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Impact of image-guided surgical techniques in complex bone reconstruction for maxillofacial fractures

Impacto de las técnicas quirúrgicas guiadas por imágenes en la reconstrucción ósea compleja de fracturas maxilofaciales

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ABSTRACT

Maxillofacial fractures present complex surgical challenges that require precise reconstruction techniques. Image-guided surgical methods, including computer navigation and 3D imaging, are increasingly used to improve surgical outcomes, yet selecting the optimal modality remains difficult due to the varying benefits of each technology. The databases used in the current research include, but are not limited to, PubMed, Scopus, and Google Scholar for article searches. Controlling for sources of bias, the review selected publications on image-guided surgical approaches to managing craniofacial fractures. Studies were identified based on the following criteria: methodology, relevance and patient-oriented results. Thus, analytical categories were developed to evaluate the results, including surgical meticulousness, complication incidences healing, and overall patient satisfaction. The research shows that the availability of enhanced imaging tools and navigation, including CT-nav, 3D-image ster, and intra-operative CBCT, enhances surgical precision and diagnostic accuracy. Preoperative planning repeatability when using CAN was up to 86.5%, and the need for revisions in maxillofacial trauma patients was reduced. Research on computation mirroring for navigation found differences between 0.12 mm, revealing enhanced surgery accuracy. Evaluations of image-guided techniques indicate their advantage over other methods in maxillofacial fracture operations in terms of accuracy and efficiency. Even nowadays, they provide significant improvements in patients' treatment and surgical precision despite certain shortcomings in terms of technology and availability. Further studies need to consider enhancements to the navigation systems and consider cost benefits, depending on the type of setting in which the patient is located.

Keywords: image-guided surgery. maxillofacial fractures. complex bone reconstruction. 3D imaging. computer-assisted navigation.

RESUMEN

Las fracturas maxilofaciales presentan desafíos quirúrgicos complejos que requieren técnicas de reconstrucción precisas. Los métodos quirúrgicos guiados por imágenes, incluida la navegación por computadora y las imágenes en 3D, se utilizan cada vez más para mejorar los resultados quirúrgicos; sin embargo, seleccionar la modalidad óptima sigue siendo difícil debido a los diferentes beneficios de cada tecnología. Las bases de datos utilizadas en la investigación actual incluyen, entre otras, PubMed, Scopus y Google Scholar para búsquedas de artículos. Controlando las fuentes de sesgo, la revisión seleccionó publicaciones sobre enfoques quirúrgicos guiados por imágenes para el tratamiento de las fracturas craneofaciales. Los estudios se identificaron con base en los siguientes criterios: metodología, relevancia y resultados orientados al paciente. Por lo tanto, se desarrollaron categorías analíticas para evaluar los resultados, incluida la meticulosidad quirúrgica, la incidencia de complicaciones, la curación y la satisfacción general del paciente. La investigación muestra que la disponibilidad de herramientas de imágenes y navegación mejoradas, incluidos CT-nav, ster de imágenes 3D y CBCT intraoperatoria, mejora la precisión quirúrgica y la exactitud diagnóstica. La repetibilidad de la planificación preoperatoria cuando se utilizó CAN fue de hasta el 86,5% y se redujo la necesidad de revisiones en pacientes con traumatismo maxilofacial. La investigación sobre la duplicación de cálculo para la navegación encontró diferencias entre 0,12 mm, lo que revela una mayor precisión quirúrgica. Las evaluaciones de técnicas guiadas por imágenes indican su ventaja sobre otros métodos en operaciones de fracturas maxilofaciales en términos de precisión y eficiencia. Incluso hoy en día, aportan mejoras significativas en el tratamiento de los pacientes y en la precisión quirúrgica a pesar de ciertas carencias en términos de tecnología y disponibilidad. Se necesitan estudios adicionales para considerar mejoras en los sistemas de navegación y considerar los costos-beneficios, según el tipo de entorno en el que se encuentra el paciente.

