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Research Article

Optimizing Orthognathic and Maxillofacial Surgery Outcomes: Integration of Surgery First Approach (SFA), Early Recovery after Surgery (ERAS), CAD/CAM and Extended Reality (XR) in the Metaverse to Minimize Overnight Hospitalization

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Abstract

To meet the increasing demand for orthognathic and maxillofacial surgery, our clinic has focused on ensuring patient safety, promoting recovery, achieving aesthetic outcomes, improving functionality, and enhancing overall quality of life. We have implemented the Surgery First Approach (SFA) and Early Recovery after Surgery (ERAS) protocols within a cross-disciplinary team framework. Through a retrospective analysis of 42 patients over a one-year period, we have demonstrated successful postoperative management, resulting in all patients being discharged within 24 hours without any complications. These improvements in practice efficiency and reduction in patient burden have had a significant positive impact on patients' quality of life. Furthermore, the integration of Holoeyes Extended Reality (XR), Computer-Aided Design (CAD)/Computer-Aided Manufacturing (CAM), and Ultrasonic Bone Aspirator (UBA) has led to substantial enhancements in surgical outcomes and reduced recovery times. Our findings unequivocally support the notion that our integrative approach not only optimizes aesthetic results but also significantly enhances patients' quality of life, thereby paving the way for the future of orthognathic and maxillofacial surgery.

Keywords: CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing); Early Recovery after Surgery (ERAS); Extended Reality (XR); Orthognathic Maxillofacial Surgery; Surgery First Approach (SFA); Ultrasonic Bone Aspirator (UBA), Virtual Reality (VR) , , Augmented Reality (AR), Mixed Reality (MR), Hologram, Holoeyes MD

Introduction and Aim

In recent years, there has surged in the demand for orthognathic and maxillofacial surgery due to increasing concerns regarding facial aesthetics. Patients often express dissatisfaction with their appearance and seek urgent improvement. While the Surgery First Approach (SFA) or the Early Surgery Approach (ESA) present potential solutions by promising early aesthetic improvements and reduced treatment duration, their adoption within the limitations of the current insurance system, which prioritizes specific predetermined steps, remains a challenge. To address the diverse needs of patients, our institution established a Class 7 (ISO14644-1) level cleanroom, operating room, and recovery room at Mirise Clinic Minamiaoyama in January 2022, offering orthognathic surgery with a primary approach of 24-hour postoperative management (Figure 1). Traditional postoperative care for orthognathic surgery often involves a week of hospitalization, intermaxillary fixation, enteral nutrition, and, in some cases, Intensive Care Unit (ICU) management with extubation on the following day. In contrast, our study investigates the safety and challenges associated with the 24-hour postoperative management approach implemented for orthognathic surgery at our facility. To improve surgical precision, reduce patient burden, and increase productivity, our facility proactively utilizes various technologies, including Computer-Aided Design (CAD)/ Computer-Aided Manufacturing (CAM), three-dimensional (3D) printers (Figure 2), Ultrasonic Bone Aspirator (UBA) surgical device (Figure 3), and Extended Reality (XR) technology encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) (Figure 4). Additionally, we have established a cross-disciplinary team consisting of orthodontists, oral and maxillofacial surgeons, plastic surgeons, anesthesiologists, nurses, dental hygienists, dental technicians, psychological counselors, nursing assistants, and dental assistants (Figure 5). Through close communication and continuous improvements, our aim is to provide high-quality patient care using XR technology in the metaverse (Figure 6). To ensure safety, we have also established partnerships with neighboring university hospitals and general hospitals equipped with ICUs and self-blood storage, creating an emergency flow and environment for rapid and safe response in emergencies.

Figure 1: Operating and Recovery Rooms at Mirise Clinic Minamiaoyama, A: An ISO Class 7 level operating room (ISO14644-1) B: 24-hour post-operative recovery room.

Figure 2: In-house simulation and 3D-printing of orthognathic surgical splints A: Polygon data of a surgical splint for maxillary positioning, produced by simulation software (Materialise PROPLAN CMF and Ortholy DOLPHIN IMAGING) B: High-precision 3D printer “cara Print 4.0 Pro” (Kulzer GmbH, Hanau, Germany). C: In-house 3D-printing of maxillary positioning surgical splints. D: Surgical splint for positioning the maxilla prior to photopolymerization E: Completed maxillary positioning surgical splint.

