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Original Article

Analysis of Guided versus Hand-Performed Orthognathic Surgery: Developments, Precision, and Clinical Impacts

Janovskiene Audra [1*], Greta Sakaliene[2]

[1] Department of the Orthodontics, Institute of Stomatology, Rīga Stradiņš University, Dzirciema Street 20, LV-1007 Riga, Latvia.
[2] Baltic Biomaterials Centre of Excellence, Institute of Stomatology, Rīga Stradiņš University, Dzirciema Street 20, LV-1007 Riga, Latvia.

***E-mail** ✉ Audrajanovskiene@gmail.com

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ABSTRACT

The evolution of orthognathic surgery through digital innovations has greatly enhanced precision and predictability. Traditional free-hand techniques depend heavily on the surgeon's skill, often producing inconsistent outcomes. Fully guided systems merge computer-assisted technologies—such as virtual surgical planning (VSP), CAD/CAM fabrication, and dynamic navigation—to improve accuracy and workflow efficiency. This review contrasts these methods and evaluates their effects on surgical accuracy, time efficiency, and clinical results. A scoping review was performed using PubMed, MEDLINE, Scopus, Cochrane Library, and Embase databases, focusing on clinical trials and cohort studies. Key aspects analyzed were accuracy, procedural efficiency, complication incidence, and functional/aesthetic performance. Fully guided methods demonstrated sub-millimetric precision, with mean linear deviations from 1.3 mm to 2.4 mm and angular deviations between 2.29° and 3.51°. These techniques also shortened operating time—averaging 34 minutes to 1.7 hours—and reduced postoperative risks. Digital integration improved workflow, consistency, and aesthetic predictability. Although free-hand surgery remains economical, it requires extensive expertise and tends to yield greater variability and prolonged recovery. Computer-guided orthognathic surgery surpasses manual methods in precision, predictability, and efficiency. Free-hand techniques remain practical for straightforward cases, yet fully guided systems deliver optimized outcomes. Future investigations should examine hybrid models that merge digital precision with manual flexibility to further enhance surgical performance.

Keywords: Fully guided, Free-hand, Mandibular reconstruction, Computer-assisted surgery, Virtual surgical planning (VSP), CAD/CAM, Dynamic navigation

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Introduction

Orthognathic surgery has been fundamentally reshaped by digital technologies, which have significantly advanced surgical precision, consistency, and clinical outcomes. Traditionally, surgeons have relied on free-hand methods using occlusal wafers and manual adjustments to reposition skeletal structures. These approaches, however, are limited by inter- and intra-operator variability, often causing postoperative discrepancies and extended recovery periods [1, 2].

The introduction of computer-assisted techniques has further revolutionized the field through tools such as artificial intelligence (AI), 3D imaging, real-time navigation, augmented reality, and dynamic tracking—all aimed at optimizing surgical accuracy. Virtual surgical planning (VSP) and CAD/CAM technologies enable customized guides and pre-shaped fixation plates, ensuring smoother execution and improved functional and aesthetic outcomes [3-5].

Studies have shown that intraoperative navigation enhances accuracy, particularly in vertical alignment—a consistent weakness of traditional surgery. Navigation systems maintain precision within 2 mm, providing superior control in the cranio-caudal axis compared to standard wafer-based positioning [6]. Additionally, augmented reality-assisted free-hand surgery is emerging as a valuable innovation, employing electromagnetic tracking and external reference markers to refine visualization and accuracy [2].

Despite these digital advances, free-hand techniques still hold relevance for less complex procedures. They remain cost-effective but often lead to longer hospitalization and less predictable results. The hierarchy of stability in orthognathic surgery indicates that maxillary expansion and mandibular rotation carry greater instability, underscoring the importance of advanced digital planning [7].

This review therefore aims to systematically evaluate and compare fully guided versus traditional free-hand approaches in orthognathic surgery, outlining their benefits, drawbacks, and clinical implications. By compiling data on digital surgical planning, intraoperative navigation, and customized guide creation, this study highlights the transformative role of digital systems in enhancing precision and patient satisfaction.