Palabras clave: cirugía guiada por imágenes. fracturas maxilofaciales. reconstrucción ósea compleja. imágenes 3D. navegación asistida por ordenador.

INTRODUCTION

Maxillary fractures are one of the most common emergencies presenting in the acute setting (Abosadegh et al., 2019). The intricate design of the area and its proximity to vital systems, such as the brain, make early diagnosis and meticulous treatment planning essential. In developing countries, between 7.4% and 8.4% of maxillofacial injuries require emergency care and are very serious. Many popular treatment methods aim to enhance the patient's quality of life. The causes of maxillary fractures are influenced by a number of factors, including national socioeconomic status, sports cultures, motor vehicle regulations, and more. Typically, high-risk behaviours like interpersonal aggression or traffic accidents (RTAs) are the cause of most adult maxillary fractures (Vujcich & Gebauer, 2018). RTAs are more frequent than motor vehicle events, with motorcycle occurrences accounting for 73.6% of all incidents, compared to 9.5% for motor vehicle events (Abosadegh et al., 2019). The majority of these injuries are caused by alcohol use (53%) or illegal drug use (47%). Interpersonal violence and assault, with or without the use of weapons, account for 19% of all maxillary fractures and are often documented, according to a Swiss study of 471 patients (Blumer et al., 2018). Sports-related injuries are responsible for between 6% and 33% of maxillary fractures. The sports culture of the country significantly influences the aetiology study. For example, in Ireland, football (22.3%), rugby (12.4%), horse sports (12.4%), and Gaelic football (35.3%) are the main causes of maxillary sporting injuries (Murphy et al., 2015).

Over time, the advancement of modern imaging equipment in plastic and reconstructive surgery has improved patient outcomes by allowing the surgeon to visualise and better understand space during complex surgical operations. Three-dimensional (3D) imaging's accuracy, precision, and versatility may be the reasons for its widespread use (Tzou et al., 2014). Computed tomography (CT), 3D photography, magnetic resonance imaging (MRI), and portable sonography scanners are some of the several modalities used in 3D imaging. Every method has unique benefits and drawbacks. Since they aid in the patient's diagnosis, treatment, and planning, all of these modalities and their sub-modalities are essential components of preoperative, perioperative, and postoperative care (Papel & Jiannetto, 1999). Given the need to use accurate facial imaging methods for such a complicated anatomical region, hyperspecialised practice in face reconstruction surgery is definitely needed (Tzou & Frey, 2011). It might be difficult to choose which case-specific imaging modality to employ due to the wide range of imaging techniques and computer processing systems accessible, as each one offers advantages that change based on the situation. This study aims to evaluate the impact of image-guided surgical techniques on complex bone repair for craniofacial fractures. It assesses various imaging modalities, looks at cost-effectiveness, studies surgical results, offers evidence-based recommendations, and identifies knowledge gaps for additional research in order to increase surgical precision and patient care.

METHODOLOGY

This review employed a comprehensive approach to gather and analyse relevant data from reputable sources, such as PubMed, Scopus, and Google Scholar. Due to the limitations in previous systematic reviews of the efficiency of image-guided surgical methods for managing maxillofacial fractures, changes were made to a mea methodology that was used in previous systematic reviews. Hence, the following search terms are used: image-guided surgery OR maxillofacial fractures OR surgical outcomes OR patient safety.

