Data-Driven Decisions: A Systematic Review of Artificial Intelligence and Machine Learning in Cleft Orthognathic Surgery

Dr. Ramya Vijeta Jathanna[1], Dr. Vinod Rakesh Jathanna[2], Dr. Rithesh Bangera[3], Dr. Prashanth Lowell Monis[4]

[1]D MDS, Reader, Department of Orthodontics and Dentofacial Orthopedics, Manipal College of Dental Sciences, Manipal Academy of Higher Education, India., Email: ramya.jathanna@manipal.edu
[2]MDS, Associate Professor, Department of Conservative Dentistry and Endodontics, Manipal College of Dental Sciences, Mangalore, Manipal Academy of Higher Education, India, Email: vinod.jathanna@manipal.edu
[3]MDS, Reader, Department of Orthodontics and Dentofacial Orthopeadics, KVG Dental college and Hospital Karunjibhag, DK, India, Email: rrbangera14@gmail.com
[4]MDS, Department of Craniofacial Surgery, Mazumdar Shaw Medical Hospital, Narayana Health Bengaluru, India, Email: monislowell@gmail.com

KEYWORDS

Artificial Intelligence, machine learning, cleft lip, cleft palate, health informatics.

ABSTRACT

Introduction: In recent times, there has been a growing interest in the integration of artificial intelligence (AI) and machine learning (ML) into the realm of cleft orthognathic surgery, presenting an exciting avenue for transformative innovations. These technologies offer the promise of optimizing treatment plans, facilitating surgical decision-making, and contributing to a more patient-centric approach. However, a systematic and in-depth exploration of the existing literature is essential to discern the true impact, challenges, and potential future directions of AI and ML in this specialized field. The present systematic review aimed to provide an overview of AI and ML algorithms and their applications in cleft orthognathic surgery. Methodology: A comprehensive search was conducted in databases using MeSH terms and other relevant terms including PubMed, Embase, and Scopus until January 2024. This systematic review was conducted following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. Results: The search strategy resulted in a total of 124 articles. After applying the inclusion and exclusion criteria, a total of 5 studies were included for final review. AI has profoundly impacted the prediction of the need for orthognathic surgeries in cleft patients using cephalometric variables with a clinically acceptable accuracy range. Also, provide guidelines to determine the amount and direction of movements of the maxilla and mandible. Conclusions: Understanding the role of AI and ML in cleft orthognathic surgery is paramount for clinicians, researchers, and policymakers alike.AI reduces the work burden of the clinician by eliminating the tedious registration procedures, thereby helping in efficient and automated planning.

1. Introduction

Cleft orthognathic surgery stands at the intersection of precision medicine and surgical innovation, offering transformative interventions for individuals born with cleft lip and palate conditions.[1] These complex craniofacial anomalies necessitate meticulous planning and execution to achieve optimal functional and aesthetic outcomes. In recent years, the integration of artificial intelligence (AI) and machine learning (ML) technologies has emerged as a promising avenue to enhance the precision, efficiency, and efficacy of cleft orthognathic procedures.[2]

This systematic review seeks to comprehensively explore the current landscape of AI and ML applications in cleft orthognathic surgery, elucidating their potential impact on surgical decision-making, patient outcomes, and the broader field of craniofacial surgery.

Rationale and objectives

The rationale for conducting this systematic review lies in the imperative to bridge the gap between technological advancements and clinical practice in cleft orthognathic surgery. While traditional approaches have yielded significant improvements in patient care, they are often constrained by inherent limitations, such as variability in surgical planning, intraoperative precision, and postoperative outcomes.[3,4] By systematically evaluating the existing literature on AI and ML applications, this review aims to address critical questions regarding the feasibility, efficacy, and safety of integrating these technologies into the cleft orthognathic surgical workflow.

Furthermore, the growing body of evidence suggests that AI and ML have the potential to revolutionize various aspects of cleft orthognathic surgery, including preoperative assessment, virtual surgical planning, intraoperative guidance, and postoperative monitoring. Through a comprehensive synthesis of published studies, this review aims to identify key trends, challenges, and opportunities in harnessing AI and ML to inform data-driven decisions in cleft orthognathic surgery.

Moreover, by critically appraising the quality and methodological rigor of the included studies, this review will provide valuable insights into the reliability and generalizability of AI and ML-based approaches in the context of cleft orthognathic surgery. Ultimately, the findings of this systematic review have the potential to inform clinical practice, stimulate further research, and contribute to the ongoing evolution of precision medicine in the management of craniofacial anomalies.

