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AI-ENHANCED SURGICAL PLANNING AND AR/VR-GUIDED MAXILLOFACIAL RECONSTRUCTION IN BROAD FACE SYNDROME: A CASE REPORT

KEY WORDS: Broad face syndrome; Artificial intelligence; Augmented reality; Virtual reality; Genioplasty; Mandibular contouring; Maxillofacial reconstruction

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ABSTRACT

Broad face syndrome is a craniofacial condition characterized by disproportionate transverse facial dimensions and reduced vertical height, resulting in aesthetic imbalance and psychosocial concerns. Conventional surgical correction often relies on subjective surgeon judgment, which may introduce variability in outcomes. Recent advances in artificial intelligence (AI), augmented reality (AR), and virtual reality (VR) have enabled structured, reproducible, and patient-specific planning tools in oral and maxillofacial surgery [1–3]. We present the case of a 20-year-old female who reported dissatisfaction with her broad facial appearance. Surgical management included bilateral mandibular angle shaving and vertical augmentation genioplasty. AI-based analytics were used for automated defect characterization and predictive outcome modelling, VR simulation facilitated preoperative rehearsal, and AR provided intraoperative guidance. The patient achieved improved facial harmony, enhanced vertical dimension, and high satisfaction with postoperative outcomes. This case demonstrates the transformative role of digital surgical informatics in maxillofacial reconstruction, highlighting the potential of AI, AR, and VR to augment surgical expertise and improve predictability [4–6].

INTRODUCTION

Broad face syndrome is a craniofacial condition characterized by increased bizygomatic and mandibular width, coupled with a reduced vertical facial dimension, resulting in aesthetic imbalance and functional concerns. Patients often present with dissatisfaction regarding facial proportions, psychosocial distress, and, in some cases, functional limitations related to occlusion or mastication [1,2]. The syndrome may be associated with congenital craniofacial anomalies, developmental variations, or acquired deformities following trauma or surgical interventions. While the condition is relatively rare compared to other craniofacial syndromes, its impact on facial aesthetics and patient self-esteem is significant, warranting careful surgical evaluation and management [3].

Conventional approaches to the correction of broad face syndrome have relied heavily on surgeon judgment, anatomical knowledge, and intraoperative estimation. Procedures such as mandibular angle shaving, genioplasty, and orthognathic surgery have been employed to restore facial harmony [4,5]. However, these methods are inherently subjective, and outcomes may vary depending on the surgeon's experience and intraoperative decision-making. Variability in surgical planning and execution has been a longstanding challenge in oral and maxillofacial surgery, particularly in complex cases where multiple anatomical and aesthetic variables must be simultaneously considered [6].

The emergence of artificial intelligence (AI), augmented reality (AR), and virtual reality (VR) has initiated a paradigm shift in maxillofacial reconstructive workflows. AI systems are capable of analyzing large volumes of clinical and radiological data, enabling automated segmentation, defect characterization, and predictive modelling of surgical outcomes [7,8]. These tools provide objective, reproducible insights that reduce reliance on subjective interpretation and enhance surgical precision. For example, deep learning algorithms have demonstrated high accuracy in delineating craniofacial structures from CT and CBCT datasets, facilitating precise preoperative planning [9]. Predictive analytics further allows surgeons to simulate postoperative outcomes, compare reconstructive options, and select the most appropriate approach [10].

Health informatics frameworks underpin the integration of AI into surgical practice by enabling structured data storage, interoperability, and longitudinal outcome tracking [11]. Informatics systems facilitate seamless communication between imaging modalities, surgical planning software, and electronic health records, thereby supporting multidisciplinary collaboration and evidence-based decision-making [12]. Importantly, the reliability of AI models is highly dependent on the quality and standardization of underlying datasets, making informatics infrastructure essential for reproducibility across clinical settings [13].

Visualization technologies such as AR and VR have further strengthened the transition toward precision-based surgery. AR enables real-time overlay of patient-specific anatomical structures onto the surgical field, improving intraoperative orientation and spatial accuracy [14,15]. This is particularly valuable in anatomically complex regions such as the midface, orbit, and skull base, where conventional visualization is limited. Clinical studies have reported that AR-assisted workflows contribute to reduced operative time, improved precision in flap positioning, and decreased risk of intraoperative complications [16]. VR, in contrast, provides an immersive environment for preoperative planning and surgical simulation, allowing clinicians to interact with three-dimensional anatomical models and rehearse complex procedures [17]. VR has also demonstrated substantial educational value, offering trainees a controlled, risk-free environment to develop surgical skills and gain familiarity with complex anatomy [18].

