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Facial analysis in patients with orofacial cleft using a 3D stereo-photogrammetric camera system:
A systematic integrative review

Indaiara Abi Rachid Moraes Caleffi Silveira

Dissertação conducente ao **Grau de Mestre** em **Medicina Dentária (Ciclo Integrado)**

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Trabalho realizado sob a Orientação do mestre José Adriano Ferreira Gomes Da Costa.

DECLARAÇÃO DE INTEGRIDADE

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Abstract

Facial analysis plays a crucial role on the treatment of orofacial clefts, offering valuable insights into facial morphology and symmetry. The emergence of three-dimensional stereophotogrammetric systems has revolutionized facial assessment, providing precise and objective measurements for diagnostic and therapeutic purposes.

This study aims to review the application of 3D stereophotogrammetric systems in facial analysis among patients with orofacial clefts and evaluate the utility of these systems in quantifying facial asymmetry, assessing treatment outcomes, and guiding surgical interventions in this population.

A systematic review of relevant literature was conducted to identify studies utilizing 3D stereophotogrammetric systems for facial analysis in patients with orofacial clefts. Articles were selected based on predetermined inclusion criteria, including study design, patient population, and outcome measures.

This review covered a total of 775 articles, followed by a deletion of duplicates articles. 49 of them were related to 3D stereophotogrammetric. Within which 19 provided the data sufficient for the purpose of this review.

The discussion section examines key findings such as clinical outcomes, abnormal appearance, surgical protocols to repair cleft, 3D documentation and measurements of facial asymmetry, facial anthropometric landmarks, comparison between 2D with 3D facial analyses, advantages, and limitations of three-dimensional stereo-photogrammetric camera, assessment of facial asymmetry measurements between cleft and noncleft and clinical relevance.

3D stereophotogrammetric camera systems represent a valuable tool for facial analysis in patients with orofacial clefts, enabling precise measurements, objective assessment of facial asymmetry, and insights into treatment outcomes, facilitating personalized care, optimizing aesthetic, and functional outcomes for affected individuals.

Keywords: oral cleft, facial asymmetry, three-dimensional imaging, 3D assessment, systematic review

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List of Abbreviations

2D - two-dimensional

3D - three-dimensional

BCLP – bilateral cleft lip and palate

CBCT - cone beam computerized tomography

CL – Cleft Lip

CLP – cleft lip and palate

CT - computerized tomography

ICP – isolate cleft palate

NAN – nonalveolar moulding

UCL - unilateral cleft lip

UCLA – unilateral cleft lip and alveolus

UCLP – unilateral cleft lip and palate

1. Introduction

Every year a significant percentage of children are born affected by some type of craniofacial defect. Cleft lip and/or palate (CLP) have the highest incidence among them. Most of the clefts are diagnosed at around twenty weeks of pregnancy through ultrasound scans. Unfortunately, a considerable part still is diagnosed after birth, and this incidence increases in developing countries. Research shows that genetic, nutrition and environmental factors contribute for the development of cleft (1). The incidence of CLP in newborns is 1:1000, in addition, women aged 35 years or over indicated the highest rate of cleft lip pregnancies (2). Cleft lip incidence is higher among males and cleft palate in females. Unilateral cleft lip rate is similar in all genders. And the incidence of incomplete cleft palate is higher than complete cleft palate (3). Commonly, CLP cognates with others congenital deformities, which congenital heart diseases being the most prevalent among them. Also, CLP associates with more than three hundred other syndromes (4). The treatment over the years of a child born with CLP include lip/palate repair surgeries, which brings to different areas of tissue scarring. Most of CLP repair results in lip and nose area asymmetry, especially in unilateral CLP and predispose the morphology of the area (5). Until now, studies in CLP did not achieve a consensus of the best tool to measure and report of the scar tissue and facial asymmetry. Clinical photographs analysed together with three-dimensional imaging or anthropometry are the techniques chosen to use for quantitative and qualitative studies in the area. It allows a psychological and measured analysis of scar tissue in patients with face asymmetry (6). The advance of technology promoted the facial three-dimensional photogrammetry as the highest standard of assessment and evaluation of scaring, allowing the comparison of facial landmarks between individuals born with CLP and non-born with CLP (7). This technique has provided a precise instrument for investigation of muscle motion, allowing an observation of morphology and residual scarring. In addition to analysing the functional symmetry of nasolabial area, indicates a deficiency of anatomical approximation (8). An asymmetric face commonly generates a self-aware image, specifically among adolescents. Additionally, social media contributes to a distorted self-perception and image, notably among young adults that are sensibilized about their self-appearances (9). Furthermore, photos modified digitally such as photography filters or software imaging editor create a potent source of unrealistic self-image (10). The increase of research in three dimensional analyses of tissue scaring in CLP repair will allow to a better understanding and selection of treatment procedures and provide better outcomes in terms of facial symmetry (11). And doing so helping to increase the self- esteem and appearance acceptance among patients born with CLP.

2. Objective

The aim of this systematic review is to comprehensively evaluate and synthesize existing literature on 3D assessment techniques for quantifying facial asymmetry in individuals born with CLP and have undergone surgical repair due to cleft lip and palate (CLP), exhibiting scar tissue. By examining different 3D stereo-photogrammetric camera system, the review aims to elucidate their utility in accurately diagnosing, monitoring, and managing facial asymmetry in this specific population. Additionally, the review focuses on comparing facial landmarks between symmetrical and asymmetrical faces using three-dimensional imaging, including the nasolabial area. This comparative analysis aims to provide valuable insights into the preservation of facial aesthetics and improve treatment planning, potentially achieving more symmetrical results and enhancing the quality of life and self-esteem of individuals born with CLP.

3. Methodology

This study is a systematic review with scientific database searching on PubMed, ScienceDirect and Medline.

Inclusion criteria:

- Articles from year between 2013- 2023.
- Language: English.
- Articles related to Cleft palate lip population.
- Soft tissue analyses and three-dimensional image (stereophotogrammetry) analyses.
- Studies comparison between cleft and non-cleft patients
- Comparative studies

Exclusion criteria:

- Articles before 2013.
- Articles no relate to cleft lip palate population.
- Articles no related to facial three-dimensional image (stereophotogrammetry) analyses
- Articles in a different language.
- Systematic reviews and longitudinal studies

Research question:

Population: Children and adults diagnosed with oral clefts, including unilateral or bilateral cleft lip and palate.

Intervention: Three-dimensional (3D) assessment techniques for evaluating facial asymmetry in individuals with oral clefts, such as 3D facial imaging, stereophotogrammetry, and 3D morphometric analysis.

Comparison: Assess the efficacy of different 3D assessment methods for quantifying facial asymmetry in oral cleft patients. Compare various 3D imaging techniques, pre- and post-operative asymmetry severity, and their accuracy against conventional 2D assessments. Explore treatment effects on reducing asymmetry and improving facial aesthetics and function.

Outcome: The primary outcome is the degree of facial asymmetry quantified through 3D measurements, including differences in landmark positions, volumes, surface area, and overall facial morphology. Secondary outcomes may include treatment efficacy, patient satisfaction, and functional improvements related to speech, mastication, and psychosocial well-being.

Research Question: "What is the comparative effectiveness of various 3D assessment methods in quantifying and evaluating facial asymmetry in individuals with oral clefts, and how do these assessments contribute to the understanding and management of facial asymmetry in this population?"