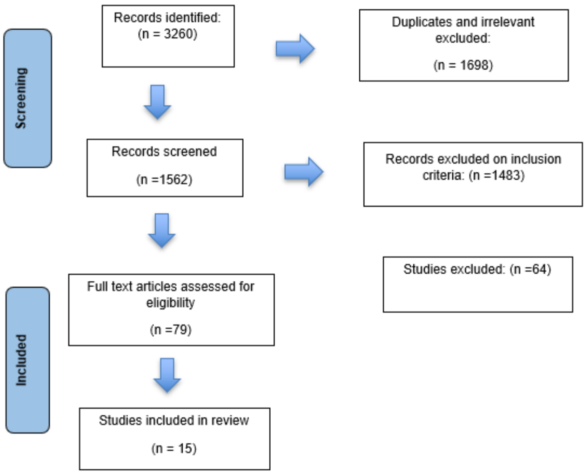
Inclusion and Exclusion Criteria

The articles on image-guided surgical approaches to fractures of the craniofacial region were considered eligible for this review. Thus, for the purpose of reiterating the most up-to-date trends and developments in the field, we limited the identified articles to English language publications of the last ten years. The literature analysis was confined only to human trials, which provided valuable information regarding the usefulness and safety of these approaches. However, the articles that I selected for the reviews did not include the following types of articles: articles that were methodologically flawed or did not address the hypothesis clearly. Every article that was highlighted was reviewed carefully, and the title and abstract of every article confirmed that it was relevant, which made the cutoff.

Categorization and Assessment

In order to review and categorise various types of articles that are related to treating maxillofacial fractures, image-guided surgical techniques were used, and a systematic categorisation technique was used. The objective of this investigation was to evaluate the safety and effectiveness characteristics of various imaging modalities and their influence on surgical outcomes. Analytic categories were developed to assess techniques that included CT-guided navi. A. A number of factors that were considered were as follows: correctness of the surgical procedures performed, the incidence of complications during or after the surgical intervention, as well as the healing period, and the general health status of the patient. With this systematic approach to classification, it was possible to fully review the mechanics, evidential clinical efficacy, and safety of image-guided procedures and, at the same time, focus on the significance of the results for patient care and surgery.

Figure 1. Categorization



Source: the authors

RESULTS

The use of surgical navigation technologies, 3D imaging, and computational planning has been shown to enhance surgical accuracy, diagnostic precision, and patient outcomes in the evaluation and surgical management of maxillofacial injuries.

Advancements in Surgical Precision and Patient Outcomes through Computer Navigation System

Computer navigation systems in surgery enhance precision by using 3D imaging and virtual planning to guide procedures, especially in complex surgeries like orthognathic and maxillofacial trauma. Another clinical study carried out by Mazzoni et al. involved an equal number of female and male participants, namely five in number. To improve the possibility of reproducing the simulation, they also described a new approach of how to transfer a patient-specific 3D plan into the operating theatre (Mazzoni et al., 2010). The general agreement of postoperative compared with the preoperative plan was 86.5 % when using the simulation-guided navigation and 80 % when no navigation was applied. The researchers have postulated that the addition of navigation increases the accuracy of simulated surgical process planning before orthognathic surgery (Mazzoni et al., 2010).

A retrospective study of 15 patients involved Class II or III maxillofacial deformities to evaluate the performance of the simulation-guided navigation in orthognathic surgery, according to Roncari et al. (2015). In the primary outcome, Hausdorff distance for 3D surface alignment was 0.99, and the repeatability was less than 1 mm in 61.88 % and less than 2 mm in 85.46 % of cases (Roncari et al., 2015). The outcomes of the study confirmed that effective maxillary positioning could indeed be achieved by using simulation-based navigation, particularly in relation to the management of the vertical facial dimension and the quality of the final surgeries. Lin et al. included thirty-seven patients who have had previous orthodontic treatment. They decided to swap their navigation system knowledge in order to preassemble positioning assistants, mimic work, and navigate by example (Liu et al., 2017). In an effort to plan and achieve outcomes, three-dimensional computer-assisted orthognathic surgery was used. The computer-assisted orthognathic surgery system, in the opinion of the authors, may enhance the surgery in terms of planning, time effectiveness, installation, and fixation of the maxillomandibular complex, as well as the result. Since the first evaluation of multiple anatomical landmarks, the second detailed discussion of the surgical plan, and the final assessment of the outcome, the use of navigation enhances functions and esthetics in patients with dentofacial abnormalities.