Materials and Methods

A scoping review design was selected instead of a formal systematic review, owing to the diversity in study structures, planning protocols, operative methods, and evaluation criteria found across literature comparing fully guided and free-hand orthognathic surgeries. This design allowed for comprehensive mapping of available evidence without forcing heterogeneous data into a single meta-analysis.

The review aimed to identify key research gaps concerning the comparative reliability, reproducibility, surgical efficiency, and clinical outcomes of both methods. Furthermore, this approach provided insight into how digital technologies are being implemented in various clinical settings and addressed challenges in integrating such tools into daily surgical practice. The ultimate goal was to generate a foundation for future systematic reviews and translational research within craniofacial surgery.

A detailed scoping review protocol was developed following the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses—Scoping Reviews) guidelines, with documentation provided in Supplementary Table S1 [8].

Defining the core research inquiry

To frame the central aim of this review, the PICO strategy (Population, Intervention, Comparator, Outcome) was used, as outlined in **Table 1**. Based on that framework, the main guiding question was articulated as follows:

Table 1. PICO (Population, Intervention, Comparator, Outcome)

Component	Description
Study Group	Individuals aged ≥18 years undergoing jaw correction surgery
Approach	Digitally assisted methods, including virtual planning, CAD/CAM technology, and 3D visualization
Comparison	Traditional manual surgical techniques
Results	Precision of surgery, operational efficiency, functional and cosmetic improvements, and minimization of complications

"For adult patients (≥ 18 years) who undergo orthognathic operations, what published evidence supports the effectiveness of fully guided or digitally assisted surgical systems—those employing virtual surgical planning (VSP), CAD/CAM design, and three-dimensional imaging—in enhancing precision, shortening procedure time, improving functional and cosmetic results, and lowering postoperative risks when compared with traditional free-hand practices over the last twenty years?"

Retrieval of relevant literature

An extensive literature exploration was completed on 1 May 2025 in PubMed, MEDLINE, Scopus, Cochrane Library, and Embase. The search strategy used the following Boolean expressions:

(("orthognathic surgical procedures"[MeSH Terms] OR ("orthognathic"[All Fields] AND "surgery"[All Fields]) OR "jaw surgery"[All Fields])) AND (("free"[All Fields] AND "hand"[All Fields]) OR ("full"[All Fields] AND ("guide" OR "guided" OR "guiding" OR "guides"))).

For Scopus, the syntax was: (TITLE-ABS-KEY(orthognathic AND surgery) OR TITLE-ABS-KEY(jaw AND surgery)) AND (TITLE-ABS-KEY(free AND hand) OR TITLE-ABS-KEY(full AND guided)).

Reference lists of the retrieved publications were additionally scanned to capture overlooked but relevant works.

Screening and eligibility criteria

Only English, peer-reviewed, full-text manuscripts were eligible. Studies had to satisfy all of the following:

• Participants: adults (≥ 18 years) who had orthognathic procedures;
• Design: randomized trial, cohort (prospective or retrospective), or clinical case report;
• Focus: direct evaluation of computer-aided / fully guided versus traditional manual techniques;
• Endpoints: accuracy of repositioning, operative timing, complication frequency, and both functional and aesthetic outcomes;
• Timeframe: publications from 2001 to 2025.

Records were excluded if they were duplicates, reviews, meta-analyses, protocols, animal or in-vitro research, abstracts, preprints, or incomplete trials.

Automated tools first filtered unsuitable material; then two reviewers (I.K. and S.T.) independently screened titles and abstracts under blinded conditions. Full texts passing this stage were re-examined for compliance. Any disagreements were adjudicated by a third evaluator (T.P.).