Variables definition:

1. Age
2. facial asymmetry
3. lip repair
4. lip scarring
5. three-dimensional photogrammetry

Research strategies:

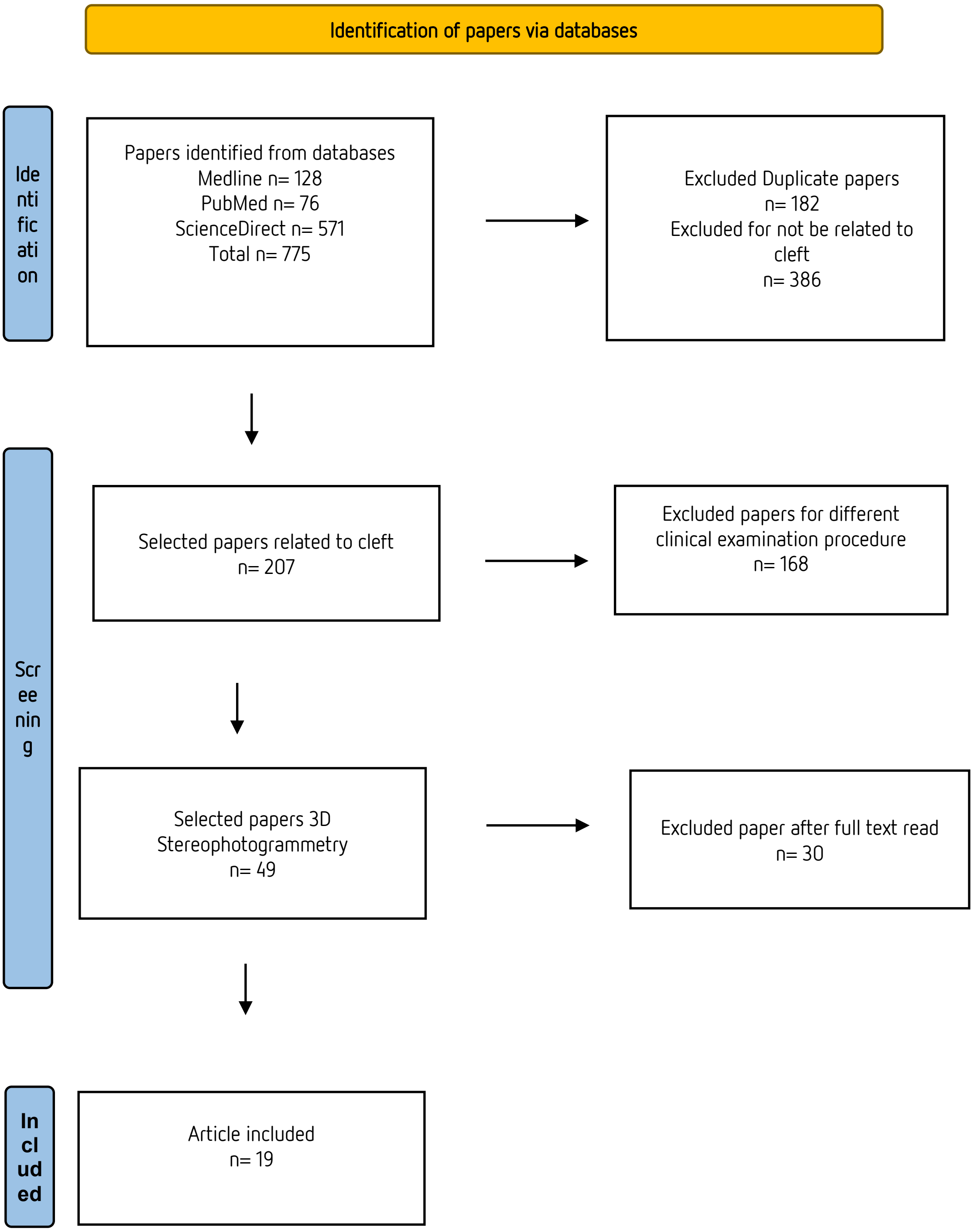
Three databases were used to perform the literature search PubMed, ScienceDirect and Medline. The search terms used were: "cleft", "anatomic landmarks", "photogrammetry", "video recording" and "3D imaging", combined with Boolean operator AND to reach the largest possible number of articles. The research expressions used were cleft [MeSH Terms] AND anatomic landmarks [MeSH Terms] AND 3D imaging [MeSH Terms]; cleft [MeSH Terms] AND photogrammetry [MeSH Terms] AND 3D imaging [MeSH Terms]; cleft [MeSH Terms] AND video recording [MeSH Terms] AND 3D imaging [MeSH Terms]. The inclusion criteria aggregated articles in English, published from 2013 to 2023, describing the use of 3D photogrammetry to analyses of facial asymmetry in patients affect with CLP. The exclusion criteria eliminated articles published before 2013, systematic reviews, longitudinal studies, articles no related to CLP or a different population on the study. And different method of 3D clinical examination (CBCT).

Nº of searches	Key- words	Nº of articles
Nº 1	cleft [MeSH Terms] AND anatomic landmarks [MeSH Terms] AND 3D imaging [MeSH Terms] • Medline n= 70 • PubMed n=7 • ScienceDirect - Research articles n=372	449
Nº 2	cleft [MeSH Terms] AND photogrammetry [MeSH Terms] AND 3D imaging [MeSH Terms] • Medline n= 52 • PubMed n=64 • ScienceDirect – Research articles n= 52	168
Nº 3	cleft [MeSH Terms] AND video recording [MeSH Terms] AND 3D imaging [MeSH Terms] • Medline n= 6 • PubMed n=5 • ScienceDirect – Research articles n= 147	158
Total: 775		

Articles selection:

The search strategy retrieved a total of 775 articles including 3 databases. On the selection of the articles the research collaboration platform Rayyan was used. 182 articles were excluded due duplicity. The studies were skimmed for pertinence by title and abstract. 386 articles were excluded for not being related to cleft. 168 articles were excluded for using a different clinical examination procedure. 49 articles were evaluated, studies that did not compared cleft with non-cleft population were also excluded. 30 articles were excluded after full content analysed. Therefore, 19 articles were included, analysed, and discussed on this systematic review.

Flowchart


Identification of papers via databases
Identification
Papers identified from databases
Medline n= 128
PubMed n= 76
ScienceDirect n= 571
Total n= 775
Excluded Duplicate papers
n= 182
Excluded for not be related to cleft
n= 386
Screening
Selected papers related to cleft
n= 207
Excluded papers for different clinical examination procedure
n= 168
Selected papers 3D Stereophotogrammetry
n= 49
Excluded paper after full text read
n= 30
Included
Article included
n= 19

4. Results

This review covered a total of 775 articles. Follow by a deletion of duplicates articles. The author selected 207 articles after studying the titles and abstracts, 49 of them were related to 3D stereophotogrammetric. From the remaining articles 30 were excluded after the full content m analysed. Therefore, exclusive 19 provided the data sufficient for the purpose of this review. From the selected articles, five (26.3%) evaluated the facial morphology, 8 (42,1%) analysed facial asymmetry and the remaining 6 (31,6%) assessed nasolabial area only. 26,3 % of the articles were captured during maximum smile, while the remaining 73.7% were captured in resting face.

Title/Author/year	Type of study	Objective	Sample	Equipment of capturing the 3D Images	Clinical relevance	Conclusion
1. Bagante I. et al. 3D Assessment of Nasolabial Appearance in Patients with Complete Unilateral Cleft Lip and Palate (2018)	Cross-sectional observational study.	The aim of this study was to assess the nasolabial appearance of patients with UCLP compared with a control group.	35 patients born between 1994 and 2004 with no syndromic complete UCLP were included. The mean age was 14.7 years old (range 10-18). In the control group, 35 noncleft participants at 10 years old.	The study utilized the 3dMDfaceSystem; 3dMD LLC, Atlanta, GA, a 3D stereo-photogrammetric camera setup, to assess nasolabial appearance in patients with complete unilateral cleft lip and palate (UCLP). Specific anthropometric landmarks and distances were analysed using the 3dMD Vultus software.	Despite achieving acceptable symmetry post-surgery in the UCLP group, the nasolabial appearance differed significantly from the control group in most anthropometric distances. The 3D photographs provided a reliable, accurate, and non-invasive method for evaluating postoperative outcomes, suggesting its potential utility in routine clinical assessments of facial symmetry and aesthetic outcomes in cleft lip and palate patients.	Findings highlighted significant nasolabial symmetry disparities between the UCLP and control groups. Specifically, within the UCLP, the only difference appeared in alar wing length between the affected and unaffected sides. Despite this variation, the postoperative nasolabial symmetry in UCLP patients was deemed satisfactory at an early school age. The research endorsed 3D photogrammetry as an effective and non-invasive means to assess and track post-surgical nasolabial outcomes in UCLP patients.

2. Bugaighis I. et al. 3D asymmetry of operated children with oral clefts (2014)	Cross-sectional study	To explore three-dimensional (3D) facial asymmetry differences in operated children with oral clefts and to compare the results with a control group.	The sample comprised one hundred and three 8- to 12-year-old children: 40 with unilateral cleft lip and palate (UCLP); 23 with unilateral cleft lip and alveolus (UCLA); 19 with bilateral cleft lip and palate (BCLP); 21 with cleft palate (CP) and 80 sex- and age-matched controls living in the Northeast of England.	3D images were captured using a non-invasive 3D stereophotogrammetry system (3dMD, Atlanta, GA, USA), comprising two units with six cameras each. Landmark asymmetry was assessed using generalized Procrustes analysis (GPA), measuring distances in millimetres between original and reflected landmarks.	Significant differences in 3D landmark asymmetry were observed among all cleft groups and controls. UCLP and UCLA groups showed the highest asymmetry, followed by BCLP, while the CP group exhibited the least asymmetry. Early intervention and customized treatment strategies are crucial for improving facial symmetry and overall well-being in individuals with oral clefts.	Significant differences in facial asymmetry were observed across all cleft groups, with the UCLP and UCLA groups showing the most pronounced asymmetry, followed by BCLP, while the CP group exhibited the least. The control group displayed minimal asymmetry. These findings highlight distinct growth patterns and aetiologies associated with different cleft types. The study emphasizes the value of 3D imaging and shape analysis in assessing treatment outcomes and understanding the clinical and psychological implications of oral clefts.