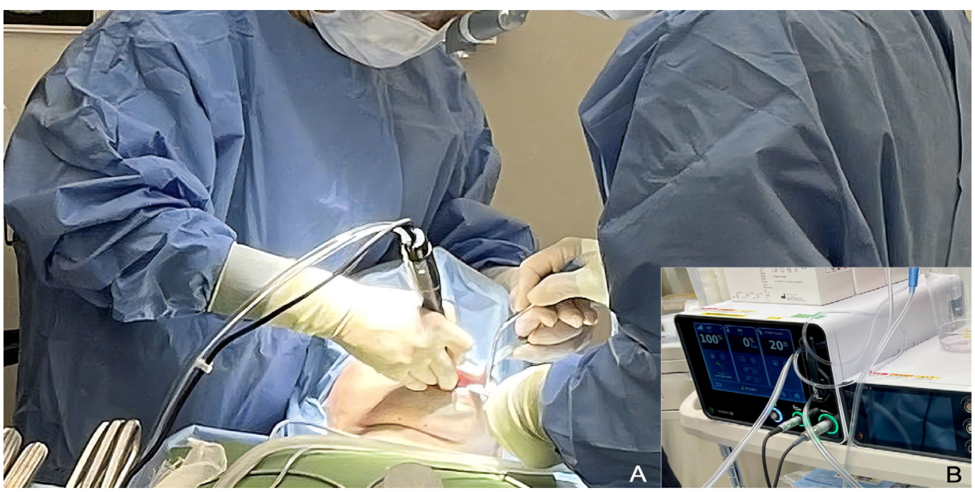

Figure 3: Precise bone resection and efficient aspiration using an Ultrasonic Bone Aspirator (UBA) A: Intraoperative use of the Sonopet IQ UBA (Stryker, Kalamazoo, MI). B: Console of the ultrasonic aspirator.

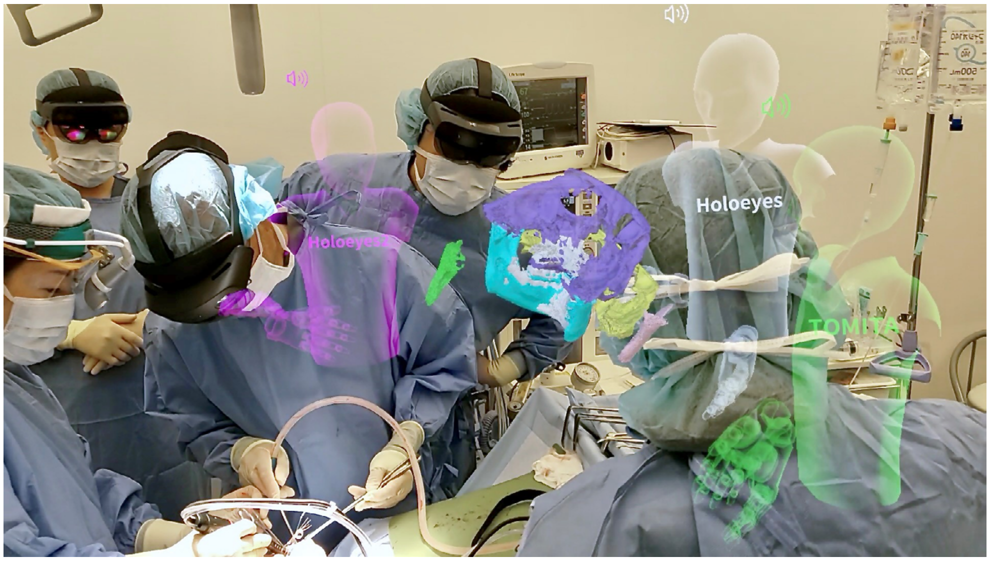

Figure 4: Use of an XR head-mounted display during surgery. The Holoeyes MD allows for 3D holographic models of a patient's specific anatomy, based on surgical simulation results, to be displayed in real space above the sterile surgical field. Their avatars (alter egos) share their opinions and procedures in the metaverse space.

Figure 5: Collaboration among various professions using XR technology in the metaverse. Holoeyes MD, capable of converting patient-specific CT data into 3D holographic images, can be utilized for a range of medical applications, including surgical planning, surgical simulation, and medical education.