Enhanced Diagnostic Accuracy in Trauma Cases through Cone Beam Computed Tomography (CBCT) Imaging

Cone Beam Computed Tomography (CBCT) significantly enhances accuracy in diagnosing and treating trauma cases, providing detailed, three-dimensional images of complex bone structures. Unlike conventional X-rays, CBCT offers precise visualisation of fractures and dental structures, enabling clinicians to plan interventions with greater accuracy, reducing complications, and improving patient outcomes (Rashid et al., 2024). In the last decade, intraoperative 3D imaging has increasingly been used in maxillofacial trauma. Moreover, several early feasibility studies pointed out that the post-operative computed tomographic (CT) scan frequently did not support the intraoperative clinical judgment of satisfactory reduction of zygomatic complicated fractures or orbital reconstructions, even among experienced surgeons. By evaluating implant or bone location instantly, intraoperative CT can reduce the need for additional surgical revision. Pohlenz et al. (2009) described the first clinical applications of intraoperative CBCT employing an integrated flat-panel detector in oral and maxillofacial surgery after ZMC fractures had been surgically treated (Pohlenz et al., 2009). The C-arm CBCT is said to be less space-consuming and easier to use than a medical-grade CT. Additional surgical time was anticipated to be 8 to 30 minutes, including preparation, sterile draping, and imaging evaluation (Alasraj et al., 2021; Singh et al., 2015). The contralateral side cannot be scanned with the present CBCT C-arm due to its narrow field of view (12 cm 12 cm 12 cm).

Ocular reconstructions and the assessment of reductions in zygomaticomaxillary fractures (ZMC) are two examples of applications. Since direct visualisation is not possible with surgical procedures, ZMC reduction is frequently assessed by sphenozygomatic suture reduction and subjective assessment of facial symmetry. In a retrospective examination, intraoperative CBCT allowed for timely revision in 6 out of 48 patients with orbit or zygoma fractures, particularly in cases of comminution, which showed that the reported CT-guided revision rates were orbital 31%, Zygomaticomaxillary complex 24%, Le fort I 8%, Le fort II and III 23%, naso-orbital ethmoid 23%, mandible 13%, and frontal sinus 0% (Gander et al., 2018). Additional uses include screw fixation and condyle reduction with regard to the inferior dental nerve and the intraoperative localisation of foreign objects following a gunshot wound, particularly when they are close to structures that are in danger (Klatt et al., 2011). Despite the benefits and logic of intraoperative imaging, repeated CBCT imaging might expose patients to accumulated ionising radiation, which can be harmful, especially if intraoperative procedures have been carried out. Johner et al. (2020) showed that the average number of CBCT scans for each patient was 1.3, which would be associated with the severity of the trauma (Johner et al., 2020). Alasraj et al. (2021) showed that the majority of alterations (63.6%) were found in ZMC patients and that only these instances required a second intraoperative scan (Alasraj et al., 2021). Furthermore, just 30% of university hospital departments and 0% of private clinics are using it, according to recent countrywide research done in France, despite the statistics supporting its use. Temporomandibular joint surgery and the treatment of ocular fractures were its main purposes.

Precision in Midfacial Fracture Treatment Using Mirroring-Based Computational Navigation