3. Bugaighis I. et al. 3D Facial Morphometry in Children with Oral Clefts (2014)	Cross-sectional study	The aim of this study was to characterize three-dimensional (3D) facial morphological variation of children with cleft lip and palate compared to an age- and sex matched control group.	Subjects were 103 children aged 8 to 12 years old with cleft lip and palate—40 with unilateral cleft lip and palate, 23 with unilateral cleft lip and alveolus, 19 with bilateral cleft lip and palate, and 21 with isolated cleft palate (ICP)—and 80 sex- and age-matched control subjects.	High-resolution 3D facial scans were obtained using a 2-megapixel 3D stereophotogrammetry system (V3.0, 3dMD, Atlanta, GA) with an acquisition time of 2 milliseconds. For landmark identification, 39 anthropometric homologous landmarks were used, based mainly on Farkas (1994), and recorded using MorphAnalyser software version 2.07.	Each cleft group (UCLP, UCLA, BCLP, ICP) displayed unique facial characteristics. The research underscores oral clefts' substantial influence on facial asymmetry and morphology. It emphasizes the critical role of precise 3D analysis in clinical evaluations and treatment planning for cleft patients, potentially enhancing surgical outcomes and overall patient care.	Distinct facial differences were observed in each cleft group, highlighting unique morphological characteristics. For the UCLP and UCLA groups, significant differences were mainly in the nasolabial region, with the UCLP group showing disparities in facial height and width. The BCLP group presented wider nasal widths and reduced facial heights, indicating midface retrusion. The ICP group showed a smaller facial form with less asymmetry, resembling controls when the cleft lip was absent, and revealed a retrognathic mandible.

4. Patel Y. et al. An innovative analysis of nasolabial dynamics of surgically managed adult patients with unilateral cleft lip and palate using 3D facial motion capture (2023)	Cross-sectional study	To compare dynamic nasolabial movement between end-of-treatment cleft and a matched non-cleft group in adult patients.	Thirteen treated adult participants with unilateral cleft lip and palate.	The Di4D system, developed by Dimensional Imaging Ltd. in Glasgow. Landmarks like the inter-pupillary line and Frankfort plane guide alignment.	Despite surgical interventions aiming to rectify facial asymmetry, residual differences persisted, impacting the patients' quality of life. Various parameters, including landmark displacement, path of motion, and dynamic asymmetry scores, were employed to evaluate facial dynamics. The findings emphasize the significance of objective measures in assessing and addressing persistent facial asymmetry in UCLP patients, suggesting a need for further research to optimize surgical outcomes and improve patient well-being.	Results revealed that adult UCLP patients exhibited significant residual asymmetry, particularly in the horizontal movement of the cleft side mouth during smiling, which persisted from infancy. This asymmetry was attributed to lip scarring and adhesion resulting from primary surgical repair. Additionally, nasal and lip periphery asymmetry increased during smiling, further accentuated concerning the clinical midline.

5.	Hallac R. et al. Dynamic facial asymmetry in patients with repaired cleft lip using 4D imaging (2017)	Cross-sectional study	Objectively quantify the asymmetry of facial movements in participants with non-syndromic CLP compared with participants with no craniofacial anomalies.	Following Institutional Review Board (IRB) approval, a total of 23 participants were recruited to the study: aged between 8 and 18 years, with a median age of 13 years. 11 participants without any known craniofacial diagnosis or previous lip trauma were recruited as a control group.	4D video stereophotogrammetry, utilizing a system from Dimensional Imaging Ltd., Glasgow, U.K. Operating at 50 frames per second, the system captures real-time facial expressions, enabling a detailed assessment of movement and asymmetry.	Participants with repaired clefts and controls were imaged while performing facial expressions. Results indicated greater asymmetry in cleft patients during smiling and puckering, particularly at the mid philtral ridge landmark. This area is susceptible to scarring after repair, emphasizing the study's importance in understanding dynamic facial asymmetry post-surgery, potentially influencing future surgical approaches and patient care.	The Participants performed facial expressions, and results revealed greater dynamic facial asymmetry in CLP patients, particularly at the mid philtral ridge landmark. This area is dynamic during expressions and prone to scarring post-repair. The study underscores the significance of evaluating dynamic facial asymmetry post-surgery, informing potential refinements in surgical approaches, and emphasizing the need for improved aesthetic outcome assessment methods for CLP patients.

6. Manyama M. et al. Facial morphometrics of children with NON-syndromic orofacial clefts in Tanzania (2014)	Observational cross-sectional study design.	Knowledge of craniofacial shape among individuals with non-syndromic CL/P in African populations will provide further understanding of the ethnic and phenotypic variation present in non-syndromic orofacial clefts.	Comparing individuals with unrepaired non-syndromic CL/P and normal individuals without orofacial clefts.	InSpeck 3D MegaCapturor camera by Creaform Inc., Quebec, Canada. This stereophotogrammetric system captures 3D facial surfaces in approximately 0.4 seconds, boasting a 640 × 480 mm field of view with high-fidelity colour and texture rendering. The process involved meticulous landmark identification, demonstrating observer precision within 0.338 mm.	Results revealed significant facial shape differences between the CL/P and control groups. Specifically, the CL/P group exhibited increased nasal and mouth width, greater interorbital distance, and reduced facial height. Additionally, variations were noted between unilateral and bilateral CL/P. This study offers valuable insights into the phenotypic aspects of orofacial clefts in African children and emphasizes the need for early intervention and treatment. The study suggests that despite variations in cleft prevalence and types, the facial shape variations associated with CL/P in African children align with patterns observed in Caucasian populations.	Significant facial shape variations were observed between the CL/P and control groups, including differences in interocular distance, nasal and mouth width, and facial height. Directional asymmetry due to cleft side was noted, likely influenced by the higher prevalence of left-sided clefts in the sample. However, after mirroring the data, no significant shape difference was found between left and right-sided clefts. The CL/P group displayed increased nasal and mouth width, increased interorbital distance, and decreased facial height compared to controls. Interestingly, no significant facial shape difference was found between isolated CL and combined CL/P groups.

7. Lee D., Tanikawal C. and Yamashirom T. Impairment in facial expression generation in patients with repaired unilateral cleft lip: Effects of the physical properties of facial soft tissues (2021)	Cross-sectional study	Examined the three-dimensional (3D) facial displacement while smiling in the Cleft and Control groups to determine whether the physical properties of facial soft tissues differ between the Cleft and Control groups and to examine the relationship between the physical properties of facial soft tissues on 3D facial displacement while smiling.	Japanese patients with a repaired UCLP (Cleft group; n = 41, mean age = 21.46 ± 4.27 years old, 21 men and 20 women) and healthy adults with a straight-type facial profile and normal occlusion (Control group; n = 41, mean age = 25.78 ± 3.35 years old, 21 men and 20 women) were enrolled in the present study.	"3-DMDcranial System" by 3-DMD, based in Atlanta, GA, USA.	Results revealed reduced upward and backward displacement of the upper lip and labial commissure during smiling in UCLP patients. Additionally, increased downward displacement of the lower lip was observed, correlating with elevated viscoelasticity of scar tissue, and surrounding facial soft tissues. Notably, asymmetric facial movement patterns were evident, with greater lateral displacement on the cleft side. However, these asymmetries were not intricately linked to skin physical properties. The findings suggest that while scar tissue influences specific facial movements in UCLP patients, other factors contribute to facial asymmetry. This study underscores the importance of understanding scar tissue properties in addressing facial movement impairments in UCLP patients for improved treatment outcomes.	These movement restrictions were associated with increased viscoelasticity of scar tissue and surrounding facial soft tissues, indicating stiffer scar characteristics than normal skin. However, the study also identified that asymmetric facial movements were not closely related to skin physical properties. The findings underscore the complex interplay between scar tissue properties and facial movement impairments in UCLP patients, suggesting that understanding these relationships could guide more targeted and effective treatment strategies to enhance functional and aesthetic outcomes for individuals with repaired UCLP.