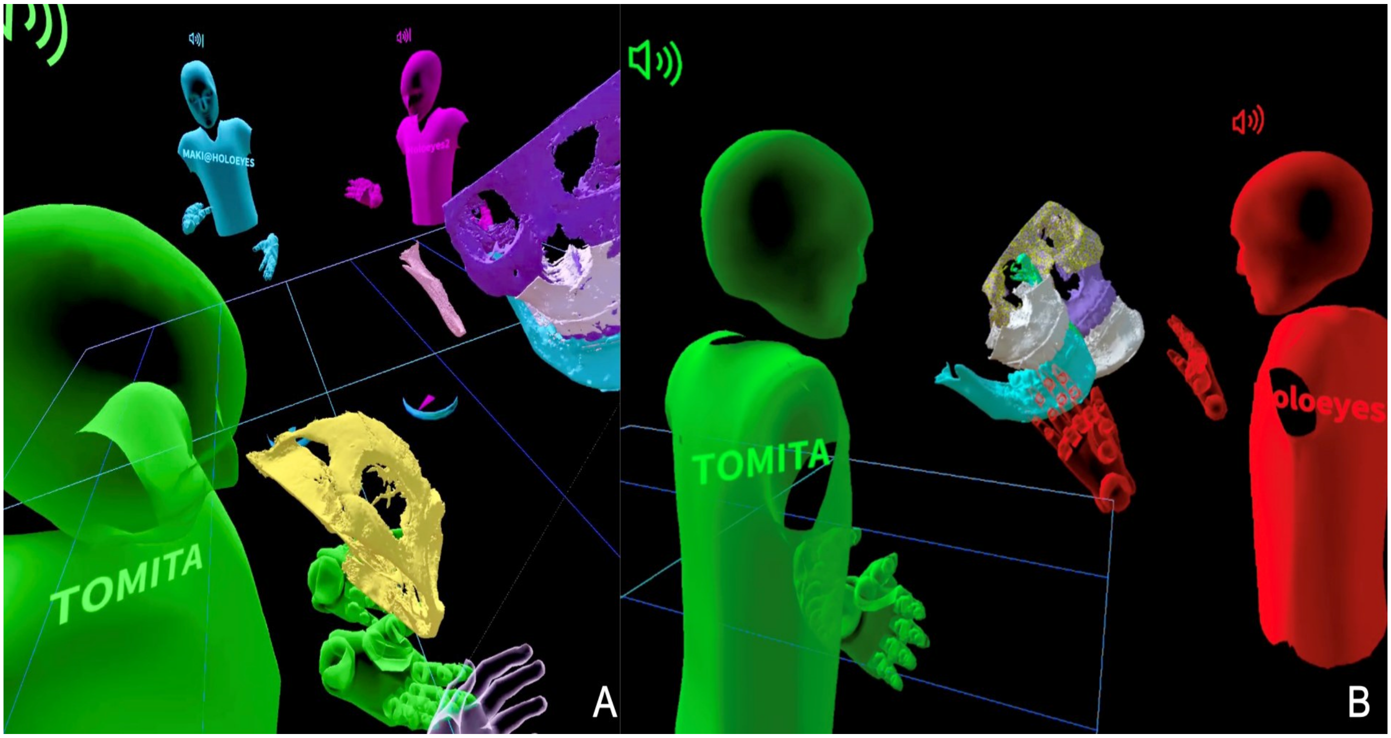

Figure 6: Online VR conference in the metaverse space using Holoeyes VS. Dentists and staff members interact via their avatars and share their skills in the metaverse space. A: The multidisciplinary surgical team shares each patient's 3D data and procedural movements in the metaverse space. B: Surgical procedures are taught using avatars, simulating a face-to-face environment.

Materials and Methods

We performed a retrospective analysis of 42 patients (8 males and 34 females, with females comprising 81% of the cases) aged 14 to 52 years (average age 29.5 years) who underwent orthognathic surgery at Mirise Clinic, Minamiaoyama, between January 2022 and February 2023 using the Surgery First Approach (SFA) or Early Surgery Approach (ESA) (Table 1). We evaluated the surgical duration, bleeding volume, and postoperative complications associated with these procedures.