Mirroring-based computational navigation uses virtual modelling to enhance precision in medical procedures. By creating mirrored, digital representations of anatomical structures, this technology helps surgeons visualise complex areas, predict surgical outcomes, and navigate accurately in real time. This approach reduces procedural risks, improves alignment, and supports optimal patient-specific interventions. In a retrospective cohort research, Pierrefeu et al. (2015) assessed the efficacy of a specific navigation system that included "mirroring" computational planning for the management of midfacial fractures in 20 patients. The research, which compared planned and actual postoperative 3D surface photos to assess the method's accuracy, had 20 Caucasian patients (15 men and 5 women) (Pierrefeu et al., 2015). The researchers' data showed that the mean discrepancy between the predicted and actual postoperative images was just 0.12 mm. The data demonstrated varying degrees of overlap between the anticipated and postoperative outcomes: 30% of patients had above 90% overlap, 30% had 80–90% overlap, 35% had 50–80% overlap, and 5% had less than 50% overlap. These results imply that although there exists a high tendency to achieve good reconstructions with the method, the level of accuracy varies across patients. It is uniquely significant to add that unlike average difference measurements; this study incorporates powerful statistics of boxplot median and quartiles (Pierrefeu et al., 2015). Through this, the researchers were able to detect a lower accuracy, which may not have been detected if the investigators applied a mean differences-only test as well as values that, in one or the other, fell at the end of the data and variability. Surgical errors related to navigation-assisted surgery are due to human factors, technicalities, imaging and registration, metal artefacts, and software factors because it is hard to obtain a proper 3D reproduction. This study confirms the usefulness of the system: 60% of the patients analysed had an adequate match between the planned and the actual reconstructed surgery (Pierrefeu et al., 2015). Due to the various observations, it is suggested that further investigations should be conducted so that the accuracy of navigation applied in therapies of midfacial reconstructions is brought out clearly, and risk factors related to differences are identified.

Superior Diagnostic Clarity through Cinematic rendering (CR) techniques for maxillofacial fracture diagnosis

Cinematic rendering (CR) techniques provide highly detailed, photorealistic 3D images for diagnosing maxillofacial fractures. Also, the depth perception and clarity of the anatomical structure by CR support the surgeons in evaluating complicated fracture patterns, visualising the bone, and planning strategies for surgical operations. This kind of imaging provides better resolution, enhances case diagnosis, and facilitates improved results in maxillofacial trauma. CR CR and VR techniques were compared and assessed for maxillofacial fractures (Hu et al., 2022). The researchers used a sample of 25 patients for the study with the assistance of radiologists and surgeons. In as much as differentiating nasal bone fractures and fracture-dislocations, the present study showed that CR accuracy was higher than VR. Particularly in consideration of the accuracy rate of fractures, the accuracy rate of CR and VR is 79.6% and 69.6%, respectively, with statistical differences ($P = 0.034$). CR provided 92.2% efficiency for the diagnosis of fracture-dislocations, whereas, on the other hand, the value of the VR method is 70.8% ($P < 0.001$). Furthermore, the current study revealed that CR improved diagnostic confidence in conjunction with shortening the amount of time it takes to reach a diagnosis. While using CR, the meantime that it took to diagnose the disorder was twenty-point eight one seconds, while the one that took using VR was twenty-seven point four eight seconds ($t = -13.155$; $P < 0.001$) (Hu et al., 2022). The results thus indicate that the concept of using CR in clinical practice is helpful since it enhances the patients' communication and the diagnosis result. Thus, the study recommends the use of CR techniques in the examination of maxillofacial fractures by embracing their ability to enrich the understanding of the topic and boost the benefits of the diagnostic exercise for improved patient outcomes.

Enhanced Fracture Detection with Multidetector Computed Tomography (CT)

Multidetector computed tomography (CT) enhances the detection of complex fractures and soft tissue injuries by employing high-resolution, cross-sectional imaging. At the same time, obtaining several slices results in accurate 3D reconstruction, which is vital for the assessment of trauma cases (Buchipudi et al. et al., 2023). This method is widely applied in emergency/trauma situations when the identification of the diagnosis and the surgical plan is essential and requires mere time. It takes multidetector CT images in three orthogonal planes to obtain high-quality 3D reconstruction. It helps to decide whether fracture segments of the fractured part are comminuted or displaced, especially when assessing complex fractures. This makes it possible for maxillofacial surgeons to coordinate their surgeries. Buchipudi Sandeep Reddy et al. (2023) conducted a cross-sectional descriptive study to examine the findings of 49 patients with maxillofacial injuries. It was evidenced from the study that males in the population had higher rates of injury than women, the highest proportion of them being in the 21-30 age bracket. Self-transportation-related injuries demonstrated that car collisions were the commonest cause of trauma (95.9%), whereas the commonest injuries included mandible fractures (40.8%) and nasal bone fractures (36.7%) (Buchipudi et al. et al., 2023). Multidetector CT scans were the preferred imaging technique for these trauma exams because they generated 3D images that were more accurate in identifying fractures and figuring out their displacement. Maxillofacial fractures, especially those involving the maxilla and mandible, are much easier to identify with 3D scans than with axial, coronal, or sagittal views. It has also been shown to be more efficient in providing information on fracture line patterns and fracture piece displacement. Other advantages of multidetector CT are its non-invasiveness, excellent accuracy, and short scan time.