The integration of AI, AR, and VR into maxillofacial surgery aligns with the broader principles of precision medicine, which emphasize individualized, data-driven treatment strategies tailored to each patient's unique anatomical and biological profile [19]. In the context of broad face syndrome, these technologies enable objective quantification of facial disproportion, simulation of corrective procedures, and real-time intraoperative guidance, thereby enhancing both aesthetic and functional outcomes.

Several studies have highlighted the transformative potential of these technologies in oral and maxillofacial surgery. Al-Sukhun et al. [20] reviewed current applications of AI in OMFS, noting its utility in diagnosis, treatment planning, and risk prediction. Heiland et al. [21] demonstrated the feasibility of AR-assisted navigation in craniofacial surgery, reporting improved accuracy and reduced operative time. Wong et al. [22] explored the role of VR simulation in genioplasty planning, emphasizing its value in preoperative rehearsal and patient communication. Choi et al. [23] investigated AI-driven predictive modelling in orthognathic surgery, showing that machine learning algorithms could accurately forecast postoperative outcomes. Collectively, these studies underscore the growing evidence base supporting the integration of AI, AR, and VR into maxillofacial reconstructive workflows.

Despite these advancements, several challenges remain. Economic considerations, including the high cost of AR/VR systems and computational infrastructure, may limit widespread adoption [24]. Technical barriers such as system calibration, registration accuracy, and user training also require further refinement [25]. Ethical and regulatory concerns related to data privacy, algorithmic transparency, and clinical accountability must be carefully addressed to ensure safe and responsible implementation [26]. Furthermore, the current evidence base is limited by a lack of large-scale prospective clinical trials validating the long-term effectiveness and cost-efficiency of AI-assisted approaches [27].

In summary, broad face syndrome is a complex craniofacial condition that requires precise surgical intervention to restore facial harmony. Conventional methods, while effective, are limited by subjectivity and variability. The integration of AI, AR, and VR offers a transformative approach, enabling objective assessment, immersive planning, and real-time intraoperative guidance. This case report illustrates the application of these technologies in managing broad face syndrome, highlighting their potential to augment surgical expertise and improve the predictability of outcomes.

CASE REPORT

A 20-year-old female presented to the Department of Oral and Maxillofacial Surgery with the chief complaint of dissatisfaction regarding her broad facial appearance. She reported psychosocial distress related to her facial proportions, noting that the increased width of her lower face and reduced vertical dimension contributed to aesthetic imbalance. Clinical examination revealed bilateral mandibular angle hypertrophy, increased bizygomatic width, and vertical deficiency of the chin. Radiological evaluation using cone beam computed tomography confirmed the presence of prominent gonial angles and reduced vertical chin height, consistent with broad face syndrome.

In the preoperative planning phase, artificial intelligence-based analytics were employed to process the CBCT datasets. Automated segmentation delineated mandibular structures, quantified gonial angle prominence, and measured vertical deficiency of the chin. Predictive modelling simulated postoperative outcomes, allowing comparison of different surgical strategies. The analysis suggested that mandibular angle shaving combined with vertical augmentation genioplasty would achieve optimal facial harmony. Virtual reality simulation was then utilized to rehearse the planned procedures. Patient-specific three-dimensional models were generated, enabling the surgical team to interact with the anatomy in an immersive environment. This rehearsal facilitated evaluation of osteotomy lines, bone graft positioning, and anticipated changes in facial proportions. VR also served as a communication tool, allowing the patient to visualize potential outcomes and participate in shared decision-making. Augmented reality was integrated into intraoperative planning, with digital overlays of anatomical landmarks prepared for real-time guidance during surgery. This ensured precise identification of gonial angles, osteotomy sites, and graft placement zones.

