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Intraoperative Navigation In Orthognathic Surgery – A Review

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Abstract

Orthognathic surgery is essential for correcting jaw and facial skeletal discrepancies, addressing functional impairments, aesthetic concerns, and airway compromise. Traditional planning methods, including 2D cephalometry and splint-based model surgery, are limited by cumulative errors and restricted intraoperative adaptability. Digital workflows, such as virtual surgical planning (VSP) and intraoperative navigation, have emerged to enhance surgical precision, reproducibility, and safety. Intraoperative navigation enables real-time guidance, precise tracking, and accurate transfer of preoperative plans, improving outcomes in both routine and complex maxillary and mandibular procedures. Evidence demonstrates that navigation-assisted surgery reduces linear and angular deviations, improves occlusion, mandibular symmetry, condylar positioning, and aesthetic results, while minimizing complications and revision rates. Integration with CAD/CAM, patient-specific guides, and adjunctive technologies further optimizes surgical workflow and multidisciplinary collaboration. Future directions include augmented/mixed reality, robotics, and AI-driven navigation to advance precision and efficiency. Overall, intraoperative navigation represents a transformative tool, enhancing predictability and patient outcomes in orthognathic surgery.

Keywords: Orthognathic surgery, Intraoperative navigation, Virtual surgical planning, CAD/CAM, Surgical precision

Introduction

Orthognathic surgery plays a vital role in correcting jaw and facial skeletal discrepancies, addressing both functional impairments and aesthetic concerns, yet it remains technically demanding due to challenges in achieving precision, symmetry, and predictable outcomes.[1] Indicated for a wide range of conditions including congenital anomalies such as cleft lip and palate, trauma, severe malocclusions associated with temporomandibular dysfunction, airway compromise like obstructive sleep apnea, and functional impairments in speech and swallowing, orthognathic procedures often combine orthodontic and surgical approaches to restore essential functions and improve quality of life.[2] Traditional planning

methods relying on 2D cephalometry, plaster model surgery, and splint fabrication are inherently limited, as they lack three-dimensional accuracy, introduce cumulative errors, and remain inflexible to intraoperative adjustments, especially in complex or asymmetric cases where even minor inaccuracies may compromise symmetry, occlusion, or soft tissue harmony, sometimes necessitating revision surgeries.[3] To overcome these limitations, digital workflows such as virtual surgical planning (VSP) and intraoperative navigation have emerged, offering surgeons precise three-dimensional simulations, patient-specific guides, and real-time intraoperative verification that collectively enhance accuracy, reproducibility, and safety. By integrating CBCT/CT data, optical scans, and CAD/CAM technology, VSP allows for meticulous planning of skeletal movements and occlusion, while intraoperative navigation translates these plans into real-time guidance, ensuring faithful execution and minimizing risks to critical anatomical structures.[4] Evidence demonstrates that these technologies reduce discrepancies between planned and postoperative outcomes, improve symmetry, and enhance both functional and aesthetic results, thereby addressing complications like condylar sag, occlusal instability, or relapse more effectively than conventional methods. Although reductions in operative time remain inconsistent, the consistency, reliability, and multidisciplinary adaptability of full digital workflows mark a paradigm shift in orthognathic surgery, positioning VSP and navigation as essential tools for future clinical practice.[5] This article gives an overview on intraoperative navigation in orthognathic surgery.

Review of Literature

Intraoperative navigation has become a pivotal advancement in orthognathic surgery, markedly enhancing surgical precision and enabling the accurate translation of preoperative plans into the operative field, particularly in complex bimaxillary procedures. Computer-aided intraoperative navigation (Ci-Navi) has been shown to substantially reduce both linear and angular discrepancies between planned and actual outcomes, with Chen et al. (2021)[6] reporting mean linear and angular differences of 0.79 mm and 1.20°, respectively, compared to 1.98 mm and 2.08° observed with conventional techniques. Similarly, Schrader et al. (2025)[7] demonstrated that the use of modified CAD/CAM splints significantly improved maxillary positioning accuracy, notably decreasing translational movements along the x and z axes. Non-invasive registration methods, such as optical navigation integrated with CAD/CAM splints, permit real-time intraoperative evaluation without additional invasive procedures, further optimizing surgical workflow (Schrader et al., 2025). Clinically, these technologies have been associated with increased surgeon and patient satisfaction, delivering consistently acceptable accuracy and favorable outcomes (Chang et al., 2015).[8] Moreover, robot-assisted navigation has achieved remarkable precision, with mean deviations under 0.5 mm across multiple dimensions, highlighting its potential for highly accurate maxillary repositioning (Han et al., 2021).[9] Nonetheless, while the evidence underscores the benefits of intraoperative navigation, questions regarding its cost-effectiveness and overall clinical advantage over traditional approaches remain, necessitating further investigation and long-term studies to establish standardized protocols (Schrader et al., 2025).[7]