Research question.

What is the extent of research on the application of AI and ML in cleft orthognathic surgery, and what are the key findings regarding their efficacy, accuracy, and clinical impact?

2. Methods:

Research design

This study was conducted and reported in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). [5]

A protocol was developed based on the PRISMA Protocols and registered (CRD42024514618) at the International Prospective Register of Systematic Reviews (PROSPERO).

Eligibility criteria

<u>Inclusion Criteria</u>

a. Studies focusing on the application of AI and ML in cleft orthognathic surgery.

b. Randomized Controlled Trials (RCTs)

c. Case controlled trials (CCTs).

d. Prospective studies

e. Restroscpective studies

f. Articles written in English.

g. Studies involving human subjects.

<u>Exclusion Criteria</u>

a. Non-English articles.

b. Studies not related to cleft orthognathic surgery.

c. case reports,

d. review articles

e. opinion articles

f. abstracts

g. Nonclinical studies

Information source and search strategy

The electronic search strategy was designed to identify relevant studies examining the role of artificial intelligence in treating cleft orthognathic patients. PubMed, Scopus, and Web of

Science Core Collection were searched for peer-reviewed literatures. Reference list of included articles were hard searched to identify additional studies. All identifies articles were imported into reference management software, Mendeley. Two independent reviewers screened the articles until January 2024. The search was conducted using keywords and Boolean operators for each database with a combination of terms related to 'artificial intelligence', 'orofacial clefts' and 'orthognathic surgery'.

Study selection and data collection.

Two independent reviewers screened the titles and abstract based on the inclusion and exclusion criteria separately and concurrently. Full texts of potentially relevant articles were assessed for eligibility. Any discrepancy between the two reviewers were resolved through discussion or consultation with a third reviewer.

Data extraction

Data extraction of the selected studies was performed independently by two reviewers, and any discrepancies was resolved through discussion. Data collection consisted of study characteristics (authors, year, country, and study design), sample characteristics (sample size, gender, and age of participants), methodology details (AI/ML techniques employed), outcome assessment, and main results.

Dealing with missing data

The analysis was conducted using only the data available, with missing data excluded from consideration.

Risk of bias assessment

The quality of the included nonrandomized studies was independently assessed using the Newcastle-Ottawa Scale.[6] The quality of the included non-randomized studies was independently evaluated using the Newcastle-Ottawa Scale. This tool consist of eight items across three dimensions: Selection(adequacy and representativeness of participants, and selection and definition of controls), comparability, and exposure (verification of exposure, distinction between cases and controls, and nonresponse rate). The maximum possible score is 9 points, with scores of 6 or higher indicating high quality and scores below 6 indicating low quality. Any disagreements between reviewers were resolved through consensus or, if needed, by consulting the third author.

Additional synthesis

An additional synthesis was conducted, as the substantial functional differences and clinical heterogeneity among the cleft classifications and machine learning models rendered a meta-analysis unsuitable.

3. Results:

Study selection

A total of 124 articles were identified through searches in Scopus, PubMed, and Web of Science using predefined search strings and relevant database keywords. The PRISMA 2020 flowchart (Figure 1) outlines the screening process, including full-text assessments and reasons for exclusion.