Case No.	Age	Gender	SFA/ESA	Blood loss (mL)	Operation Time (min)
1	27	F	ESA	300	373
2	45	M	ESA	360	378
3	25	M	ESA	400	349
4	39	F	ESA	300	290
5	37	F	SFA	200	318
6	23	F	ESA	380	288
7	25	F	ESA	1000	330
8	31	F	ESA	140	298
9	14	F	ESA	300	268
10	29	M	SFA	150	262
11	27	F	SFA	327	296
12	26	F	ESA	375	262
13	39	F	ESA	180	231
14	23	M	SFA	450	264
15	31	F	SFA	530	277
16	27	F	SFA	320	277
17	29	F	ESA	255	267
18	30	M	ESA	280	260
19	30	F	ESA	200	255
20	28	F	SFA	170	240
21	25	M	ESA	450	234
22	38	F	ESA	140	234
23	46	M	ESA	80	235
24	18	F	ESA	200	264
25	22	F	ESA	110	217
26	23	F	ESA	650	244
27	27	F	SFA	500	239
28	30	F	ESA	440	257
29	52	F	ESA	100	220
30	32	F	SFA	93	264
31	26	F	ESA	200	270
32	30	F	SFA	320	238
33	20	F	ESA	780	240
34	28	F	SFA	240	315
35	34	F	SFA	150	209
36	26	F	ESA	230	214
37	32	F	ESA	320	217
38	34	F	ESA	260	200
39	18	F	ESA	360	210
40	24	F	ESA	520	227
41	33	M	ESA	420	233
42	29	F	ESA	110	195
average	29.3			316.4	260

Table 1: The profile list of all 42 cases.

Results

The surgical duration ranged from 3 hours 18 minutes to 6 hours 18 minutes (average 4 hours 20 minutes), with a negative correlation observed between the number of surgeries performed and the time taken (r=-0.77) (Table 2). This suggests an established, more efficient operation as multiple surgeries were performed from the initial stages of the clinic's establishment. The volume of bleeding ranged from 80 to 1000 mL (average 316.4 mL, median 310.4 mL), with a weak positive correlation noted with surgical duration (r=0.22) (Table 3). No complications such as inferior alveolar artery damage or postoperative bleeding were observed intraoperatively, and all patients were discharged within 24 hours after the removal of the drain. One patient received remote psychological care through a social networking service communication tool (the official LINE application of Miraise Clinic) due to psychological anxiety after discharge.

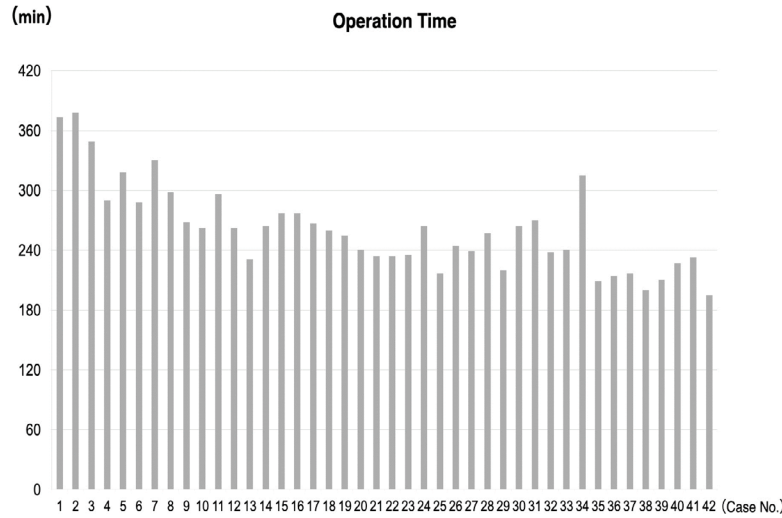

Table 2: The operating time of all 42 cases.

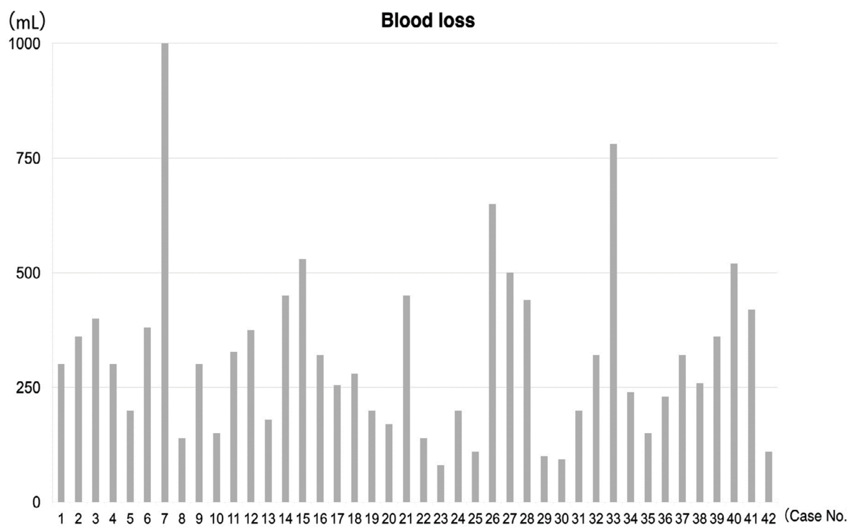

Table 3: The blood loss for all 42 cases.