Principles and Workflow of Navigation Systems

Navigation systems in orthognathic surgery utilize computer-assisted technologies to provide continuous tracking and real-time guidance, seamlessly integrated with virtual surgical planning (VSP) and CAD/CAM fabrication. These systems measure and display the spatial position and orientation of surgical instruments relative to the patient's anatomy and preoperative imaging, enabling surgeons to perform procedures with enhanced precision and safety.[10] A typical setup includes a localizer or tracking device, instrument-mounted trackers, and high-resolution CT, CBCT, or MRI data. Tracking can be achieved through optical systems, which use infrared cameras to detect reflective or LED markers and offer high accuracy (≤1 mm TRE) but are susceptible to line-of-sight obstruction, or through electromagnetic systems, which operate independently of line-of-sight but may be affected by metal interference and nearby electronic devices. The preoperative workflow involves data acquisition, imaging segmentation to define anatomical structures, virtual simulation of osteotomies and

repositioning, and the generation of CAD/CAM-based guides, templates, and implants. Intraoperatively, registration aligns the patient with the virtual plan using fiducial markers, surface matching, or custom dental splints, followed by real-time tracking of instruments and anatomy to ensure precise execution.[11] Verification steps, sometimes augmented by intraoperative CBCT, allow immediate feedback and correction, confirming accurate positioning of bone segments and surgical devices. The integration of VSP with CAD/CAM workflows facilitates the fabrication of patient-specific guides and prosthetics that interface directly with navigation systems, enabling fully digital, multidisciplinary collaboration, streamlined surgical execution, and reliable postoperative assessment.[12] Overall, these navigation systems combine precise tracking, robust registration protocols, and digital planning tools to deliver high-precision, safe, and predictable outcomes in orthognathic surgery.[13]

Clinical Applications in Orthognathic Surgery

Orthognathic surgery encompasses a broad spectrum of clinical applications for both maxillary and mandibular corrections, achieving high-precision outcomes in routine and complex cases through the integration of advanced navigation, virtual surgical planning (VSP), and adjunctive technologies.[14] Maxillary procedures, particularly Le Fort osteotomies (I, II, III), are performed to reposition the maxilla for improved occlusion, facial proportions, and airway function, with navigation systems enhancing repositioning accuracy by translating three-dimensional surgical plans to the operative field, thereby minimizing asymmetry and optimizing esthetic outcomes.[15] In syndromic patients and revision cases, navigation facilitates complex skeletal movements while safeguarding critical anatomical structures. Mandibular corrections, most commonly via bilateral sagittal split osteotomy (BSSO) for advancement, setback, or asymmetric adjustments, benefit from real-time navigation and splint-based registration, which improve condylar seating, segment control, and overall precision, reducing the risk of relapse or temporomandibular joint complications.[16] Complex cases, including syndromic deformities such as cleft lip/palate or craniofacial microsomia, and revision surgeries, require individualized virtual planning and navigation to ensure accurate bony repositioning and soft-tissue adaptation, optimizing both functional and aesthetic outcomes.[17] Adjunctive applications of navigation further enhance surgical accuracy, enabling precise placement of osteosynthesis plates and screws, guided dental or facial implant positioning, and real-time verification and adjustment of condylar alignment.[18] Additionally, navigation supports airway-focused procedures, such as maxillomandibular advancement for obstructive sleep apnea, by directly improving airway dimensions while maintaining skeletal and facial harmony, demonstrating its broad clinical utility across diverse orthognathic interventions.[19]

Clinical Outcomes

Comparative studies consistently demonstrate that navigation-assisted orthognathic surgery provides superior accuracy, improved outcomes, and more streamlined workflows compared to conventional free-hand techniques.[20] Fully guided navigation approaches achieve sub-millimeter precision, with mean linear deviations ranging from 1.3 mm to 2.4 mm and angular deviations between 2.29° and 3.51°, surpassing the variability typically observed in free-hand methods. Vertical positioning, often a challenge in traditional surgery, is significantly enhanced, contributing to improved occlusion and facial symmetry.[20] Virtual surgical planning (VSP) similarly enhances precision; a study reported that VSP outperforms conventional surgical planning (CSP) for transverse and horizontal mandibular movements, with 80–93% of cases within an acceptable 2-mm deviation range.[21]By closely replicating preoperative designs, navigation and VSP improve mandibular symmetry, condylar positioning, and occlusal relationships, thereby supporting functional masticatory outcomes and achieving superior aesthetic results, particularly in complex or asymmetric cases. Operatively, navigation-assisted procedures reduce intraoperative trial and error, streamline the use of prebent plates and patient-specific guides, and can decrease surgical durations by approximately 30 minutes to over an hour.[22] Although VSP may require longer preoperative planning, it shortens the overall learning curve for less experienced surgeons, though concerns exist regarding potential overreliance on digital workflows and diminished intraoperative adaptability.[23] Clinically, these technologies are associated with lower complication rates, more predictable postoperative stability, and fewer revision surgeries. While navigation systems entail higher

initial costs, long-term economic benefits arise from shorter operative times, reduced complications, and decreased hospital stays.[24] Overall, navigation-assisted orthognathic surgery combined with VSP improves bone movement accuracy by millimeters and degrees, enhances occlusion, symmetry, and aesthetics, reduces operative time, and facilitates the surgical learning curve, ultimately providing superior patient outcomes compared to conventional methods.[25]

Conclusion

Future advancements in orthognathic surgery are likely to be driven by the integration of augmented and mixed reality, robotics-assisted procedures, AI-driven adaptive navigation, and fully digital, personalized workflows. These innovations promise to further enhance surgical precision, efficiency, and patient-specific outcomes. However, to maximize clinical benefits while ensuring cost-effectiveness and accessibility, there is a pressing need for standardized protocols and larger clinical trials to validate these technologies. In conclusion, intraoperative navigation represents a transformative adjunct in orthognathic surgery, improving accuracy and predictability, but its widespread adoption will depend on balancing technological sophistication with practical, evidence-based implementation.

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