dimensional CBCT-based evaluation of condylar morphology and TMJ joint space characteristics in patients with complete unilateral cleft lip and palate during the growth phase. We hypothesize that compared with noncleft controls. Individuals with CUCL demonstrate significant interside differences in condylar morphology and altered joint space distribution, reflecting asymmetric craniofacial growth and functional adaptation of the TMJ complex [6-12].

Materials and Methods

A cross-sectional observational study, which included patients treated at the Dr Manuel Gea González General Hospital in Mexico City, was conducted. The study population included patients of both sexes diagnosed with unilateral cleft and lip palate (UCLP). The sample comprised 15 CBCT (Eagle Edge AXR120-Brasil) scans of patients aged 12–18 years without prior orthodontic treatment, systemic diseases, or associated syndromes, and a total of 30 temporomandibular joints from the unaffected and affected sides were analyzed (4–6). Informed consent was obtained from the patients before they underwent CBCT.

Procedure

The CBCT images were imported into OnDemand3D software (Cybermed, Inc., South Korea) for three-dimensional analysis. The morphological criteria described by Nithin et al. [7] were considered for the evaluation of the joint space and the condyle–glenoid fossa complex. The largest cross-section of the condyle was identified, and the long condylar axis was used as a reference to obtain the central sagittal section. The anterior, superior, and posterior joint spaces were measured using the method described by Kamelchuk et al. [12] and the width, height, and spatial position of the condyle were also recorded [8] (Figure 1 and 2). The data were compiled into an Excel table for future analysis.

Statistics

The data are expressed as mean ± standard deviation (SD). Differences between the affected side and the normal side of the TMJ were determined by Student’s t test using Graph Pad Prism 10 software (San Diego, CA, USA), with the level of significance set at $P < 0.05$.

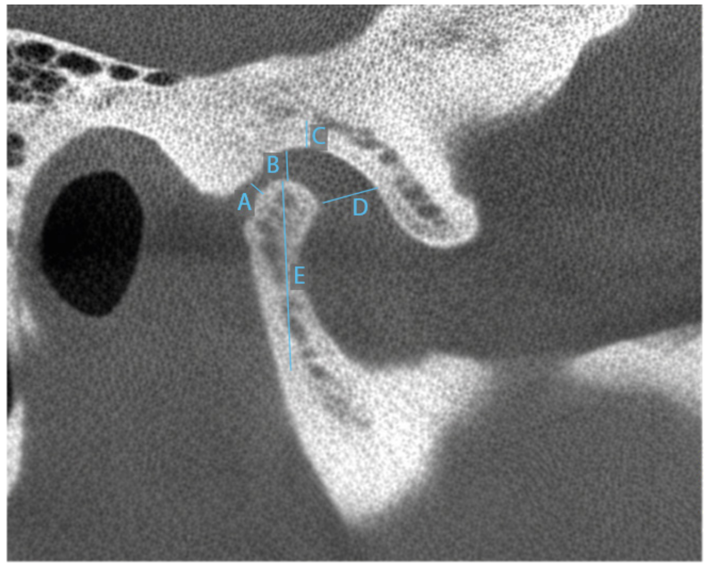


Figure 1: (A) Posterior joint space. (B) Superior joint space. (C) Glenoid fossa thickness. (D) Anterior joint space. (E) Condylar height.