Data extraction and organization

Key data were charted independently by the two main reviewers (I.K. and S.T.) using a standardized template. The information collected included:

• **Bibliographic details:** author, year of issue, study type, number of participants, and mean age;
• **Surgical characteristics:** kind of jaw correction (mandibular, maxillary, or bimaxillary), mode of intervention (digitally guided using VSP / CAD/CAM / 3D imaging versus conventional free-hand), and planning or execution protocol;
• **Outcome variables:** numerical accuracy (linear and angular deviation, occlusal match, condylar position), operative indicators (duration, ischemia time, preplanning time), complication incidence, and cosmetic / functional scores including patient satisfaction;
• **Authors' conclusions:** summarized judgments about the comparative merits of guided and manual surgery.

Data synthesis and presentation

All extracted elements were compiled into summary tables for descriptive evaluation. Because this was a scoping rather than a quantitative review, no meta-analysis was attempted. Instead, the data were qualitatively interpreted to compare fully guided and traditional orthognathic operations.

The synthesis highlighted contrasts in surgical accuracy, procedural efficiency, complication frequency, and patient-centered outcomes, outlining the present level of knowledge and pointing to areas needing deeper empirical investigation.

Results

The PRISMA diagram **(Figure 1)** displays the progression from identification to inclusion. A total of 427 citations were found (PubMed and MEDLINE = 208; Scopus = 183; Cochrane and Embase = 36). After automated removal of 319 irrelevant records, 108 entries were screened in detail. Twenty-four duplicates were deleted manually, and 73 studies were excluded for design or topic ineligibility. The remaining 11 papers satisfied all criteria and were retained. Reference screening yielded an extra 14 publications, giving a final sample of 25 studies for inclusion in this review.

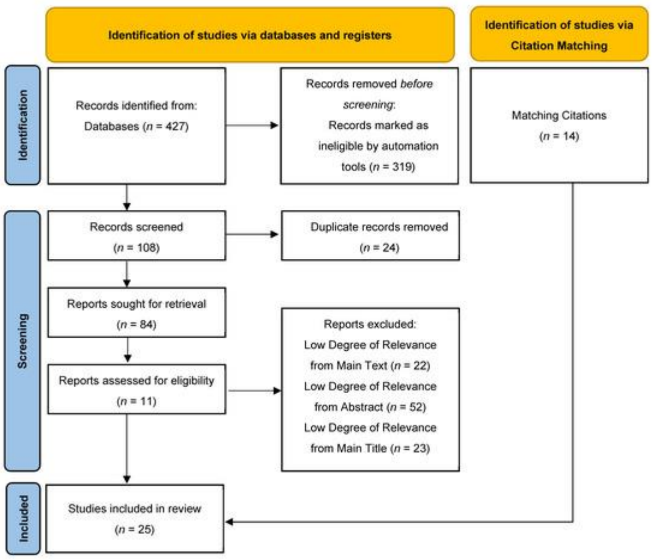

Figure 1. PRISMA flow diagram

Included studies spanned the years 2013 to 2022 **(Table 2)**. In numerous publications, fully guided orthognathic procedures consistently demonstrated greater precision, with intraoperative navigation achieving linear deviations between 1.34 mm and 2.4 mm and angular discrepancies from 2.29° to 3.51°, particularly enhancing vertical alignment. The incorporation of digital planning tools such as virtual surgical planning (VSP) and computer-aided design/manufacturing (CAD/CAM) enabled exact skeletal repositioning, minimizing intraoperative corrections and producing superior postoperative facial symmetry.