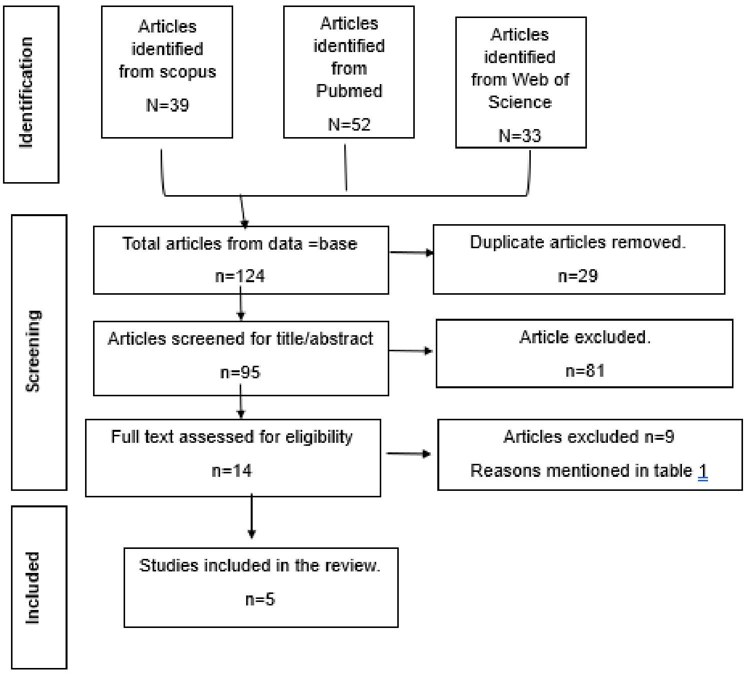

Figure 1: PRISMA flow diagram for studies searched.

After a thorough review, 29 duplicate articles were removed, and 81 were excluded based on title and abstract screening. Fourteen full-text articles were assessed, with 5 meeting the criteria for final inclusion. The specific reasons for exclusion are detailed in Table 1.

Table 1: Articles excluded and reason for exclusion after reading the full paper.

No	Authors and Year of publication	Title	Reason for exclusion
1	Numan Shafi, Faisal Bukhari,Waheed Iqbal,Khaled Mohamad Almustafa, Muhammad Asif, Zubair Nawaz [7] 2020	Cleft prediction before birth using deep neural network	This paper evaluates the cleft prediction using AI and not need for Orthognathic surgery
2	Yizhou Li, Junhao Cheng, Hongxiang Mei, Huangshui Ma, Zhuojun Chen and Yang Li[8] 2019	CLPNet: Cleft Lip and Palate Surgery Support with Deep Learning	The authors established a robust dataset for the localization of cleft lip and palate surgery with deep learning for plastic 3surgeries of clef tip and palate repair (surgical markers) and not need for orthognathic surgery
3	Meng Xu, Bingyang Liu,Zhaoyang Luo, Hengyuan Ma, Min Sun, Yongqian Wang, Ningbei Yin, Xiaojun Tang, and Tao Song [9] 2023	Using a New Deep Learning Method for 3D Cephalometry in Patients With Cleft Lip and Palate	Clinical study to apply a new deep learning method based on a 3D point cloud graph convolutional neural network to predict and locate landmarks in patients with cleft lip and palate based on the relationships between points. Not need for orthognathic surgery
4	Conrad J Harrison1, Chris J Sidey-Gibbons, Anne F Klassen, Karen W Y Wong Riff, Dominic Furniss,Marc C Swan, Jeremy N Rodrigues [10] United Kingdom 2021	Recursive Partitioning vs Computerized Adaptive Testing to Reduce the Burden of Health Assessments in Cleft Lip and/or Palate: Comparative Simulation Study	Decision tree models incorporating clinician-reported data into adaptive CLEFT-Q assessments. and compare their accuracy to traditional CAT models. Not needed for orthognathic surgery
5	M.R. Ortiz-Posadasa, L. Vega-Alvaradob, B. Toni Mexico [11] 2008	A mathematical function to evaluate surgical complexity of cleft lip and palate	Mathematical model
6	M.R. Ortiz-Posadasa, L. Vega-Alvaradob, B. Toni [12] Mexico 2003	A similarity function to evaluate the orthodontic condition in patients with cleft lip and palate	Mathematical model
7	Sara C Chaker, BS, Ya-Ching Hung, MD, MPH, Mariam Saad, Michael S Golinko, and Izabela A Galdyn. [13] USA 2024	Easing the Burden on Caregivers- Applications of Artificial Intelligence for Physicians and Caregivers of Children with Cleft Lip and Palate	evaluated artificial intelligence (AI) as a tool to mitigate high level of anxiety in caregivers of cleft lip and palate children
8	Shuang Chen, Amir Atapour-Abarghouei, Edmond S.L. Ho, Hubert P.H. Shum[14] United Kingdom 2023	INCLG: Inpainting for non-cleft lip generation with a multi-task image processing network	Software publication
9	Jia Wu, Carrie Heike, Craig Birgfeld, , Kelly Evans, Murat Maga, Clinton Morrison, Babette Saltzman, Linda Shapiro, Raymond Tse. [15]	Measuring Symmetry in Children with Unrepaired Cleft Lip: Defining a Standard for the Three-Dimensional Midfacial Reference Plane	Does not involve orthognathic surgery

Characteristics of included studies

As per the inclusion criteria, we included 5 articles, and their characteristics are listed in Table 2. These 5 studies discuss different applications of AI/ML models in predicting the need for orthognathic surgery in patients with CLP. Also, provide guidelines to determine the amount and direction of movements of the maxilla and mandible.