8. Brons S. et al. Influence of involuntary facial expressions on reproducibility of 3D stereophotogrammetry in children with and without complete unilateral cleft lip and palate from 3 to 18 months of age (2018)	Cross-sectional study	To assess the influence of involuntary facial expressions on 3D facial stereophotogrammetry reproducibility in children with and without unilateral cleft lip, alveolus, and palate (UCLP) aged 3–18 months.	31 children with UCLP and 50 controls at 3, 12 and 18 months of age. 3	3dMDcranial System. The images were assessed for quality and neutral facial expression using the 3dMDpatient V4.0 software.	The results indicated that there was no significant difference in variation between the UCLP and control groups for the entire face. However, a statistically significant difference was observed in the nasolabial area at 3 months of age, suggesting that this region is more susceptible to variations due to involuntary facial expressions. Overall, the study underscores the importance of maintaining a neutral facial expression during 3D image capture, especially in young children with UCLP, to ensure reproducibility and accuracy in clinical assessments and treatment planning.	The nasolabial area at 3 months of age, was the only area to observe significant difference in variation between the UCLP and control groups for the entire face, suggesting that this region is more susceptible to variations due to involuntary facial expressions.

9. Kuijpers M. et al. Nasolabial shape and aesthetics in unilateral cleft lip and palate: an analysis of nasolabial shape using a mean 3D facial template (2019)	Cross-sectional study	The aim of this study was to determine the amount of deviation in nasolabial shape in patients with a cleft compared with an average non-cleft face, and to assess whether this difference is related to nasolabial aesthetics.	A total of 60 patients with a unilateral orofacial cleft, born between 1998 and 2004, were included in the study. For comparison , four average non-cleft faces were constructed from stereophotogrammetric images of 141 girls and 60 boys.	2-pod camera set-up for stereophotogrammetric imaging (3dMDface System; 3dMD LLC, Atlanta, GA, USA. The 3D images were processed using the 3dMDpatient v3.1.0.3 software and further analysed using Maxilim software (Medicim NV, Mechelen, Belgium).	Results indicated that more significant shape differences were found in the nasolabial area of CLP patients compared to non-cleft individuals. However, these shape differences did not consistently correlate with aesthetic ratings, except for the nasal profile. The study highlights the complexity of facial aesthetics in CLP patients, suggesting that factors other than just nasolabial deviation might influence aesthetic perceptions. The findings emphasize the importance of individualized treatment approaches to address facial asymmetry and improve aesthetic outcomes in CLP patients.	While CLP patients displayed more shape differences in the nasolabial area than controls, these variations had minimal impact on aesthetic ratings except for the nasal profile. Aesthetic scores decreased with increasing cleft severity, but overall, shape deviations did not significantly influence aesthetic perceptions. The study suggests that aesthetic judgments in CLP patients are complex and not solely determined by nasolabial shape differences.

10. Matsumoto K. et al. Preliminary analysis of the three-dimensional morphology of the upper lip configuration at the completion of facial expressions in healthy Japanese young adults and patients with cleft lip (2016)	Cross-sectional study	To develop criteria for analysis of the upper lip configuration of patients with 3 cleft lips while they produce various facial expressions, by comparing the 4 three-dimensional (3D) facial morphology of healthy Japanese adults and patients with 5 a cleft lip.	Twenty healthy adult Japanese volunteers (10 men, 10 women, as reference 7 subjects), without any observed facial abnormalities, and eight patients (four men, four 8 women) with unilateral cleft lip and palate, who had undergone secondary lip and nose 9 repair in our department, were recruited for this study.	Artec MHT 3D scanners to capture detailed 3D facial images of participants, complemented using 3D-Rugle V software for subsequent analysis.	The study's 3D morphological analysis emphasizes the necessity of comprehensive evaluations during dynamic facial expressions to guide surgical improvements. Addressing these asymmetries is vital for achieving a harmonious blend of aesthetics and functionality, enhancing the overall quality of life for individuals with cleft lip.	It highlighted persistent challenges in achieving facial symmetry and balance, particularly during dynamic movements like smiling. The limited upper lip movement in cleft lip patients, due to scar tissue in the orbicularis oris muscle, revealed the intricacies of morphological reconstruction. Notable laterality differences were evident in cleft lip patients, indicating pronounced asymmetries compared to healthy individuals. Postoperative changes were observed, albeit with some inconsistencies across facial expressions.

11. Kuijpers M. et al Regional facial asymmetries in unilateral orofacial clefts (2015)	Cross-sectional study	Assess facial asymmetry in subjects with unilateral cleft lip (UCL), unilateral cleft lip and alveolus (UCLA), and unilateral cleft lip, alveolus, and palate (UCLP), and to evaluate which area of the face is most asymmetrical.	Standardized three-dimensional facial images of 58 patients (9 UCL, 21 UCLA, and 28 UCLP; age range: 8.6–12.3 years) and 121 controls (age range 9–12 years).	"3dMD face™ System" by 3dMD LLC, based in Atlanta, Georgia, USA. The acquired 3D images were processed using the "3dMD patient™ Software Platform" by 3dMD LLC to remove confounding regions like neck, ears, and hair. Further analysis, involving mirroring and distance map creation, was performed using the Maxilim® software by Medicim NV, Mechelen, Belgium.	Notably, the nose was identified as the most asymmetric area across all CLP groups, followed by the lips. In contrast, the chin was found to be the most asymmetric area in the control group. These findings highlight the distinct patterns of asymmetry associated with different unilateral cleft types, suggesting that the anatomical defect of the facial skeleton plays a significant role in facial asymmetry. Understanding these patterns can guide treatment approaches to improve facial symmetry in CLP patients, potentially enhancing both aesthetic outcomes and overall patient well-being.	Findings revealed that UCLP patients exhibited significant facial asymmetry, particularly in the nasolabial area. In contrast, the control group showed the chin as the most asymmetrical area. The study also highlighted distinct asymmetry patterns for each unilateral cleft type: the nose was the most asymmetric in UCLP and unilateral cleft lip and alveolus (UCLA) patients. This research provides valuable insights into the anatomical differences associated with cleft deformities, emphasizing the need for tailored treatment approaches for different cleft types.

12. Harrison L., Hallac R. and Derderian C. Three-Dimensional Analysis of Bilateral Cleft Lip and Palate Nasal Deformity (2020)	Retrospective comparative cross-sectional study	This cross-sectional study utilizes 3-dimensional analysis to assess nasal morphology in patients with bilateral cleft lip and palate (BCLP) compared to controls across the timeline of cleft care.	One hundred and twelve patients with BCLP and an equal number of age and sex-matched control participants.	The research employed the 3dMD imaging system to capture three-dimensional facial photographs.	Traditional methods like anthropometric measurements and nasolabial casts faced limitations, including time consumption and lack of detail. Analysing 112 BCLP patients at various ages revealed persistent nasal deformities, such as widened nasal tip, shorter columella, and broader alar base compared to controls. These anomalies often remained even after surgical interventions, suggesting the complexities of achieving normalized nasal morphology in BCLP patients. The research underscores the utility of 3D photogrammetry for detailed and reproducible assessment of nasal morphology, contributing to better understanding and management of facial asymmetry in BCLP patients.	Results showed that BCLP patients exhibited less nasal projection and shorter columella length up to age 5. However, columella width was wider and alar width and base width were increased up to age 10. The nasolabial angle and nasal tip width remained significantly greater throughout the study period up to 15 years of age. The study highlights the utility of 3DP in tracking nasolabial morphology changes in BCLP patients over time, providing valuable insights for surgical interventions.

13. Krimmel M. et al. Three-Dimensional Assessment of Facial Development in Children with Unilateral Cleft Lip With and Without Alveolar Cleft (2013)	Cross-sectional study	The research aimed to identify standard anthropometric landmarks on the facial images and superimpose them to calculate growth curves for normal facial development.	344 healthy children and 30 children with cleft lip or cleft lip and alveolus were scanned three-dimensionally at the age of 0 to 6 years.	3dMD Face System for capturing three-dimensional surface images. The resulting three-dimensional data sets, complete with colour information, were exported in VRML/JPG format and imported into Autodesk 3ds Max software for landmark placement and subsequent analysis.	Using the 3dMD Face System, significant differences were observed in the transverse direction, particularly in nasal landmarks, indicating a broadening of the nose and face in affected children. While sagittal and vertical facial dimensions did not differ significantly from unaffected children, there was a tendency towards lengthening in some regions. Despite surgical and orthodontic treatments improving vertical and sagittal dimensions in affected children, the transverse dimension, notably the nose, remained broader. The findings emphasize the persistent facial asymmetry in children with UCL and UCLA, suggesting a need for continued interdisciplinary care to address these challenges effectively.	Results indicated significant differences primarily in the transverse direction, with notable widening of nasal landmarks and a broader face in the nasal and oral areas in UCL and UCLA children. In the sagittal and vertical dimensions, these children did not differ significantly from unaffected children. Surgical and orthodontic treatments were found to restore vertical and sagittal dimensions effectively. However, the transverse dimension, particularly the nose, remained broader post-treatment.