Table 2. Summary of outcomes from the included research

Authors, Publication Year	**Research Design; Cohort Size**	**Patient Age Range**	**Surgical Procedure**	**Method Employed**	**Planning and Execution Strategies**	**Accuracy Measures**	**Operative Performance**	**Adverse Event Rates**	**Practical and Visual Outcomes**	**Core Insights**
Hanasono *et al.*, 2013 [9]	Comparative Analysis; 38	51.0 ± 17.4 years	Jaw Reconstruction	Technology-Driven (CAD/RPM) vs. Traditional	Digital modeling with bespoke guides and preformed hardware vs. surgeon's real-time decisions	Minimized total positional errors; improved balance	Significant time savings in surgery, particularly for single flap cases	Not documented	Enhanced structural alignment and facial harmony	Technology-driven methods boost precision and streamline operations.
Ma *et al.*, 2021 [10]	Historical Review; 118	55.8 ± 18 years	Jaw and Facial Surgery	Tech-Assisted Surgery vs. Traditional	3D digital design with tailored templates vs. conventional manual planning	Similar post-surgical positioning; detailed metrics not provided	Shortened surgery duration, ischemia, bleeding, and hospital/ICU stays	Reduced early adverse events in tech-assisted group	Comparable bite function and performance; slight patient-reported differences	Tech-assisted surgery optimizes resource use with similar long-term results.
Liu *et al.*, 2014 [11]	Historical Review; 15	39.8 years	Jaw Reconstruction	Technology-Driven (bespoke templates) vs. Traditional	3D preoperative modeling with guides vs. surgeon's intraoperative assessment	Average positional shift ~2.40 mm; angular shift ~3.51°	Surgery duration cut by ~2 hours	Fewer early adverse events in tech group (1/15 vs. 2/7)	Slight functional gains; both methods restored satisfactory function and appearance	Tech-driven methods enhance accuracy and reduce surgery time.

Ciocca *et al.*, 2015 [12]	Forward-Looking Study; 10	Not specified	Facial Surgery	Technology-Driven (CAD/CAM) vs. Traditional (pre-plating)	Custom digital guides vs. real-time manual adjustments	Better side and arch alignment; vertical differences not significant	Surgical duration not specified	Not documented	Satisfactory restoration; slightly improved consistency with tech method	Tech-driven approaches enhance consistency, though skilled surgeons achieve similar traditional results.
Weitz *et al.*, 2016 [13]	Historical Review; 50	56 years (SD 13) vs. 55 years (SD 16)	Jaw Reconstruction	Technology-Driven with VSP and stereolithographic models vs. Traditional	Comprehensive digital planning with custom guides vs. intraoperative manual techniques	Reduced post-surgical jaw angle discrepancies	~34-minute surgery time reduction; enhanced bone healing	Comparable early adverse event rates	Improved bite alignment, facial balance, and long-term bone union	Digital planning improves predictability and efficiency in complex cases.
Zhang *et al.*, 2016 [14]	Historical Review; 22	35.5 years	Jaw Reconstruction	Technology-Driven (CAD/CAM) vs. Traditional	Digital planning with bespoke guides vs. manual intraoperative adjustments	Positional shift ~1.34 mm; angular shift ~2.29°	Reduced ischemia time (~52.5 min vs. 94.2 min)	Not documented	Superior bite alignment and bone contact; better symmetry	Tech-driven methods reduce errors and surgery time compared to traditional approaches.
De Maesschalck *et al.*, 2017 [15]	Historical Review; 18	65.8 years vs. 55.9 years	Jaw Reconstruction	Tech-Assisted Surgery vs. Traditional	3D digital planning with custom tools vs. conventional manual methods	Positional shifts 1.3–2.4 mm; angular shifts 2.29°–3.51°	Comparable overall performance; influenced by surgeon expertise	Similar adverse event rates	Acceptable structural outcomes; minor tech method advantages	Tech-assisted surgery improves uniformity, especially for less experienced surgeons, though traditional methods remain effective with skill.