Discussion

By ensuring a stable occlusal condition without the need for intermaxillary fixation, effectively utilizing ultrasonic surgical instruments, innovating upper jaw surgical techniques, reducing surgical duration, reducing bleeding volume, and alleviating total body burden and postoperative swelling under appropriate anesthesia management, enable to safely conduct orthognathic surgery under 24-hour postoperative management. The use of social networking communication tools for nighttime responses by doctors, counselors, and assistants was considered useful for patients' psychological care. The modern orthognathic surgical landscape is rapidly evolving, with new techniques and technologies being developed and adopted. A significant shift in recent years has been the increased prevalence of the Surgery First Approach (SFA). According to Peiró-Guijarro [1], the SFA protocol in orthognathic surgery could offer benefits such as shortened treatment times and immediate aesthetic improvement compared to traditional methods. However, due to variations in study designs, outcome variables, reporting biases, and the lack of long-term prospective follow-ups, these results should be approached with caution. Despite the promising outcomes and high acceptance reported in some studies, consensus regarding patient selection, technical protocol, and stability is still lacking. Further emphasizing the success of the SFA, Hernández-Alfaro [2] outlined its potential for expediting the correction of maxillofacial deformities in carefully selected patients. Based on a study of 45 patients, they demonstrated that this approach could significantly shorten treatment times and yield high levels of patient and orthodontist satisfaction. However, they also underscored the importance of meticulous patient selection, precision in treatment planning, and robust bidirectional feedback between the surgeon and the orthodontist. Despite the apparent advantages of the SFA, they identified certain limiting factors, such as the requirement for experienced orthodontic management and the need to exclude cases with complicating issues like periodontal or temporomandibular joint problems.

As outlined by Lin [3], the application of 3D computer-assisted technology in orthognathic surgery has significantly advanced surgical planning and outcomes. Their review of the literature over the past decade revealed an increasing trend in the use of such techniques, demonstrating their role in enhancing the precision of surgical planning, simulation, translation of virtual surgery to intraoperative practice, and postoperative evaluation. According to their findings, the integration of 3D computer-assisted technology not only facilitates intraoperative manipulation but also optimizes functional and aesthetic results, thereby leading to greater patient satisfaction. Thus, it can be concluded that the application of computer-assisted techniques in orthognathic surgery offers considerable benefits in achieving precise treatment outcomes. As elucidated by Wahlstrom[4], the implementation of Early Recovery After Surgery (ERAS) protocols in orthognathic surgery has shown significant potential in improving patient outcomes and expediting recovery. In their retrospective study involving 56 patients, they observed that patients managed with ERAS protocols experienced less postoperative pain and nausea compared to those who received traditional care. Specifically, the maximum pain score in the ERAS group was markedly lower, and the consumption of morphine equivalents was significantly reduced. Thus, their findings underscored the safety and efficacy of the ERAS protocols, not just for orthognathic surgery, but also suggested their considerable relevance for other maxillofacial surgeries. Oliveira [5] conducted a randomized, blind, and prospective clinical trial comparing two rehabilitation protocols for patients undergoing orthognathic surgery. The study, which focused on the initial 60 days post-surgery, evaluated variables such as pain, edema, mandibular movement, masticatory efficiency, and quality of life. The findings demonstrated that the addition of an ERAS protocol, performed by speech therapists and involving specific motor exercises and lymphatic drainage, led to a significant decrease in pain perception during the first 14 days compared to a control group. However, it was found that the ERAS protocol did not lead to significant improvements in other variables. Although many variables did not show significant differences, the study concluded that surgeons can delegate postoperative patient rehabilitation to qualified professionals, optimizing postoperative clinical time. Stratton [6] examined the effectiveness of ERAS protocols in orthognathic surgeries in a retrospective cohort study from 2017 to 2018. The focus was on two primary outcomes: postoperative opioid consumption and the incidence of Postoperative Nausea and Vomiting (PONV). The findings from the study revealed that the group of patients who underwent surgery with the ERAS protocol used significantly fewer opioids during the postoperative period and experienced fewer episodes of PONV compared to the traditional non-ERAS group. These results underscore the effectiveness of the ERAS protocol in decreasing postoperative opioid consumption and PONV in orthognathic surgeries. In this study, we employed the Sonopet IQ Ultrasonic Bone Aspirator (UBA) (Stryker, Kalamazoo, MI) in conjunction with XR technology in the metaverse to facilitate bone resection and efficient aspiration (Figure 3).