14. Bell A. et al. Three-Dimensional Assessment of Facial Appearance Following Surgical Repair of Unilateral Cleft Lip and Palate (2013)	Cross-sectional study	Assess residual asymmetry in surgically repaired unilateral cleft lip (UCL) and unilateral cleft lip and palate (UCLP) patients and to compare this with noncleft controls.	Fifty-one 10-year-old children with surgically managed UCLP and 44 children with UCL were compared with a control group of 68 ten-year-olds.	3D imaging system called Di3D for capturing facial images. Additionally, anatomic facial curves were extracted from the 3D models using this system.	The findings revealed that children with clefts exhibited higher facial asymmetry scores compared to controls. Specifically, the upper lip and nose regions were the most asymmetric areas in both cleft groups. The study highlights the persistence of facial dysmorphology even after surgical correction of cleft lip and palate, emphasizing the need for continuous evaluation and potential further interventions to improve facial symmetry and overall appearance in these patients	Results indicated that surgically managed children with clefts exhibited higher facial asymmetry scores than controls, with the UCLP group showing more pronounced asymmetry. Specifically, the upper lip was identified as the most asymmetric area, followed by the nasal complex. These findings underscored the challenges in achieving complete facial symmetry through surgical interventions, suggesting a need for meticulous primary repair to optimize long-term facial aesthetics and function.

15. Othman S. and Koay N. Three-dimensional facial analysis of Chinese children with repaired unilateral cleft lip and palate (2016)	Cross-sectional study	Analysed the facial features of Chinese children with repaired unilateral cleft lip and palate (UCLP) and compared them with a normal control group using a three-dimensional (3D) stereophotogrammetry camera.	20 Chinese children with repaired UCLP and 40 unaffected Chinese children aged 7 to 12 years old.	VECTRA-M5 360, featuring a five-pod configuration with ten lenses to capture high-resolution, photorealistic images.	The research found several clinically significant differences between the UCLP group and the control group. Notably, children with UCLP exhibited wider and flatter noses, broader alar base root width, and wider left nostril floor width. Additionally, they displayed shorter upper lip length and thinner upper vermilion. The findings emphasize the importance of comprehensive facial evaluations post-repair of UCLP. Understanding these asymmetries is crucial for refining surgical techniques, optimizing aesthetic outcomes, and enhancing psychosocial well-being in affected individuals.	Results indicated that the UCLP group displayed notable differences in the nasolabial region, including a wider and flatter nose, wider nostril floor, shorter upper lip length, and thinner upper vermilion compared to the control group. However, the intercanthal width, though wider in the UCLP group, was statistically insignificant. The study underscores the importance of using 3D imaging to evaluate the outcomes of cleft lip and palate surgeries and to understand the facial differences in CLP patients.

16. Brons S. et al. Three-dimensional facial development of children with unilateral cleft lip and palate during the first year of life in comparison with normative average faces (2019)	Cross-sectional study	This study aimed to compare the three-dimensional (3D) facial morphology of infants born with unilateral cleft lip and palate (UCLP) with an age-matched normative 3D average face before and after primary closure of the lip and soft palate.	Thirty infants with a non-syndromic complete unilateral cleft lip, alveolus, and palate participated in the study. Three-dimensional images were acquired at 3, 6, 9, and 12 months of age. All subjects were treated according to the primary surgical protocol consisting of surgical closure of the lip and the soft palate at 6 months of age.	The 3dMDfacial System with a 2-pod configuration was employed for image acquisition.	Using stereophotogrammetry and a generic mesh superimposition technique, high-quality 3D facial images were collected. The findings highlighted significant morphological differences between UCLP patients and controls, particularly in the upper lip, nose, and chin regions. UCLP subjects showed retrusive facial dimensions compared to controls, with notable asymmetry in the nasal and labial regions. Surgical interventions, including lip and soft palate closures, partially restored facial symmetry, but some asymmetry persisted, especially in the nasal region.	Results showed significant morphological differences between UCLP patients and controls, especially in the upper lip, nose, and chin regions. Surgical interventions partially restored facial symmetry, but some asymmetry persisted, particularly in the nasal region. These results underscore the importance of early intervention and continuous monitoring to optimize facial aesthetics and function in infants with UCLP.

17. Verzé L., Bianchi F., and Ramieri G. Three-dimensional laser scanner evaluation of facial soft tissue changes after LeFort I advancement and rhinoplasty surgery: patients with cleft lip and palate vs patients with noncleft maxillary retrognathic dysplasia (control group) (2014)	Cross-sectional study	The aim of this study was to analyse the differences in facial soft tissue changes, despite the same extent of upper jaw forward movement, between patients with unilateral cleft lip and palate (u CLP) and those without, after LeFort I osteotomy and secondary rhinoplasty.	Twelve patients fulfilled inclusion criteria for the study and were divided in 2 groups 6 patients born with CLP and 6 patients born without CLP.	The study utilized a head and face colour 3D scanner (3030RGB; Cyberware Inc, Monterey, CA, USA). The acquired 3D data were then transferred to a graphics workstation for viewing and further processing using the Cyberware Echo software (Cyberware Inc, Monterey, CA, USA).	Despite surgical interventions, adult UCLP patients exhibited residual asymmetries in the upper lip and nasal tip projection compared to the control group. Both groups showed improvements in facial symmetry post-surgery, but the control group displayed a more pronounced nasal tip projection. The study highlights the challenges in achieving perfect facial symmetry in UCLP patients, emphasizing the need for further technical advancements in orthognathic surgery to address these residual deformities effectively.	Results showed that while both groups exhibited improved facial symmetry post-surgery, UCLP patients displayed residual asymmetries in the upper lip and nasal tip projection compared to the control group. Challenges in achieving perfect facial symmetry in UCLP patients were attributed to inherent tissue deformities, previous surgical interventions, and scar tissue. The findings emphasize the need for further advancements in surgical techniques and technologies to effectively address these residual deformities and enhance the aesthetic outcomes in patients with oral clefts.

18. Othman S. et al. Three-dimensional quantitative evaluation of facial morphology in adults with unilateral cleft lip and palate, and patients without clefts (2014)	Cross-sectional study	The aims of this study were to assess the quantitative values of measurements using proportion indices in the craniofacial region in patients with repaired, non-syndromic, complete unilateral cleft lip and palate (UCLP).	15 Malay patients who had UCLP repaired, and 100 Malay control patients aged 18–25 years were analysed.	The study utilized the VECTRA-3D dual module system by Canfield Scientific Inc., Fairfield, NJ, USA. Following image capture, the 3D Mirror Software was employed for image display and analysis.	Significant differences were found in seven out of eleven craniofacial proportion indices between the two groups. Specifically, the nasal and orolabial regions, including the nose (nasal and nasal tip) and upper lip, showed the most pronounced discrepancies. A difference of 5 mm or more was considered clinically relevant. Patients with UCLP displayed larger facial dimensions, particularly in the nose and upper lip areas. The findings emphasize the importance of accurate assessment and potential corrective measures for facial asymmetry in individuals with UCLP, aiding in surgical planning and treatment evaluation.	Notably, the nose and orolabial regions, particularly the nasal and upper lip indices, showed the most pronounced differences. The study established a threshold of 5 mm as clinically relevant for facial asymmetry in UCLP patients. These findings suggest that UCLP patients exhibit distinct facial asymmetries, mainly in the nasolabial region, which could be attributed to surgical interventions and growth patterns.