Sieira Gil *et al.*, 2015 [16]	Forward-Looking Study; 20	47 years (SD 14) vs. 64 years (SD 13)	Jaw Reconstruction	Technology-Driven with CAD and RPM vs. Traditional	Digital planning with custom guides and pre-shaped plates vs. manual plate contouring	Improved jaw contour replication	Surgery time reduced by 42 min to 1.7 h	Fewer early adverse events	Enhanced bite alignment and facial appearance due to precise bone contact	Tech-driven methods optimize surgery despite higher initial costs.
Zweifel *et al.*, 2015 [17]	Forward-Looking Study; 9	65.9 years vs. 57.5 years	Head and Neck Flap Reconstruction (Jaw Focus)	Technology-Driven (VSP and 3D planning) vs. Traditional	Digital design with tailored templates for precise flap shaping vs. conventional adjustments	Not directly evaluated	Surgery time cut by 60–102 min; cost savings ~$47.50/min	Not documented	Indirectly supports improved function through precision	Tech-driven methods enhance efficiency and cost-effectiveness.
Tarsitano *et al.*, 2016 [18]	Forward-Looking Study; 4	Not specified	Jaw Reconstruction	Technology-Driven (CAD/CAM) vs. Traditional	Digital planning with custom guides and pre-shaped plates vs. manual plate shaping	Enhanced jaw contour replication; improved side accuracy	Fibular preparation time reduced from 26 min to 10 min	Not documented	Better bite function and appearance	Tech-driven methods significantly reduce surgery time and improve precision.
Wang *et al.*, 2016 [19]	Historical Review; 56	52 years	Jaw Reconstruction (Free Fibula Flap)	Technology-Driven vs. Traditional	Preoperative digital modeling with custom guides vs. surgeon-reliant methods	Higher structural precision with lower deviations	Reduced ischemia time (~70 min) and overall surgery time	Fewer alignment-related adverse events	Better bone healing and bite outcomes	Tech-driven methods improve plan execution and efficiency.
Culié *et al.*, 2016 [20]	Historical Review; 29	64.8 ± 8.9 years vs. 60.6 ± 10.9 years	Jaw Reconstruction	Technology-Driven (CAD/CAM) vs. Traditional	Digital guide design for precise bone segmentation vs. manual intraoperative adjustments	Improved side and vertical fibular alignment	Faster bone cuts, reducing total surgery time	Not documented	Enhanced jaw arch restoration and symmetry	Tech-driven methods offer reliable shape restoration.

Bouchet *et al.*, 2018 [21]	Single-Center Historical Review; 25	59.2 years vs. 60.2 years	Jaw Reconstruction	Technology-Driven (CAD/CAM) vs. Traditional	Custom guides and pre-shaped plates via digital design vs. manual techniques	Improved objective measures (e.g., reduced chin deviation)	Surgery time not specified	Not documented	Tech methods improved objective measures (e.g., motion range); traditional cases sometimes had higher subjective satisfaction	Tech-driven methods enhance objective functional outcomes, though subjective appearance varies.
Bartier *et al.*, 2021 [22]	Historical Review; 33	55.9 ± 12.7 years	Jaw Reconstruction (Free Fibula Flap)	Technology-Driven (CAD/CAM with VSP) vs. Traditional	Comprehensive digital planning with multiple checkpoints and custom guides vs. manual adjustments	Enhanced sagittal/coronal balance and condyle positioning	No notable surgery time difference	Not documented	Superior appearance and functional consistency	Tech-driven methods improve midskeletal balance and outcomes.
Kwon *et al.*, 2014 [23]	Historical Review; 42	21.9 ± 3.0 years vs. 23.1 ± 5.2 years	Maxillary (Le Fort I Osteotomy)	Technology-Driven (VMS/Digital) vs. Traditional (AMS)	3D dental data and cephalometric analysis with rapid digital modeling vs. impression-based methods	Positional error within 1 mm in 63.2% of VMS vs. 26% of AMS cases	Reduced lab time; streamlined digital workflow	Not documented	Comparable reliability with enhanced precision	Digital VMS improves workflow without sacrificing accuracy.
Schwartz, 2014 [24]	Historical Review; 30	28.3 years	Bimaxillary Jaw Surgery	Technology-Driven (CASS) vs. Traditional	Comprehensive digital planning with multiple sessions vs. manual planning with dental casts	Not applicable—focus on time/resources	Clinician time reduced from 865 min to 805 min (~60 min saved)	Not documented	Increased efficiency, potentially improving surgical throughput	CASS reduces planning time, optimizing clinical resources.