Enhancements in Surgical Outcomes with 3D-Printed Titanium Reconstruction Plates

3D-printed titanium reconstruction plates are revolutionising surgical outcomes in complex maxillofacial procedures. These custom implants improve fit and stability and, in turn, encourage better tissue incorporation. Evidence is found in several clinical reports that demonstrate reduced healing periods, minimal complications, and the satisfaction of functional and cosmetic outcomes with unique facial implants. In their case report, Melville et al. (2018) reported on a 62-year-old woman who presented with a maxillary tumour that was fixed with a single-unit 3D-printed titanium reconstruction plate due to her tumour (Melville et al., 2018). The method provided an anatomic reconstruction without further manipulation and shorter operation time thanks to the vascularised fibula flap and VSP options. The study also recommends the use of almost simultaneously the VSP combined with 3D printing titanium plates to provide increased effectiveness of the surgery in the conditions of complex virtually reconstructed maxillary grafts, thus identifying the accuracy of the suggested surgical plan under certain conditions. As a matter of fact, virtual surgical planning has now become valuable in orthognathic and oral maxillofacial surgery. First of all, it obtains the imaging data of the individual patient, which is mainly from CT or CBCT images, and then reconstructs it into a 3D model. These models allow for the approximation of different post-surgery scenarios and the determination of individual surgical solutions (Park et al., 2019). The surgical team may use it to perform virtual osteotomies and repositioning, as well as to visualise various characteristics of complex anatomy and appreciate spatial relationships between structures (Dod et al., 2023). Now, let us consider examples of how VSP works: Chen et al. reported that using VSP-aided navigation in orthognathic surgery significantly shortened the operation time and improved patients' satisfaction with the operation outcome in terms of facial esthetic balance. In another study by Valls-Ontañón et al. (2020), VSP has also been demonstrated to yield better postoperative occlusal position due to the application of the surgical plan with higher precision (Valls-Ontañón et al., 2020). These examples show how VSP is becoming indispensable in the surgical planning of new oral, maxillofacial and orthognathic surgery.

Surgical titration has made it possible to perform a precise intraoral mandibular osteotomy using a 3D print surgical guide, as suggested by Zhang et al. (2014). Despite having an unclear field of vision during the surgery, the surgeon easily identifies the osteotomy site using the surgical guide (Zhang et al., 2014). The method achieved accurate anatomical reconstruction without additional alteration and reduced operating time due to the vascularised fibula flap and VSP. The study also suggested that VSP can be used alongside 3D printing titanium plates to show improved efficiency of the surgery in the case of complex, virtually reconstructed maxillary grafts, making the surgical plan significantly accurate in such conditions. Virtual surgical planning has, in fact, emerged as an important tool in orthognathic and oral maxillofacial surgery.