19. Wong K. et al. Using three-dimensional average facial meshes to determine nasolabial soft tissue deformity in adult UCLP patients (2018)	Cross-sectional study	The purpose of this study is to determine the site and severity of the residual nasolabial soft tissue deformity between adult unilateral cleft lip and palate (UCLP) patients and a non-cleft reference group, prior to orthognathic surgery.	Sixteen adults male UCLP patients, who all received primary lip and palate surgery compared to a previous published Hong Kong non-cleft reference group of 48 male adults	The study utilized the Di3D stereophotogrammetry system (Di4D, Dimensional Imaging Ltd, Hillington, Glasgow, UK).	The primary outcome measure was the difference in alar base width between the two groups, with secondary measures including conventional linear and angular measurements and facial asymmetry scores. The study utilized advanced imaging techniques like stereophotogrammetry to capture detailed facial topography. Results indicated that UCLP patients exhibited significant facial asymmetry, with wider noses, reduced lip and philtrum lengths, and other distinct deformities compared to the reference group. The findings are clinically relevant as they offer a comprehensive, 3D-based approach to diagnosing and planning surgical corrections for UCLP patients, surpassing the limitations of conventional 2D methods.	The study shows narrower nostril floor width, wider nasal base width, longer right columella length, shorter cutaneous lip height, and various other differences. The UCLP group also demonstrated increased facial asymmetry compared to the reference group. Distance colour maps revealed substantial soft tissue deficiencies in the nasal and upper lip regions of the UCLP patients, which were asymmetrically skewed towards the unaffected side. These findings provide valuable insights for clinicians to consider when planning orthognathic surgeries for UCLP patients, highlighting areas requiring correction and potential challenges in surgical prediction planning.

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5. Discussion

One of the most impacting sequelae of a treatment of oral cleft is the facial asymmetry. Affecting the self-esteem and quality of life of patients. The task of assess the location and extension of the asymmetry is normally given to the orthodontist or surgeon treating the patient. The feasibility of a 3D non-invasive imaging system is clinically relevant, especially when could provide an enhanced guide for nasolabial reconstruction, allowing similar facial symmetry to a non-cleft patient (12)

5.1 Clinical outcomes of oral cleft

The clinical outcomes and management of oral clefts, encompassing cleft lip, cleft palate, and their combinations, pose significant challenges in both surgical and aesthetic realms. This is primarily due to the intricate nature of the deformities and the subsequent wide impact they have on affected individuals. Several studies have investigated the use of advanced three-dimensional (3D) imaging techniques, such as 3D stereophotogrammetry and 4D video stereophotogrammetry, to assess the anatomical, functional, and aesthetic aspects of orofacial clefts (12–15).

The research by Bagante et al. (2018), emphasizes in evaluating the nasolabial appearance of patients with unilateral cleft lip and palate (UCLP) (13). Notably, significant differences in nasal symmetry were observed between cleft and noncleft sides, underscoring the intricate challenges in achieving aesthetic symmetry in these patients. Similarly, Bugaighis et al. (2014), utilized 3D stereophotogrammetry to identify significant facial asymmetry among different cleft groups, highlighting the distinct facial shape differences resulting from various types of oral clefts and their respective surgical repairs (12,16). Kuijpers et al. (2021), provided valuable insights into the relationship between nasolabial shape and aesthetics in CLP patients, highlighting that while nasolabial shape differences were evident, they did not always correlate with aesthetic perceptions (17). This suggests that other factors, possibly psychological and social, may influence aesthetic ratings in these patients.

Furthermore, dynamic assessments using advanced 3D facial motion capture technology, as seen in Patel et al. (2023), revealed less movement and increased asymmetry in UCLP patients during smiling, underscoring the persistent functional and aesthetic challenges even after corrective surgeries (15). This is further supported by Hallac et al. (2017), who employed 4D video stereophotogrammetry to demonstrate significant dynamic asymmetry in patients with repaired cleft lips during voluntary facial expressions (14).

In addition to functional challenges such as speech difficulties, feeding difficulties, dental issues, and hearing problems, as well as psychological and social impacts like social stigma, bullying, and self-esteem issues (18). Furthermore, the long-term repercussions of cleft-related facial deformities on patient well-being persist as an active area of research, emphasizing the need for continued monitoring and personalized treatment strategies tailored to the unique facial characteristics of affected individuals (19,20).

5.2 Abnormal appearance in patients with clefts

The appearance of patients with clefts, particularly those with complete unilateral cleft lip and palate (UCLP), presents a complex challenge due to the inherent facial asymmetry and morphological differences associated with these congenital craniofacial defects.

The study by Bagante et al. (2018), highlighted a significant difference in alar wing length between the cleft and noncleft sides and other anthropometric distances when compared to a control group. Such findings underscore the necessity for specialized assessment tools to identify and address the specific asymmetries and morphological differences in cleft patients accurately (13).

Bugaighis et al. (2014) further explored the 3D facial asymmetry in children with various oral clefts, noting distinct facial asymmetry patterns across different cleft types (12,16). Furthermore, unilateral cleft lip and palate (UCLP) and unilateral cleft lip and alveolus (UCLA) groups exhibited the greatest asymmetry, while the bilateral cleft lip and palate (BCLP) group showed less asymmetry but more than the cleft palate (CP) group.

In addition, Patel et al. (2023) and Hallac et al. (2017) respectively utilized advanced 3D imaging techniques to assess facial movements and dynamics in UCLP and cleft lip with or without palate (CLP) patients. The results revealed significant differences in movement, symmetry, and dynamic asymmetry between cleft groups and controls, highlighting the need for better objective measures to assess and improve treatment outcomes, especially in adult UCLP patients. (14,15).

Scar tissue properties and their influence on facial movement and appearance were examined by Lee et al. (2021). The study found that UCLP patients exhibited reduced upward and backward displacement of the upper lip and labial commissure, increased downward displacement of the lower lip, and increased asymmetric lateral displacement due to increased viscoelasticity of scar and surrounding facial tissues (21).

Furthermore, the study by Kuijpers et al. (2015), revealed that although deviations in nasolabial shape did not significantly impact overall aesthetic scores in CLP patients, factors beyond nasolabial shape deviation may influence aesthetic ratings. This highlights the complexity of addressing both functional and aesthetic consequences of cleft lip and palate conditions, requiring a multidisciplinary approach involving surgeons, orthodontists, speech therapists, and psychologists (22).

Nevertheless, the studies by Manyama et al. (2014), Matsumoto et al. (2016), and Harrison et al. (2021), emphasized the importance of understanding unique facial shape variations, the impact of cleft lip conditions on facial morphology and function, and the utility of 3D imaging in assessing nasal morphology in cleft patients, respectively (19,23,24).

5.3 Surgical protocols to repair the oral cleft

The management of orofacial clefts, encompassing cleft lip (CL), cleft palate (CP), and their combinations, is a multidisciplinary endeavour involving surgical, orthodontic, and speech therapies. This comprehensive approach aims not only to correct the anatomical defects but also to restore function and aesthetics, thereby improving the quality of life for affected individuals. The surgical protocols and techniques have evolved over the years, with advancements in technology providing more accurate and detailed assessments of surgical outcomes.

Several studies have emphasized the importance of specific surgical techniques in achieving favourable outcomes. For instance, primary lip repair using the Millard rotation-advancement technique has been demonstrated to be effective, with subsequent secondary rhinoplasty addressing nasal deformities (13). Similarly, the McComb technique for primary nose correction (16) and modified von Langenbeck procedure for soft palate closure (17) are established methods that contribute to comprehensive cleft care.

However, despite advancements in surgical techniques, studies have highlighted the challenges in achieving perfect symmetry and function. Bugaighis et al. (2014), found significant facial asymmetry among different cleft groups, with the UCLP and UCLA groups displaying the greatest asymmetry (12). Dynamic assessments revealed pronounced asymmetry during facial expressions, suggesting that surgical interventions may not always achieve optimal functional outcomes (14). Further corroborated these findings, demonstrating residual dynamic asymmetry in UCLP patient post-treatment (15).

The advent of 3D stereophotogrammetry has revolutionized the evaluation of surgical outcomes in orofacial cleft patients. These advanced imaging techniques allow for detailed morphological analyses, capturing even subtle changes in facial symmetry and dimensions (16,23). Such detailed assessments are crucial for refining surgical techniques and postoperative care strategies. For instance, the study by Hallac et al. (2017), emphasized the importance of dynamic 4D imaging in identifying areas for potential improvement in surgical techniques (14).

The timing of surgical interventions is another critical aspect of cleft management. Early lip closure, typically performed between two to four months of age, aims to correct the orofacial congenital condition, and lays the foundation for subsequent treatments (21) . Palatoplasty and alveolar bone grafting are performed at specific developmental stages to ensure optimal outcomes (25) . However, the study by Manyama et al. (2014), highlighted the need for early interventions and proper surgical planning, especially in African populations where surgical correction often occurs late in childhood (19).

Orthodontic treatments, such as the use of orthodontic appliances according to Hotz and Tennison-Randall techniques, play a crucial role in restoring vertical and sagittal dimensions of the face. These interventions, combined with surgical corrections, aim to achieve harmonious facial aesthetics and function (26).