Van Hemelen *et al.*, 2015 [25]	Randomized Forward-Looking Study; 66	19.78 years	Jaw Surgery	Technology-Driven (3D planning) vs. Traditional (2D planning)	3D digital modeling for tissue outcomes vs. 2D cephalometric analysis and model fabrication	Significant improvement in soft tissue prediction; hard tissue errors (<2 mm) acceptable	Planning predictability emphasized; surgery time not detailed	Not documented	Enhanced facial balance and soft tissue outcomes	3D planning improves soft tissue predictability in complex cases.
Resnick *et al.*, 2016 [26]	Historical Review; 43	Not specified	Bimaxillary Jaw Surgery	Technology-Driven (VSP with 3D-printed splints) vs. Traditional	Digital workflow with 3D-printed splints vs. traditional plaster model surgery	Not applicable—focus on economic factors	Cost savings ~$650–$930 per case; ~25 working days saved annually (200 cases)	Not documented	Acceptable outcomes; enhanced predictability with digital planning	VSP improves time and cost efficiency.
Wrzosek *et al.*, 2016 [27]	Forward-Looking Study; 41	Not specified	Bimaxillary Jaw Surgery	Technology-Driven (VSP with 3D-printed splints) vs. Traditional	Office-based digital planning reducing manual lab steps vs. traditional model preparation	Improved consistency (exact numbers not provided)	Planning time reduced by ~2.2 h; reduced resident workload	Not documented	Maintained or improved bite/skeletal accuracy	VSP reduces planning time and labor, benefiting throughput.
Ritto *et al.*, 2018 [28]	Historical Review; 30	Not specified	Maxillary Repositioning	Technology-Driven (VSP) vs. Traditional (CMS)	Cone-beam CT and digital simulation vs. traditional cast mounting	Mean positional error ~1.20 mm (VSP) vs. 1.27 mm (CMS)	Improved workflow in digital planning; surgery time not detailed	Not documented	Comparable functional outcomes; workflow benefits	VSP achieves similar accuracy with streamlined planning.
Steinhuber *et al.*, 2018 [29]	Prospective Comparative Study; 40	24.6 years	Jaw Surgery (Single/Double-Jaw)	Technology-Driven (VSP) vs. Traditional	Digital planning by technicians minimizing manual steps vs. labor-intensive model preparation	Not reported—focus on planning efficiency	Planning time savings: 36 min (single-jaw), 74 min (double-jaw)	Not documented	Maintained outcomes; improved workflow	VSP reduces planning time and resident workload.

Schneider *et al.*, 2019 [30]	Randomized Controlled Study; 21	31.1 years	Jaw Surgery	Technology-Driven (VSP with CAD/CAM and 3D printing) vs. Traditional	Advanced digital workflow with rapid modifications and pre-shaped plate simulation vs. traditional cephalometric tracing	Lower angular errors (SNA, SNB, ANB); improved splint accuracy	~31% reduction in splint-based intervention time	Not documented	Enhanced function and facial balance	Tech-driven VSP improves precision and intraoperative efficiency.
Al-Sabahi *et al.*, 2022 [31]	Prospective Randomized Study; 22	41 ± 18.5 years vs. 47.81 ± 13.6 years	Jaw Reconstruction	Technology-Driven (CAD/CAM, "COG" group) vs. Traditional ("MB" group)	Digital planning with custom guides and pre-shaped plates vs. manual reconstruction	Improved contour balance; lower angular deviations	Shorter surgery and ischemia times in tech group	Not documented	Higher patient satisfaction (VAS, PSS); better appearance	Tech-driven methods enhance aesthetic balance and efficiency.
Bao *et al.*, 2017 [32]	Historical Review; 35	Not specified	Jaw Reconstruction	Technology-Driven (CAD/CAM) vs. Traditional	3D modeling with custom guides and pre-shaped plates vs. intraoperative judgment	Improved cut angle precision and segment positioning	Ischemia time ~70 min (tech) vs. 120–180 min (traditional); shorter surgery time	Not documented	Better bite relationships and symmetry; less tissue trauma	Tech-driven CAD/CAM enhances accuracy and reduces ischemia time.
Ritschl *et al.*, 2017 [33]	Historical Review; 30	63.07 ± 8.08 years vs. 61.94 ± 11.64 years	Jaw Reconstruction	Technology-Driven (CAD/CAM/virtual planning) vs. Traditional	3D modeling with custom guides and pre-shaped plates vs. intraoperative adjustments	Better jaw anatomy replication; reduced deviations	~35 min shorter surgery time in tech group	No significant difference	Comparable function; improved predictability in complex cases	Tech-driven methods improve contour replication and reduce surgery time.