To start with, the program acquires imaging data of the individual patient, which is common from CT or CBCT images, before reconstructing it into a 3D model. It is possible to simulate various surgical outcomes and develop patient-specific surgical recommendations by adjusting these models. In order to improve the surgical plan, the surgical team may utilise it to do virtual osteotomies and repositioning, visualise complex anatomical characteristics, and better understand spatial linkages. The effectiveness of VSP has been shown in several case studies. According to a study by Chen et al., the use of VSP in orthognathic surgery resulted in a significant reduction in operating time and an improved postoperative outcome in terms of patient satisfaction and facial symmetry (Chen et al., 2020). Another study by Valls-Ontañón et al. (2020) shows superior postoperative occlusal outcomes as a result of using VSP to execute the surgical plan with more accuracy (Valls-Ontañón et al., 2020). These examples demonstrate how, in oral, maxillofacial, and orthognathic surgery, VSP is increasingly important to surgical planning.

A precise intraoral mandibular osteotomy has been accomplished with the use of a 3D-printed surgical guide (Zhang et al., 2014). Though the visibility can be quite poor during the surgery, the surgeon locates the osteotomy site using the surgical guide with ease (Zhang et al., 2014). Before the operation, this advice is generated through integrated conversion into the three-dimensional digital model (Tominaga et al., 2016). Adaptable and writable various ranges of 3D-printed surgical guides or templates have been used successfully. They have proved to be effective in mandibular contouring procedures and, therefore, advocate their usability in surgical procedures only (Papel & Jiannetto, 1999). Therefore, to ensure the flow of preoperative surgical templates through a mandibular osteotomy is correct, computer-aided simulation planning or CASP is very important (Lim et al., 2015). Most conventional mandibular contouring surgeries employ two-dimensional images for planning (Liu et al., 2011). Unfortunately, the imprecise nature of these surgical designs results in permanent asymmetry and nerve-related problems in around 10% of patients (Liu et al., 2011). Traditionally, the success of mandibuloplasty outcomes has been evaluated by simply comparing clinical pictures taken before and after the procedure (Souza et al., 2016). In mandibular contouring surgery, the use of CASP in conjunction with a 3D-printed surgical guide offers benefits over traditional planning techniques that rely on 2D images (Seok et al., 2017). By incorporating CASP and the surgical guide, operating time can be reduced, d and surgical accuracy can be increased (Seok et al., 2017).

By improving accuracy, cutting down on operating hours, and enabling more precise surgery, it illustrates how developments in 3D imaging, computational planning, and surgical navigation greatly enhance results in maxillofacial trauma evaluation and reconstructive surgery. For surgeons performing maxillofacial surgeries who want to strengthen alignment, reduce recovery periods, and boost patient satisfaction, these technological developments are crucial. The capacity of additive manufacturing and 3D printing to quickly create intricate structures and exact geometry sets them apart from conventional production techniques. 3D printing was created in response to the growing need for goods with a wide variety of designs, applications, and materials (Chen et al., 2020). This discovery sparked the fourth industrial revolution and the digitisation of industry. Since patient-specific implants are gradually taking the place of generic implanted medical equipment, 3D printing has had an impact on healthcare globally (Buchipudi et al. et al., 2023). Because doctors often use precision medicine, the field of oral and maxillofacial surgery has been most affected by this change. Orthognathic surgery, complete joint replacement treatment, and trauma are all being improved by 3D technology. Surgical teams may now take part in the 3D design and production of equipment thanks to the emergence of point-of-care treatment facilities with internal infrastructure brought about by the rapid and widespread adoption of 3D technologies in clinical settings. 3D technology has fundamentally altered how physicians approach clinical outcomes and treatment planning.

DISCUSSION

Technology has advanced since the COVID-19 pandemic, especially with the digitisation of several occupations. Modern imaging techniques have improved surgical success rates and treatment outcomes. Computational navigation systems, 3D-printed surgical guides, and VSP have all been shown to enhance surgical accuracy and patient outcomes (Pierrefeu et al., 2015; Badiali et al., 2015; Buchipudi et al. et al., 2023). One study (Valls-Ontañón et al., 2021; Buchipudi et al. et al., 2023; Melville et al., 2018) reported significant reductions in operating times and improved postoperative outcomes in terms of occlusal accuracy and symmetry. Another study (Valls-Ontañón et al., 2021) reported similar improvements. Improved accuracy in maxillary repositioning in orthognathic surgery has been reported (Pierrefeu et al., 2015; Roncari et al., 2015; Hu et al.,2022; Melville et al., 2018). Roncari et al. (2015) state that this is a crucial factor in attaining balanced facial symmetry and overall patient satisfaction (Roncari et al., 2015).