The UBA has been previously reported to be beneficial in various surgical procedures [7], including maxillectomy [8]. The UBA operates by inducing high-frequency oscillations that disrupt hydrogen bonds and lead to protein denaturation within the tissue, resulting in tissue elimination. The emulsification of the tissue occurs due to the creation of vapor bubbles, which are quickly rinsed off by an integrated irrigation system. Apart from its ability to preserve soft tissue, evidence suggests that piezoelectric surgery with the UBA, compared to traditional drill-based surgery, promotes superior bone regeneration postoperatively and reduces the presence of inflammatory cells at the surgical site [9]. The Sonopet IQ UBA possesses distinct properties that enable surgeons to excise bone precisely while preserving critical microstructures such as nerves and blood vessels. Its selective removal of solid tissue, particularly bone, without affecting soft tissues, minimizes damage to surrounding essential structures. This contributes to faster patient recovery, fewer complications, improved patient comfort and satisfaction, and a reduction in hospital readmission rates and long-term costs. Our data indicate a significant improvement in the surgeon's ability to accurately resect bone while safeguarding critical soft tissue structures, leading to a reduction in postoperative complications. Additionally, the ergonomic design of the Sonopet IQ UBA has the potential to alleviate surgeon fatigue, thereby enhancing the overall quality of surgical interventions. The device's adjustable settings offer versatility and the ability to tailor its performance to the specific requirements of each case. Our comprehensive analysis of postoperative outcomes and patient recovery times indicates that the utilization of the

Sonopet IQ UBA is associated with a reduction in postoperative management time, earlier hospital discharge, and decreased costs. These findings underscore the potential of the Sonopet IQ UBA as a valuable tool in orthognathic maxillofacial surgery, highlighting the need for further investigation and wider implementation in clinical practice.

CAD/CAM, XR, and Metaverse in Surgical Workflow

The recent advancements in CAD/CAM, XR, and Metaverse applications have seen recent advancements, opening up new avenues in the field of oral and maxillofacial surgery. These technologies have the potential to enhance surgical precision and improve educational effectiveness in multiple aspects [10-17]. Recent studies have demonstrated the integration of CAD/CAM and XR technologies, specifically Holoeyes, in surgical procedures, leading to improved effectiveness and outcomes [10-12]. We employed cara Print 4.0 Pro (Kulzer GmbH, Hanau Germany) as our CAD/CAM technology (Figure 2). This printer employs DLP (Digital Light Processing) technology with a wavelength of 385 nm and an XY resolution of 53.6 microns. It offers a customizable layer thickness ranging from 0.1mm to 0.3mm, allowing for precise customization according to specific requirements. Moreover, its large capacity of 124 mm in length, 70 mm in width, and 130 mm in height enhances its functionality. These features enabled us to create highly accurate surgical simulations and in-house models, optimizing efficiency and cost-effectiveness. The integration of CAD/CAM and XR technologies into our surgical workflow has led to improved surgical outcomes. Koyachi [13] demonstrated the significant benefits of mixed reality and Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technology in mandibular reconstruction. Additionally, studies by Sugahara [14,15] showcased the efficacy of these tools in addressing maxillary non-union after Le Fort I osteotomy and resecting maxillary tumors. Furthermore, Koyachi [16] emphasized the precision of Le Fort I osteotomy achieved through the combined use of CAD/CAM technology and mixed reality. These findings are particularly encouraging, highlighting the potential of these technologies to significantly enhance the success of orthognathic procedures. In terms of surgical training, XR and Metaverse offer a promising platform for immersive, interactive, and repetitive surgical simulations. These tools enable clinicians to visually learn and practice surgical procedures repeatedly, potentially improving their skills and enhancing patient outcomes. The use of XR technologies facilitates preoperative planning by creating patient-specific 3D models based on individual pathologies. Surgeons gain better understanding of patient anatomy, anticipate procedure complexities, and plan the necessary steps meticulously. During actual surgical procedures, real-time visualization of 3D anatomical models through XR can provide valuable guidance, enhancing surgical precision and potentially reducing the risk of complications. Beyond the clinical setting, XR and Metaverse are revolutionizing education and collaboration. They facilitate a shared educational environment among physicians and students across different locations, bridging physical distances, particularly beneficial during circumstances such as pandemics. These examples highlight the potential benefits and recent trends in the utilization of XR and Metaverse in oral and maxillofacial surgery. As these technologies continue to evolve, we anticipate discovering new applications that could revolutionize patient care and education in the discipline. From 2022 onward, we have continued to utilize Holoeyes MD for surgical support in clinical practice at Mirise Clinic. Holoeyes MD seamlessly integrates CBCT and optical impression data of individual patients, presenting pathological conditions in a three-dimensional holographic space. It has been extensively utilized for surgical planning, simulation, conferences, and medical education across disciplines (Figure 4). Surgeons can manipulate and view the patient's 3D holographic images from various angles, gaining a comprehensive understanding of the patient's condition and facilitating more effective surgical planning. The use of 3D holographic images allows surgeons to simulate and practice complex surgical procedures, potentially improving the actual surgery outcomes by reducing the likelihood of unexpected complications. Medical students and trainees can utilize these 3D holographic images for interactive and intuitive study of human anatomy and understanding various medical conditions (Figure 5).