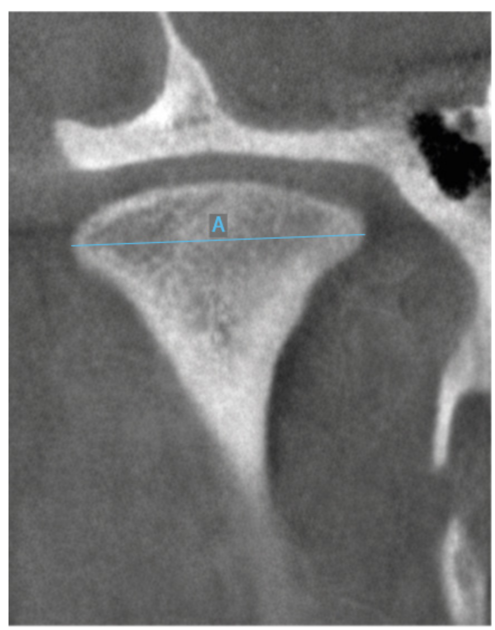
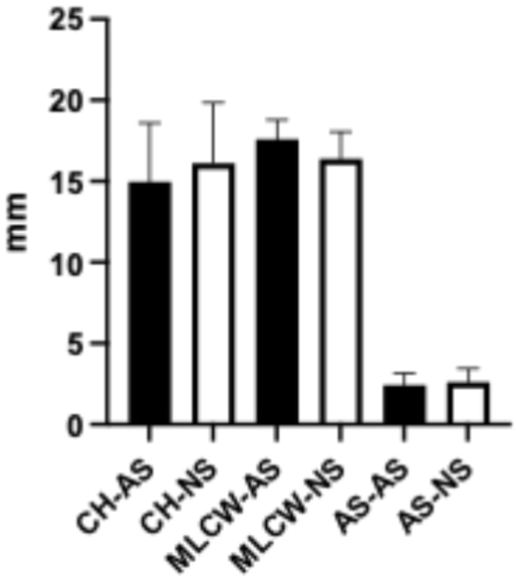
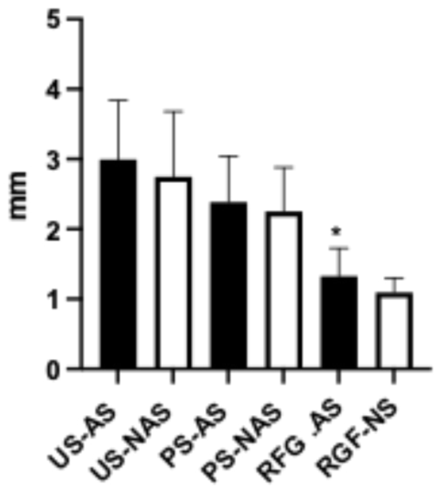


Figure 2: (A) Mediolateral condyle width.

Results



Graph 1: Comparison of both sides of the TMJ. Condylar height-affected side (CH-AS). Condylar height-normal side (CH-NS). Medio-lateral condylar width-affected side (W-AS). The lateral condyle width-normal side (W-NS), anterior space-affected side (AS-AS), and anterior space-normal side (AS-NS).



Graph 2: Comparison of both sides of the TMJ. Upper space-affected side (US-AS) Upper space-normal Side (US-NS), Posterior space-affected side (PS-AS). Posterior space-normal side (PS-NS). Roof of the glenoid fossa-affected side (RFG-AS). RFG-normal side (RFG-NS).

Discussion

The intra-articular spatial analysis revealed notable asymmetries between the affected and nonaffected sides but no statistically significant difference between the measurements of the temporomandibular joint (TMJ), space on the two sides, except for the roof of the glenoid fossa (RGF) (Graph 1 and 2, Table 1 and 2), highlighting the impact of the unilateral cleft lip and palate (UCLP) on, TMJ, morphology and positioning. A substantial proportion of patients (73%) exhibited a more anterior condylar position on the affected side of the RGF. These findings are consistent with those of previous investigations reporting altered condylar positioning in patients with UCLP Which may reflect functional adaptations or compensatory mandibular positioning associated with craniofacial asymmetry [9-11]. Anterior displacement of the condyle could be influenced by altered occlusal relationships, muscular imbalance, or growth disturbances inherent to UCLP. Moreover, the high prevalence (86%) of condylar morphological alterations further supports the presence of adaptive remodeling processes. The observed pattern-characterized by increased condylar width and reduced height on the affected side suggests that the condyle undergoes structural modifications in response to altered biomechanical loading. This adaptive growth pattern aligns with earlier reports indicating that TMJ structures are highly responsive to functional demands and asymmetrical growth conditions [12-18]. From a clinical perspective, these positional and morphological changes have important implications for treatment planning. Orthodontic interventions in patients with UCLP should account for condylar asymmetry, particularly when transverse discrepancies, dental compensation, and occlusal canting are addressed. Early orthodontic approaches, including maxillary expansion and alignment, may help reduce functional shifts and improve symmetry, potentially minimizing abnormal joint loading. In growing patients, orthopedic treatment strategies such as maxillary protraction with facemask therapy [19] may improve sagittal relationships and indirectly influence mandibular positioning and condylar adaptation [20]. However, intrinsic asymmetry may limit the extent of skeletal correction, underscoring the importance of early intervention and careful monitoring of TMJ development. In more severe cases, particularly in skeletally mature patients, orthognathic surgical procedures may be required to correct maxillomandibular discrepancies and restore facial symmetry. Procedures such as Le Fort I osteotomy and bilateral sagittal split osteotomy (BSSO) can improve occlusion and facial balance. Nevertheless, they must be carefully planned to account for preexisting condylar asymmetry and the risk of postoperative TMJ instability.