Regarding operative efficiency, computer-assisted systems markedly shortened the surgery duration compared with conventional free-hand approaches, typically ranging from 34 minutes to 1.7 hours. The integration of customized guides and pre-shaped fixation plates improved the procedural flow, as several investigations reported measurable decreases in total operation time. Enhanced preoperative virtual simulations further allowed surgeons to perform faster and more confidently, reducing the need for intraoperative revisions.

In terms of postoperative recovery, patients treated with digitally guided surgery experienced shorter hospital stays and lower complication rates. The increased precision of computer-based planning corresponded with higher patient satisfaction scores and improved aesthetic and functional results when compared with the manual free-hand method.

A comparative overview of both strategies is displayed in **Table 2**, summarizing differences in accuracy, efficiency, outcomes, and complication incidence reported by the reviewed studies.

Discussion

Orthognathic procedures require meticulous skeletal repositioning to restore both functionality and facial balance. Extensive research has analyzed the relative advantages of computer-guided workflows versus traditional free-hand methods. The guided approach combines 3D virtual modeling, VSP, CAD/CAM design, and rapid prototyping, enabling the fabrication of individualized surgical templates, prebent plates, and occlusal splints. This integrated workflow provides precise preoperative visualization, reproducible intraoperative performance, and predictable postoperative outcomes. In contrast, manual approaches depend on 2D cephalometric evaluation, stone model surgery, and handcrafted splints, making them inherently reliant on surgical experience and prone to variability between operators.

The evolution of fully guided systems has revolutionized pre-surgical preparation through three-dimensional imaging and virtual simulation, translating digital plans into accurate intraoperative execution [9, 13, 30]. Conversely, conventional methods continue to depend on 2D planning and manual steps that lack the spatial accuracy of modern digital tools [23, 24]. Although skilled surgeons can still achieve acceptable results with free-hand techniques, their outcomes often suffer from limitations in precision and increased error margins when dealing with complex anatomical configurations [12, 25].

Research consistently demonstrates the superiority of guided approaches in terms of accuracy and reproducibility. For instance, Zhang *et al.* reported mean linear deviations around 1.34 mm and angular errors near 2.29° in digitally executed osteotomies—considerably less variable than those observed with manual techniques [14]. Similarly, multiple analyses [11, 15, 20] have confirmed that guided protocols enhance replication of planned bone movements, mandibular alignment, and fibular segment positioning. Although De Maesschalck *et al.* noted that highly skilled free-hand surgeons can approach similar precision levels, computer-assisted planning ensures standardized results and reduces inter-operator discrepancies [15].

One of the most recognized advantages of digital workflows is the reduction in operative time and ischemia. Multiple reports [9, 10, 17, 18] confirm that patient-specific cutting guides and prebent fixation plates minimize intraoperative adjustments—such as manual plate shaping and repeated repositioning—leading to shorter overall surgical durations and reduced ischemic exposure. Moreover, studies focusing on the planning phase [24, 27, 29] emphasize that digital preoperative design significantly decreases laboratory workload and planning time, while simplifying resident training.