Despite significant advancements in surgical techniques and imaging technologies, challenges remain in achieving optimal outcomes for orofacial cleft patients. Future research should focus on refining surgical protocols, exploring innovative techniques like LeFort I osteotomy and mandibular setback, and integrating multidisciplinary approaches involving surgery, orthodontics, and speech therapy (27).

5.4 3D Documentation and Measurements of facial asymmetry

The advent of three-dimensional (3D) stereophotogrammetric imaging has revolutionized the assessment of facial asymmetry, particularly in patients with orofacial clefts. These advanced imaging techniques offer non-invasive, qualitative, and quantitative methods to evaluate nasolabial appearance and facial morphology with unprecedented precision and reliability (13).

Several studies have employed 3D stereophotogrammetric imaging to assess nasolabial appearance in patients with unilateral cleft lip and palate (UCLP) and other types of oral clefts (12,17). For instance, Bagante et al. (2018), utilized 3D photographs taken with the 3dMDfaceSystem (3dMD LLC, Atlanta, GA), to accurately quantify nasal symmetry, demonstrating the method's suitability for routine evaluation after surgery (13). Similarly, Kuijpers et al. (2021), applied a quantitative evaluation method to measure shape differences and aesthetic ratings objectively, further highlighting the utility of 3D stereophotogrammetry in assessing surgical outcomes (17).

Facial asymmetry is a prominent feature in patients with oral clefts, as evidenced by Bugaighis et al. (2014) study, which revealed significant differences in facial asymmetry among different cleft groups. These findings suggest distinct growth patterns and etiological differences among various cleft groups and emphasize the potential of 3D imaging in aiding treatment planning and evaluating surgical outcomes (12). Together with dynamic assessment using 3D facial motion capture has further expanded our understanding of facial asymmetry in UCLP patients. Despite surgical intervention, residual dynamic deficiencies persist in UCLP patients, particularly affecting the corner of the mouth on the cleft side. Such findings underscore the importance of comprehensive assessment methods in evaluating surgical outcomes and planning targeted treatments to enhance functional and aesthetic outcomes (14,15). While 3D stereophotogrammetry offers numerous advantages, including fast image capture, high resolution, and safety, challenges remain in standardizing surgical techniques and minimizing changes in position and facial expression during image acquisition (16,18). Proper training, rigorous image selection, and complex image processing techniques are essential to ensure the accuracy and reliability of 3D facial imaging, particularly in young children and diverse populations (19,25).

5.5 Facial Anthropometric Landmarks

The evaluation of facial anthropometric landmarks plays a crucial role in understanding the intricate facial morphologies associated with orofacial clefts. These landmarks serve as essential reference points for assessing facial symmetry, asymmetry, and the impact of surgical interventions on the nasolabial appearance of cleft lip and palate (CLP) patients.

In a study by Bagante et al. (2018), detailed attention was given to landmarks such as the nasal tip, alar points, and height of nares. The study captured 25 landmarks and 18 distances manually on each image. Significant differences in the nasolabial appearance between UCLP and control groups were identified, with particular emphasis on alar wing length. This highlights the importance of specific landmarks in capturing and quantifying post-surgical outcomes, aiding in the development of enhanced surgical techniques for improved facial symmetry (13).

Bugaighis et al. (2014) conducted multiple studies focusing on 3D facial asymmetry in CLP patients, capturing 39 landmarks on each face. Also, they highlighted the significance of shape analysis in detecting differences in the growth patterns and aetiology of different cleft types. These studies underscore the importance of a comprehensive set of landmarks in understanding the multifaceted impact of clefts on facial morphology (12,16)

Transitioning to dynamic assessments, Patel et al. (2023) concentrated on the dynamic symmetry of the nasolabial complex during a maximum smile. Landmark displacement, path of motion, and dynamic asymmetry scores were primary outcome measures, assessed using MATLAB software. Their study highlighted the corner of the mouth on the cleft side as a significant landmark exhibiting greater asymmetry in UCLP patients, emphasizing the need for precise landmark tracking in evaluating dynamic facial expressions post-surgery (15). Together with Hallac et al. (2017), assessed facial movements during smiling and puckering, tracking thirteen anatomical landmarks using DI4D view software (Dimensional Imaging Ltd., Hillington Park, Glasgow, U.K). Their findings underscored the importance of dynamic asymmetry assessment, with the mid philtral ridge identified as a crucial landmark prone to muscle and skin scarring post-repair (14).

Several studies delved into specific anatomical landmarks crucial for assessing 3D soft tissue changes post-surgery. Brons, Darroudi, et al. (2019)utilized landmarks such as the exocanthion, endocanthion, tip of the nose, and cheilion to create boundary planes of the nasolabial region, integral for the analysis and mapping of 3D facial images (18). Matsumoto et al. (2016)emphasized the lip commissure and orbicularis oris muscle as critical landmarks for assessing morphological changes during facial expressions in patients with cleft lip (23).

5.6 Advantages of 3D Facial Analyses Over 2D Facial Analyses

Several studies have highlighted the superiority of 3D facial analyses in capturing detailed and accurate facial morphology compared to conventional 2D methods. Bagante et al. (2018) and Bugaighis et al. (2014) emphasized that 3D evaluation provides more precise measurement of anthropometric distances and landmarks, offering comprehensive data on facial symmetry and deformities post-surgery (13,16). The 3D approach captures the depth, volume, and spatial relationships between facial features, thus providing a more detailed and accurate representation of facial structures (23,26). Moreover, 3D imaging reduces errors from facial expression changes due to its quick acquisition time (16).

While 2D methods often rely on direct physical measurements, moire contourography, and laser scan imaging, 3D facial analyses utilize advanced techniques such as 3D scanners, providing higher resolution and more precise results (17,28). The geometrical accuracy of 3D analyses has been reported to be better than 0.5 mm (26). Also, 3D analyses offer enhanced reproducibility and accuracy, with minimal measurement errors observed even in healthy individuals (20).

In addition, 3D facial analyses allow for precise superimposition and alignment of facial images taken during different facial expression production, enabling detailed analysis of morphological changes between expressions (14,23, 15,29). Also, 3D facial analyses provide enhanced reproducibility and accuracy, reducing the potential for unnatural movement and improving accuracy compared to marker-dependent 2D methods (16,30) .

Despite the advantages of 3D facial analyses, 2D methods have their merits, such as simplicity and quickness. However, they are often more subjective and rely heavily on the experience of the judges (30). 2D analyses might focus on specific landmarks or regions, potentially missing broader facial asymmetries, or deformities (29).

5.7 Advantages of Three-dimensional Stereo-photogrammetric Camera

Three-dimensional (3D) stereo-photogrammetric cameras have revolutionized the field of craniofacial analysis, offering unparalleled advantages over traditional imaging methods.

One of the standout features of 3D stereo-photogrammetry is its remarkable precision. The 3dMDfaceSystem; 3dMD LLC, Atlanta, GA for instance, offers high geometrical accuracy with an average error validation of merely 0.5 mm (16). This precision surpasses many conventional methods, making it an invaluable tool for detailed anthropometric measurements and shape analyses (12,17). Moreover, the technology captures a continuous point cloud of the face, facilitating meticulous landmark placement and accurate coordinate extraction.

Unlike traditional methods that may expose subjects to radiation or require invasive procedures, 3D stereo-photogrammetry is non-invasive (14). This non-invasive nature ensures patient comfort, particularly in young children, enhancing cooperation during the imaging process. Additionally, the absence of physical contact or discomfort associated with the procedure improves patient experience and minimizes potential risks (25).

In addition, 3D stereo-photogrammetry allows for comprehensive 3D assessments of facial structures, capturing depth, volume, and spatial relationships with high precision (23). Its versatility enables the capture and analysis of multiple facial expressions, providing insights into dynamic facial asymmetry and movements (15).

The technology facilitates easy data storage, making it suitable for longitudinal analysis and comparison over time (16). Its compatibility with specialized software allows for detailed visualization, precise measurement calculations, and rigorous validation processes. This compatibility ensures consistency, facilitates standardized analysis of facial structures, and offers long-term monitoring capabilities (16).

Furthermore, 3D stereo-photogrammetry offers objective data analysis, minimizing bias and ensuring standardized and reliable assessment of facial symmetry and asymmetry (14). The system's reproducibility allows for reliable comparisons across different facial expressions and individuals, overcoming the subjectivity associated with manual assessment methods (20).