Table 2: characteristics of included studies

Author year country	purpose	sample	AI dataset	algorithm	Validation method	outcome	Author,s conclusion
Lim 2021 Japan[16]	Determine prognostic factors for OGS in cleft patients	126 Japanese patients with bilateral and unilateral clefts	Lateral cephalograms taken at different age	Machine learning		Mean AUC of six models: 0.93 (0.91 to 0.99) and need for orthognathic surgery at T1 and T2 AUC: 0.91 Sensitivity: 0.78 Specificity: 0.87	The prognostic factors for OGS determined by the AI systems were the number of clefts in the lip and alveolus, the palatal repair method, male sex, several cephalometric variables for the sagittal and vertical dimensions, growth patterns and the number of missing teeth.
Park 2015;[17] South Korea	Predict future need for OGS or DO in cleft patients using cephalometric variables	131 patients (surgical: 27 and nonsurgical: 104)	Lateral cephalograms taken at different age	Machine Learning (Feature Wrapping method with support vector machine/ sequential forward search algorithms)	10-fold cross validation	Adjusted classification Accuracy: 77.3% Sensitivity: 99.0% Specificity: 74.1%	Ten effective cephalometric predictors of the future need for OGS were identified
Lin 2021 Korea[18]	Prediction of the need for OGS	56 unilateral cleft lip and palate patients	Lateral cephalograms taken at different age	Machine learning model (Boruta method & XG algorithm	10-fold cross validation	Cross-validation accuracy: 87.4%	At age of 6 years it was possible to predict the future need for surgery to correct their sagittal skeletal discrepancy in patients with UCLP using cephalometric predictors with a good accuracy
Seo 2021; South Korea[19]	3D facial soft tissues changes after OGS in cleft patients	34 young adult cleft patients with skeletal Class III malocclusion	CT	Automatic digitization of landmarks using 3DONS	17 images re-digitized by same operator at a 2-week interval	Clinical findings were summarized	recommended to perform adjunctive aesthetic surgeries, including corrective rhinoplasty, cheiloplasty, and allograft after BOGS in cleft patients
Alam [20] 2021 Saudi	Sagittal Jaw Relationship of Different Types of Cleft and Non-cleft Individuals	123 subjects with different types of clefts including 29 = BCLP (bilateral cleft lip and palate), 41 = UCLP (unilateral cleft lip and palate), 9 = UCLA (unilateral cleft lip and alveolus), 13 =	Digital lateral cephalograms	Machine learning (webCeph software)		AI based cephalometric assessment showed 95.6% accuracy.	study advocates a decrease in sagittal development (SNA, ANB and Wits appraisal) in different types of cleft compared to NC individuals.

		UCL (unilateral cleft lip) and NC = 31					

Results of risk of bias

Bias assessments were carried out independently by two reviewers. Out of the 5 included studies, four studies were of high quality, with a Newcastle-Ottawa Scale score of 6 or more. One study was regarded as being of low quality, with a Newcastle-Ottawa Scale score of less than 6. Table 3 summarizes the results of Risk of bias assessment as per Newcastle-Ottawa Scale.

Table 3: The summary of risk of bias assessment as per Newcastle-Ottawa Scale

	Selection (4)				Comparability (2)	Outcome (3)			Total (9)
	Is case definition adequate? (1)	Representativeness of the subjects (1)	Selection of controls (1)	Definition of controls (1)	Comparability on basis of design or analysis (2)	Ascertainment of exposure (1)	Same method of ascertainment for subjects and controls (1)	Nonresponse rate (1)	
Lim 2020[16]	*	*		*	**	*	*		7
Park 2015[17]	*	*		*	**	*			6
Lin 2021[18]	*	*		*	**	*			6
Seo 2021[19]	*	*	*	*		*			5
Alam 2021[20]	*	*	*	*	**	*			7

4. Discussion:

The application of artificial intelligence (AI) and machine learning (ML) in healthcare has evolved significantly over the past few decades, with dentistry and oral surgery gradually adopting these technologies. In the 1990s, early forms of computer-aided diagnosis (CAD) emerged, using simple algorithms to assist clinicians with cephalometric analysis and treatment planning. However, the limited computing power and data availability restricted their utility.