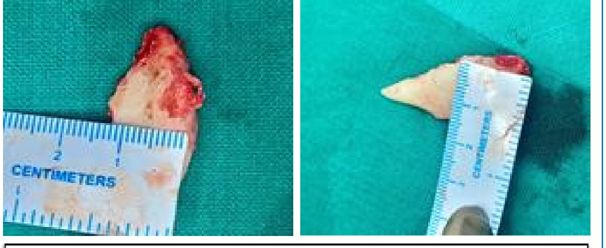

Figure 1: shows the shaved mandibular angles

Under general anesthesia, intraoral vestibular incisions were placed bilaterally, extending from the second premolar region to the middle of the ramus. Through these approaches, mandibular angle shaving was performed to reduce gonial prominence and achieve narrowing of the transverse facial dimension. Augmented reality–assisted navigation provided real-time visualization of anatomical landmarks, ensuring symmetrical reduction of both angles and minimizing reliance on intraoperative estimation. Osteotomy lines were executed according to artificial intelligence–predicted measurements, which reduced variability and enhanced precision (as shown in Figure 1).

Following contouring of the mandibular angles, vertical augmentation genioplasty was undertaken. A vestibular incision extending from the 1^{st} premolar to the 1^{st} premolar was made, followed by a carefully planned horizontal osteotomy from the first premolar on one side to the first premolar on the contralateral side. Care was taken to preserve the mental nerve, with the osteotomy line positioned inferior to its branches. After mobilization of the segment, the required vertical augmentation was achieved using autogenous bone grafts harvested from the mandibular angles that were trimmed. Fixation was accomplished with one Y-shaped titanium miniplate and two four-hole miniplates, providing stable support and maintaining symmetry (as shown in Figure 2).

Figure 2 shows the vertical augmentation genioplasty achieved using autologous bone grafts followed by fixation.

Throughout the procedure, AR guidance facilitated accurate graft positioning and plate fixation, while AI-driven predictive analytics continuously provided intraoperative feedback on anticipated changes in facial proportions. This digital workflow ensured precise execution of the surgical plan, optimized aesthetic outcomes, and enhanced intraoperative confidence.

The patient's immediate postoperative outcome demonstrated improved facial harmony, with elongated vertical dimension and reduced mandibular width. Healing was uneventful, with no complications such as infection, graft resorption, or neurosensory deficits. Postoperative imaging confirmed symmetrical reduction of gonial angles and stable graft integration. At the six-month follow-up, the patient reported high satisfaction with facial aesthetics and psychosocial confidence. Objective evaluation using AI-based outcome analysis confirmed significant improvement in facial proportions, with enhanced vertical dimension and balanced transverse width.

This case illustrates the value of integrating artificial intelligence, augmented reality, and virtual reality into maxillofacial reconstructive workflows. AI provided objective defect characterization and predictive outcome modelling, reducing reliance on subjective assessment. VR enabled immersive preoperative rehearsal, enhancing surgical preparedness and patient communication. AR facilitated intraoperative navigation, improving accuracy and reducing operative time. Collectively, these technologies contributed to a reproducible, patient-specific approach that augmented surgical expertise and improved predictability of outcomes.

DISCUSSION

Conventional vs AI-Enhanced Workflows

Conventional reconstructive approaches for craniofacial deformities such as broad face syndrome have historically relied on surgeon expertise, intraoperative judgment, and heuristic reasoning. While experienced surgeons can achieve reliable outcomes, variability remains a significant limitation. Factors such as anatomical complexity, patient-specific variation, and intraoperative decision-making contribute to inconsistent results [1,2]. Traditional planning methods often depend on two-dimensional imaging and manual estimation, which may not fully capture the three-dimensional complexity of craniofacial structures [3].

In contrast, AI-enhanced workflows introduce objectivity and reproducibility into surgical planning. Machine learning algorithms can analyze radiological datasets to automatically segment anatomical structures, quantify deformities, and simulate corrective procedures [4,5]. Predictive modelling enables surgeons to anticipate postoperative outcomes, compare different surgical strategies, and select the most appropriate approach [6]. This reduces reliance on subjective interpretation and enhances surgical precision. Studies have demonstrated that AI-driven planning improves accuracy in orthognathic surgery, flap selection, and risk prediction [7–9]. In the present case, AI analysis quantified mandibular angle hypertrophy and vertical deficiency, guiding the decision to perform angle shaving and vertical augmentation genioplasty.