5.8 Limitations of Three-dimensional Stereo-photogrammetric Camera

Three-dimensional (3D) stereo-photogrammetric cameras have emerged as powerful tools in craniofacial research, particularly in assessing facial asymmetry and morphology in patients with cleft lip and palate (CLP). Despite their numerous advantages, including reliability, accuracy, and non-invasiveness, these systems are not devoid of limitations.

One of the primary concerns with 3D stereo-photogrammetric cameras is the potential for errors during image reconstruction. Dark regions, such as nostrils, pose challenges due to their intricate anatomy, making accurate capture difficult (13). Similarly, movements during image acquisition can introduce inaccuracies, affecting the precision of measurements (16). The reliance on software-based triangulation and mesh modelling may also introduce computational errors, potentially compromising the reliability of the results (16).

Moreover, the cost of the equipment remains a significant barrier, limiting its accessibility for widespread use, especially in resource-constrained settings (13). This high cost is compounded by the need for specialized software and trained personnel to operate and interpret the 3D images accurately (20).

Furthermore, maintaining a neutral facial expression during image capture is crucial for reproducibility. However, young children and infants, particularly those with conditions like unilateral cleft lip and palate (UCLP), often struggle to cooperate, leading to variations in facial expressions that can introduce errors (25). Several studies have highlighted limitations related to sample size and population diversity. For instance, studies focusing on specific ethnic, or age groups may not be representative of broader populations, limiting the generalizability of the findings (21,28). Moreover, some studies have small sample sizes, potentially impacting the statistical power and reliability of the results (27).

In addition, the ethical constraints, such as obtaining informed consent from parents or guardians, especially for repetitive image captures, can pose challenges in recruiting larger sample sizes (18). Additionally, the complex nature of 3D data requires specialized expertise for accurate interpretation and analysis, making it potentially time-consuming and challenging (29).

5.9 Assessment of Facial Asymmetry Measurements between Cleft and Noncleft

The study by Bagante et al. (2018), focused on the nasolabial appearance in patients with complete unilateral cleft lip and palate (UCLP) using 3D stereo-photogrammetry. They found a significant difference between the cleft and noncleft sides only in alar wing length in the UCLP group. In contrast, the control group did not show significant differences between the left and right sides (13).

Bugaighis et al. (2014), examined 3D facial asymmetry in children with oral clefts compared to a control group. They identified significant differences in all cleft groups compared to the controls. Specifically, the UCLP and UCLA groups displayed the greatest asymmetry, followed by the BCLP group. The CP group showed the least asymmetry among the cleft groups (12).

In another study by Bugaighis et al. (2104), distinct facial morphological differences were identified in each cleft group compared to controls. The UCLP and UCLA groups exhibited significant asymmetries mainly in the nasolabial region, with the UCLP group showing broader intercanthal width and shorter upper lips. The BCLP group presented wider nasal widths and reduced maxillary prominence angles, indicating midface retrusion (16).

Patel et al. (2023), investigated nasolabial dynamics in adult patients with UCLP using 3D facial motion capture. They found increased asymmetry in UCLP patients, especially in the horizontal movement of the cleft-side mouth corner. The path of motion and shape of the lips and nose also showed significant differences between the groups (15).

Lee et al. (2021), explored facial displacement differences and found that patients with UCLP exhibited greater viscoelasticity in scar and surrounding facial areas compared to healthy adults. They also revealed a significant association between the physical properties of the scar tissue and facial displacement during smiling (21).

In a study focusing on involuntary facial expressions, Brons, Darroudi et al. (2019), found that the mean variation in 3D images was slightly higher in UCLP subjects compared to control subjects, suggesting caution in interpreting 3D facial imaging data, especially in young children (18).

Kuijpers et al. (2015), examined nasolabial shape and aesthetics in patients with unilateral cleft lip and palate (CLP) using 3D stereophotogrammetric imaging. They found that the severity of the cleft corresponded with lower aesthetic ratings, but shape differences between cleft and noncleft faces did not significantly affect aesthetic ratings, except for the nasal profile (22).

Matsumoto et al. (2016) conducted a detailed 3D morphological assessment comparing facial asymmetry between healthy subjects and cleft lip patients, both pre- and post-surgery. They found distinct facial asymmetries in cleft lip patients, especially in laterality across facial sections, and highlighted the critical role of the orbicularis oris muscle in upper lip structure and function (23).

5.10 Clinical Relevance

The array of studies presented offers comprehensive insights into the complexities surrounding facial asymmetry in individuals with cleft lip and palate (CLP). 3D stereophotogrammetry emerges as a crucial tool in evaluating and monitoring postoperative outcomes in cleft lip and palate patients (13). Its non-invasive nature coupled with its accuracy in capturing specific anthropometric landmarks makes it an asset in routine clinical practice. Moreover, advanced techniques like 4D imaging and facial motion capture technology provide dynamic assessments that offer a more nuanced understanding of facial asymmetry (14,15).

Additionally, studies consistently highlight significant differences in facial morphology between cleft and non-cleft individuals. These differences encompass various regions, including the nasolabial area, intercanthal width, nasal widths, and midface retrusion, underscoring the profound impact of oral clefts on facial symmetry and morphology. Such insights are crucial for devising targeted treatment strategies and improving surgical outcomes (12,16,19).

Despite advancements in surgical techniques, achieving optimal facial symmetry remains a challenge. Scar tissue, muscle restrictions, and anatomical defects often contribute to persistent asymmetry and functional limitations, necessitating ongoing research and refinements in surgical approaches (23,24).

Furthermore, facial asymmetry not only affects aesthetic appearance but also impacts functional movement and psychosocial well-being (20,21). Residual asymmetry post-surgery can lead to reduced facial expressions, affecting emotional expressions like smiling, which can significantly impact an individual's quality of life. Studies highlight potential variations in facial characteristics among different populations (19,30). Understanding these population-specific nuances is vital for tailoring treatment approaches and ensuring culturally sensitive care.

Facial aesthetics play a crucial role in shaping patients' self-perception and societal interactions (17). The complexity of facial aesthetics in CLP patients underscores the importance of individualized treatment approaches and ongoing evaluations to address nasolabial deviation and other aesthetic concerns effectively.

6. Conclusion

The extensive body of research highlights the significant impact of facial asymmetry on both aesthetic and functional outcomes in patients with cleft lip and palate (CLP) following surgery. Advanced 3D stereophotogrammetry has proven invaluable for objectively assessing and quantifying these asymmetries across different cleft types. However, despite surgical interventions aiming to restore facial symmetry and enhance patient well-being, challenges like scar tissue formation, altered tissue properties, and inherent deformities often lead to residual asymmetry.

These complexities emphasize the importance of individualized treatment strategies, early intervention, and ongoing monitoring to effectively address the multifaceted nature of facial asymmetry. The careful identification and analysis of facial anthropometric landmarks are essential for understanding the complex facial morphologies associated with CLP. Advanced 3D stereophotogrammetry techniques, combined with accurate landmark tracking, offer valuable insights into nasolabial appearance, facial symmetry, and dynamic facial asymmetry, guiding surgical interventions and evaluating treatment outcomes effectively.

While 2D facial analyses have been crucial in previous studies, 3D facial analyses provide a more comprehensive, detailed, and accurate assessment of facial morphology. Three-dimensional stereo-photogrammetric cameras have transformed facial analysis by offering precision, non-invasiveness, versatility, and compatibility with advanced software. These tools have become essential in both clinical research and routine clinical practice, enabling clinicians and researchers to evaluate facial structures, understand facial deformities, assess surgical outcomes, and monitor patient progress reliably.

However, despite the benefits of 3D imaging techniques, they come with their own set of challenges. Issues like improving image reconstruction accuracy, reducing costs, enhancing patient cooperation, and ensuring broader population representation must be addressed to fully leverage the potential of this technology in craniofacial research and clinical applications. Additionally, while facial asymmetry is more pronounced in individuals with clefts compared to those without, and varies depending on the type of cleft, understanding these variations is essential for developing targeted interventions and improving treatment outcomes.

Overall, the discussed studies collectively highlight the multifaceted nature of facial asymmetry in individuals with CLP and stress the significance of advanced imaging techniques, individualized treatment strategies, and interdisciplinary care. Ongoing research, interdisciplinary collaboration, and personalized treatment planning are essential to tackle the challenges associated with facial asymmetry comprehensively. Despite significant progress in assessment techniques, surgical interventions, and comprehensive care approaches, there are still considerable challenges in achieving optimal functional, aesthetic, and psychosocial outcomes for affected individuals. Therefore, continued research and technological advancements are vital for enhancing surgical outcomes, improving patient quality of life, and advancing holistic care for individuals with CLP and other craniofacial deformities.

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