Table 1: There was no statistically significant difference between the affected side and the normal side.

	CH-AS mm	CH-NS mm	MLCW-AS mm	MLCW-NS mm	AS-AS mm	AS-NS mm
Mean (SD)	14.96±1.34	16.11±1.56	17.3±0.02	16.18±0.58	2.47±0.77	2.62±0.28

Table 2: There was no statistically significant difference between the affected side and the normal side. *P<0.05. There was a statistically significant difference in the roof of the glenoid fossa.

	US-AS	US-NAS	PS-AS	PS-NAS	RGF-AS	RGF-NS
Mean (SD)	2.99±0.42	2.74±0.32	2.38±0.34	2.25±0.23	1.32±0.00*	1.09±0.11

In some cases, adjunctive procedures or modified surgical approaches may be necessary to ensure proper condylar seating and long-term joint health. These findings collectively indicate that UCLP is associated not only with positional changes in the condyle but also with significant morphological adaptations. Such changes are likely multifactorial, and involve both intrinsic developmental disturbances and extrinsic functional influences. Previous studies have emphasized that craniofacial anomalies, including UCLP, can disrupt normal mandibular growth trajectories and joint remodeling [21,22]. Therefore, a multidisciplinary approach involving orthodontists, maxillofacial surgeons, and other specialists is essential for optimizing functional and esthetic outcomes. The use of CBCT has significantly advanced the understanding of TMJ adaptations in patients with CLP providing more reliable and reproducible measurements than conventional imaging techniques.

However, several limitations, such as radiation exposure, variability in landmark identification, and differences in CBCT protocols, should be considered. Future studies incorporating standardized CBCT methodologies, larger sample sizes, and longitudinal designs are recommended to better understand the progression and clinical significance of these condylar adaptations. The use of CBCT has significantly advanced the understanding of TMJ adaptations in patients with CLP providing more reliable and reproducible measurements than conventional imaging techniques [8,14,15,17]. Nevertheless, it is important to consider potential limitations, including sample size and variability in imaging techniques, which may influence the generalizability of the results.

Conclusions
This study confirms that UCLP is associated with significant condylar asymmetry, characterized by anterior displacement and adaptive morphological remodeling. CBCT plays a critical role in detecting these three-dimensional changes, offering superior diagnostic precision and improving clinical decision-making.

From a clinical perspective, these findings emphasize the following: TMJ evaluation should be routinely included in the diagnostic workup of patients with UCLP.

- Orthodontic and orthopedic interventions must consider the condylar position to avoid exacerbating asymmetry or joint loading.
- Surgical planning should account for preexisting condylar morphology to ensure proper condylar seating and postoperative stability:
- A multidisciplinary approach is essential for achieving optimal functional and esthetic outcomes.

  Overall, the integration of CBCT-based TMJ assessment into treatment protocols may enhance the predictability and stability of outcomes in patients with UCLP. Longitudinal studies are needed in the future to clarify the progression of condylar adaptations and their long-term clinical implications.

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