The reproducibility of AI-assisted planning is particularly valuable in complex cases where multiple variables must be considered simultaneously. By integrating radiological, clinical, and surgical data, AI systems provide comprehensive insights that support evidence-based decision-making [10]. This represents a paradigm shift from experience-driven to data-assisted surgical practice, aligning with the principles of precision medicine [11].

Applications of AR/VR in Maxillofacial Surgery

Visualization technologies such as AR and VR have further strengthened the transition toward precision-based surgery. AR enables real-time overlay of patient-specific anatomical structures onto the surgical field, improving intraoperative orientation and spatial accuracy [12]. This is particularly valuable in anatomically complex regions such as the midface, orbit, and skull base, where conventional visualization is limited. Clinical studies have reported that AR-assisted workflows contribute to reduced operative time, improved precision in flap positioning, and decreased risk of intraoperative complications [13,14].

VR, in contrast, provides an immersive environment for preoperative planning and surgical simulation. Surgeons can interact with three-dimensional anatomical models, rehearse complex procedures, and anticipate technical challenges [15]. VR has also demonstrated substantial educational value, offering trainees a controlled, risk-free environment to develop surgical skills and gain familiarity with complex anatomy [16]. In genioplasty, VR simulation allows precise evaluation of osteotomy lines, graft positioning, and anticipated changes in facial proportions [17].

In the present case, VR simulation facilitated preoperative rehearsal of mandibular angle shaving and genioplasty, enhancing surgical preparedness and patient communication. AR provided intraoperative guidance, ensuring symmetrical reduction of gonial angles and accurate graft positioning. These technologies collectively contributed to improved surgical accuracy, reduced variability, and enhanced predictability of outcomes [18–20].

Ethical, Economic, and Technical Challenges

While AI, AR, and VR technologies offer transformative potential in maxillofacial surgery, several challenges must be acknowledged. Economic considerations represent a major barrier, as the acquisition and maintenance of advanced visualization systems and computational infrastructure require substantial financial investment [21]. Smaller institutions and resource-limited settings may find it difficult to adopt these technologies, potentially widening disparities in access to precision surgical care [22].

Technical challenges also persist. AR systems require precise calibration and registration to ensure accurate overlay of anatomical structures during surgery. Errors in calibration can compromise intraoperative guidance and reduce reliability [23]. Similarly, VR platforms demand high-quality imaging datasets and robust computational power to generate realistic simulations. Inconsistent imaging protocols or incomplete datasets can limit the fidelity of VR models [24].

Ethical and regulatory concerns are equally important. AI systems rely on large volumes of patient data, raising issues related to privacy, consent, and data governance [25]. Algorithmic transparency and accountability must be ensured to prevent bias and safeguard patient trust [26]. Furthermore, the integration of AI into surgical decision-making raises questions about clinical responsibility. While AI can provide predictive insights, ultimate accountability for surgical outcomes rests with the clinician [27].

Future Directions

Future developments in AI-enhanced maxillofacial reconstruction are expected to focus on deeper integration of computational technologies into real-time surgical workflows. Intraoperative AI support, where machine learning algorithms provide continuous decision assistance based on live surgical data, represents a promising direction [28]. Robotic-assisted surgical systems are also anticipated to expand, offering improved precision, stability, and reproducibility in complex procedures [29]. When combined with AI-driven planning and AR guidance, robotic platforms could further enhance surgical accuracy and reduce operator-dependent variability [30].

Cloud-based surgical platforms and health informatics systems are likely to play an increasingly important role. By enabling large-scale data sharing and collaborative planning, these systems can facilitate the development of more robust and generalizable AI models [31]. Access to diverse, multi-institutional datasets will improve model accuracy and reliability, addressing current limitations related to dataset standardization [32].

Another promising direction is the integration of patient-specific biological data, including genetic, molecular, and regenerative parameters, into reconstructive planning. This approach aligns with the principles of precision medicine, allowing for highly individualized treatment strategies tailored to each patient's unique biological profile [33].

Educational applications of AR and VR are also expected to expand. VR simulation provides trainees with immersive, risk-free environments to practice complex procedures, while AR offers real-time intraoperative guidance that enhances learning during live surgeries [34]. These technologies may redefine surgical training, shifting from apprenticeship models to simulation-based curricula [35].