The effectiveness of mirroring-based computational navigation for accurate fracture alignment was also validated by research looking at midfacial fracture treatments, including (Pierrefeu et al., 2015 Valls-Ontañón et al., 2021; Badiali et al., 2015). Achieving over 90% overlap in almost one-third of instances and reducing the risk of postoperative complications, the method's precision is demonstrated by the mean 3D alignment variance of just 0.12 mm (Pierrefeu et al., 2015; Badiali et al., 2015; Buchipudi et al. et al., 2023; Melville et al., 2018). Furthermore, compared to virtual reality imaging, the incorporation of cinematic rendering (CR) into maxillofacial diagnostics shows superior fracture visualisation capabilities (Badiali et al., 2015; Pierrefeu et al., 2015; Melville et al., 2018). In addition to improving diagnostic speed and accuracy, CR helps patients and the surgical team communicate the specifics of injury (Badiali et al., 2015; Pierrefeu et al., 2015; Melville et al., 2018).

Melville et al. (2018) claim that because 3D-printed titanium plates achieve precise anatomical alignment and reduce operating time, they are beneficial for complex maxillary reconstructions in reconstructive surgery (Melville et al., 2018; Badiali et al., 2015; Pierrefeu et al., 2015). By providing reliability for patient-specific, precision-driven surgical procedures, these plates enhanced the surgeon's ability to design and execute challenging reconstructions (Badiali et al., 2015; Pierrefeu et al., 2015; Melville et al., 2018). Maxillofacial surgeons will comprehend that the use of these latest technologies in imaging and navigation will present a major impact on the clinical field. Virtual Surgical Planning (VSP) and 3D printing are two image-guided strategies which define a surgical plan and have beneficial effects on several aspects of patient treatment. Complications and postoperative recovery may decline because surgeons will be more delicate in reconstructive operations.

Moreover, these technologies improve patients' preoperative counselling through graphic illustrations of their operations that raise patient satisfaction and confidence (Melville et al., 2018). The higher accuracy also minimises the chances of performing additional surgeries after the first operation has been conducted and the time spent in the operation theatre, which may have an impact on the operating costs of a healthcare facility (Roncari et al., 2015). All of these innovations, in turn, alter the field of maxillofacial surgery by enhancing patient results and optimising surgery (Alkhayatt et al., 2023). However, certain limitations are inevitable in the current research despite the identified positive findings. The time taken to familiarise oneself with new technologies is a major challenge in the implementation of image-guided procedures. The synthesis reported that, relative to laparoscopic procedures, it may consume much time and funds before surgeons are trained in these complex systems (Badiali et al., 2015; Melville et al., 2018). All of these developments, taken together, underscore the need to merge CBCT imaging with other navigational support, such as surgical applications in maxillofacial surgery.

CONCLUSION

In conclusion, the development of maxillofacial reconstruction relies on image-guided surgical operations. Due to the delivery of formulas for patient-specific therapies depending on certain variations in anatomy, they significantly enhance the precision of operations and clients' experiences. The use of state-of-the-art navigation and imaging systems reduces the potential for issues and methods. It is necessary to continue the study to review the effectiveness of these methods in the course of their development while investigating the problems associated with the application of these techniques in the process of implementation. The future of the technology remains unknown because it will depend on the result of user-defined values and certain milestones in surgical technical progression, including the miniaturisation of devices and enhancement of image processing formulas. However, planning operations have a positive impact on the patient in terms of time and outcome. These methods could be rather difficult to set up in underdeveloped nations and facilities where neither the tools nor the human capital to work it is available.

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