Recent research underscores the potential of VR-HMD technologies provided by Holoeyes including their effectiveness in enhancing surgical procedures [10-12]. For example, Sueyoshi [17] demonstrated the feasibility of a multimodal image-assisted 3D endoscopic surgical training system using VR-HMD for robotic-assisted endoscopic radical prostatectomy. The usefulness of these techniques has also been reported in oral and maxillofacial surgeries. Looking at recent technological trends, the incorporation of Artificial Intelligence (AI) and Machine Learning (ML) holds the potential to further revolutionize the planning and execution of these surgeries. These technologies can enhance our ability to predict surgical outcomes and develop optimal surgical strategies. They can also be utilized to create personalized treatment plans based on individual patient characteristics. Furthermore, advancements in XR technologies offer surgeons the ability to visualize and practice complex surgeries before the actual procedure, potentially improving surgical outcomes. These technologies can also provide real-time 3D images during surgery, enabling precise and efficient surgical procedures. With the digitalization of healthcare and the evolution of telemedicine, preoperative and postoperative follow-ups can be facilitated remotely, further enhancing the patient care experience and outcomes. To fully harness the potential of these innovative technologies, rigorous clinical trials and research are imperative. These advancements have the potential to lead to more efficient and effective surgical outcomes, promoting patient recovery and overall quality of life. Embracing these new approaches and innovations is crucial for shaping the future of orthognathic and maxillofacial surgery. In terms of future perspectives, the optimization of orthognathic and maxillofacial surgery is an ever-evolving field, with expanding possibilities for the integration and application of novel technologies. The integration of SFA, ERAS, and XR Simulation has shown promise in improving surgical protocols and reducing hospitalization time. However, further research and development are still needed.

Conclusion

The implementation of the SFA, digital systems, and ERAS protocols at our clinic aligns with the latest medical literature. We anticipate continued advancements in these areas, leading to even greater improvements in patient outcomes. Through careful simulation, comprehensive patient care, and a team-based medical approach, safe perioperative management of orthognathic surgery with overnight postoperative management is achievable. The integration of XR technologies by Holoeyes and CAD/CAM in our surgical workflow has resulted in improved surgical outcomes. As this field continues to develop, we can expect further advancements to refine the processes and outcomes of orthognathic surgery.

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Disclosures of Conflicts of Interest:

Daisuke Tomita: Activities related to the present article: a board member of MEDiDENT Inc., Japan Oral Health Association, Mirise Clinic Minamiaoyama, Mirise Orthodontics Minamiaoyama, Mirise Oral Health Minamiaoyama, and Mirise Oral Health Ginza, Japan.

Maki Sugimoto: Activities related to the present article: a co-founder, board member of Holoeyes Inc. Activities not related to the present article: research grants from Fujitsu Inc. and RiverField Inc.

Other relationships: disclosed no relevant.

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