Ultimately, the convergence of AI, AR, VR, robotics, and health informatics is expected to redefine maxillofacial surgery, advancing it toward a more precise, efficient, and patient-centered discipline [36].

Comparative Outcomes and Literature Synthesis

The integration of AI, AR, and VR into maxillofacial surgery has demonstrated measurable improvements in surgical accuracy, reproducibility, and patient satisfaction compared to conventional workflows. Studies comparing traditional planning with AI-assisted approaches have consistently reported enhanced precision in osteotomy execution, improved symmetry, and reduced operative time [37,38]. In orthognathic surgery, AI-driven predictive modelling has been shown to forecast postoperative outcomes with high accuracy, allowing surgeons to select optimal strategies and reduce the risk of relapse [39].

AR-assisted intraoperative navigation has been particularly valuable in complex craniofacial procedures. Heiland et al. [40] reported that AR overlays improved spatial orientation and reduced reliance on mental reconstruction of anatomy, leading to more accurate flap positioning and decreased intraoperative uncertainty. Similarly, VR simulation has been shown to enhance preoperative preparedness, enabling surgeons to anticipate technical challenges and rehearse complex procedures in a risk-free environment [41].

In the present case, the combination of AI-based defect characterization, VR-enabled rehearsal, and AR-guided intraoperative execution resulted in improved facial harmony and high patient satisfaction. These outcomes align with findings from previous studies, underscoring the reproducibility and predictability of digital surgical workflows [42,43].

Broader Implications for Maxillofacial Surgery

Beyond individual cases, the integration of AI, AR, and VR has broader implications for the field of oral and maxillofacial surgery. These technologies support a transition from experience-driven to data-assisted surgical practice, reducing variability and enhancing reproducibility across institutions [44]. They also facilitate multidisciplinary collaboration by enabling seamless data sharing and interoperability between imaging modalities, surgical planning software, and electronic health records [45].

Educationally, VR simulation offers trainees immersive environments to practice complex procedures, while AR provides real-time intraoperative guidance that enhances learning during live surgeries [46]. This may redefine surgical training, shifting from apprenticeship models to simulation-based curricula that emphasize reproducibility and safety [47].

From a systems perspective, health informatics frameworks underpin the successful implementation of these technologies by ensuring structured data capture, standardization, and interoperability [48]. Without robust informatics infrastructure, the integration of AI into surgical practice would be fragmented and inefficient.

Synthesis

Taken together, the literature supports the conclusion that AI, AR, and VR represent transformative tools in maxillofacial surgery. They augment surgical expertise by providing objective, reproducible, and patient-specific insights, thereby improving both aesthetic and functional outcomes. While challenges related to cost, technical complexity, and ethical considerations remain, ongoing advancements are expected to enhance accessibility and integration into routine practice [49,50].

CONCLUSION

Broad face syndrome presents a unique challenge in maxillofacial surgery, requiring precise correction of transverse facial width and vertical dimension to restore harmony. Conventional approaches, while effective, remain limited by subjectivity and variability in planning and execution. The present case of a 20-year-old female illustrates how the integration of artificial intelligence (AI), augmented reality (AR), and virtual reality (VR) can transform surgical workflows. AI provided objective defect characterization and predictive outcome modelling, VR enabled immersive preoperative rehearsal and patient communication, and AR facilitated real-time intraoperative guidance. Together, these technologies enhanced surgical accuracy, reproducibility, and patient satisfaction.

Beyond individual cases, the broader implications of AI, AR, and VR in oral and maxillofacial surgery are profound. They support a paradigm shift from experience-driven to data-assisted practice, aligning with the principles of precision medicine. By enabling structured, reproducible, and patient-specific planning, these tools augment surgical expertise rather than replace it, ensuring that clinical judgment remains central. While challenges related to cost, technical complexity, and ethical considerations persist, ongoing advancements in computational modelling, robotics, and health informatics are expected to further enhance accessibility and integration into routine practice.

In conclusion, AI-enhanced, AR/VR-guided maxillofacial reconstruction represents a transformative approach to managing craniofacial deformities such as broad face syndrome. By bridging preoperative planning, intraoperative execution, and postoperative evaluation, digital surgical informatics offers a comprehensive framework for optimizing outcomes and advancing the discipline toward a more precise, efficient, and patient-centered future.

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