With the rise of 3D imaging technologies in the 2000s, including cone-beam computed tomography (CBCT) and stereophotogrammetry, more advanced AI models began to be developed. These tools offered improved precision in identifying anatomical landmarks and provided surgeons with enhanced visualization for complex procedures like orthognathic surgery.

Cleft lip and palate (CLP) are a congenital condition that significantly impacts craniofacial development and requires comprehensive treatment. Orthognathic surgery (OGS) is often a crucial component of the treatment plan for individuals with CLP, aiming to correct skeletal discrepancies and improve facial harmony. In this systematic review, we synthesized findings from five studies that investigated various cephalometric predictors and craniofacial characteristics associated with CLP using different methodologies and analytical approaches.

Most (3) of the studies included in this systematic review were conducted in South Korea[17,18,19], one study each from Japan[16] and Saudi Arabia[20]. Although CLP is a common congenital deformity, its prevalence varies across different ethnic groups. The higher occurrence of clefts among Asians, compared to other populations, likely explains the extensive research in South Korea and Japan—driven both by the need to address a prevalent issue and the availability of relevant data. The six included studies involved a total of 470 patients with 423 patients with different types of clefts and 47 non cleft patients.

Lim et al. (2021) identified prognostic factors for OGS in children with CLP using artificial intelligence (AI) systems. They found that the number of clefts in the lip and alveolus, palatal repair method, male sex, and specific cephalometric variables were predictive of the future need for surgery. This highlights the importance of early assessment and personalized treatment planning to optimize outcomes in this population.

Seo et al. (2021) examined three-dimensional facial soft tissue changes after orthognathic surgery in patients with cleft lip and palate. Their study revealed differences in soft tissue responses to surgery between cleft and non-cleft individuals, suggesting that scar tissues and abnormal muscles in the nose and upper lip may influence outcomes. Understanding these differences is essential for tailoring surgical approaches and managing patient expectations.

Lin et al. (2021) employed machine learning techniques to predict the need for orthognathic surgery in patients with repaired unilateral cleft lip and palate. They identified cephalometric predictors that could accurately classify patients into surgery and non-surgery groups, providing valuable insights for early intervention and treatment planning. Early identification of patients who may benefit from surgery can help improve long-term outcomes and reduce the need for extensive interventions.

Park et al. (2022) examined cephalometric predictors for determining the future need for orthognathic surgery or distraction osteogenesis in Korean male patients with nonsyndromic cleft lip and palate. Their findings underscored the importance of cephalometric variables in predicting the need for surgery, with specific measurements demonstrating significant differences between surgery and non-surgery groups. These findings contribute to the development of personalized treatment plans and enhance clinical decision-making.

Alam et al. (2023) analyzed craniofacial sagittal jaw relationships in patients with non-syndromic cleft compared to non-cleft individuals using AI-driven lateral cephalometric analysis. Their study identified significant differences in sagittal development between cleft and non-cleft individuals, emphasizing the impact of CLP on craniofacial morphology. This underscores the importance of comprehensive evaluation and tailored interventions to address these differences and achieve optimal outcomes.

5. Conclusions:

The findings from these studies provide valuable insights into prognostic factors for orthognathic surgery, soft tissue changes after surgery, predictive modeling for surgical intervention, and craniofacial characteristics in patients with CLP. These insights contribute to the development of evidence-based treatment protocols and personalized approaches to care, ultimately improving outcomes and quality of life for individuals with CLP. Understanding the role of AI and ML in cleft orthognathic surgery is paramount for clinicians, researchers, and policymakers alike. AI reduces the work burden of the clinician by eliminating the tedious registration procedures, thereby helping in efficient and automated planning. However, further research is needed to validate these findings and explore additional factors that may influence treatment outcomes in this population. Additionally, longitudinal studies with larger sample sizes are warranted to assess the long-term stability of surgical outcomes and evaluate the effectiveness of interventions over time

Clinical significance:

1. The integration of AI and ML into cleft orthognathic surgery enhances surgical planning precision and personalizes treatment, significantly improving patient outcomes.2.

2. AI technologies accurately predict surgical needs and guide jaw movements, reducing clinician workload and streamlining planning processes.

3. Although AI shows promise, further research with larger samples and rigorous validation is needed to address current limitations and fully realize its potential as a supplementary tool in cleft orthognathic surgery

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