The enhanced aesthetic and functional performance achieved through digital guidance reflects the precision of computer-based simulations. Numerous investigations confirm that guided procedures yield better mandibular symmetry, optimized occlusion, and accurate condylar placement, improving both mastication and facial appearance [13, 21, 31, 32]. Objective metrics, such as soft tissue prediction and landmark fidelity, often favor the guided system [22, 25], though experienced surgeons performing manual free-hand operations can still achieve satisfactory outcomes in select cases [21]. The accuracy afforded by digital systems is particularly crucial for complex reconstructions, where even minor deviations may result in long-term functional deficits or aesthetic asymmetry.

While fully guided surgical systems involve a greater initial financial commitment—owing to the need for specialized hardware, proprietary software, and custom-fabricated components [16, 26, 30]—a number of investigations suggest that these expenses are later compensated by overall economic efficiency. This is particularly evident in high-throughput surgical centers, where reductions in operation time, ischemia duration, and secondary corrective procedures contribute to a more cost-effective workflow [17, 26]. Economic modeling further indicates that digital preoperative planning may deliver significant yearly savings and enhance institutional productivity, especially when indirect expenditures such as operating room utilization and surgeon labor are factored into the analysis.

Another important aspect involves the impact on surgical education and procedural adaptability. The digitally guided model can help accelerate skill acquisition among novice surgeons by supplying a structured, replicable virtual roadmap [11, 27]. Nevertheless, some authors caution that excessive dependence on computerized planning could diminish manual dexterity and spatial judgment, skills that remain vital in unforeseen intraoperative conditions [12, 18]. Conversely, the traditional free-hand technique provides greater flexibility for real-time modification during surgery, though this adaptability often increases procedure time and introduces greater performance variability [9, 19].

In the context of maxillary repositioning and bimaxillary reconstruction, both digital and conventional strategies can achieve clinically acceptable precision. For example, Kwon *et al.* [23] and Ritto *et al.* [28] found that digitally assisted maxillary adjustments maintain error margins within 1–2 mm, with some reports noting improvements in occlusal alignment and skeletal correspondence. Likewise, Schwartz [24] and Van Hemelen [25] demonstrated that three-dimensional guided systems enhance soft-tissue predictability and facial symmetry, which are critical determinants of aesthetic harmony in bimaxillary orthognathic interventions.

Looking forward, the incorporation of next-generation digital technologies—including direct intraoral scanning and in-house desktop 3D printing—is expected to streamline guided workflows even further, lowering both production costs and planning duration [26, 30]. However, prospective multicenter trials remain necessary to verify these early benefits and assess their long-term effects on functionality, patient-reported satisfaction, and training standards.

Despite the encouraging evidence surrounding fully guided orthognathic procedures, certain limitations persist. Chief among these are the variations in study design, patient demographics, and evaluation criteria across existing literature, which complicate direct comparisons between digital and manual modalities. Furthermore, the implementation of comprehensive digital systems demands not only significant financial resources but also specialized surgeon training, factors that may restrict accessibility in resource-limited environments. These challenges underline the importance of developing standardized frameworks, cost-efficient workflows, and integrated educational programs that balance technological competency with traditional surgical expertise. Future research should thus emphasize large-scale, harmonized investigations that assess scalable deployment models, ensuring that digital innovation translates effectively into routine clinical practice.

Conclusions

Fully guided orthognathic surgery offers marked advantages in precision, consistency, and workflow optimization compared with conventional free-hand operations. Through digital planning and patient-specific instrumentation, surgeons can reproduce preoperative simulations with submillimetric accuracy, resulting in enhanced functional restoration and facial aesthetics, while also minimizing surgical duration. Although initial setup costs and a potential decrease in intraoperative adaptability remain challenges, the reduction in procedural variability and long-term cost efficiency, particularly in high-volume institutions, highlight the transformative value of digital integration. Continued exploration of hybrid surgical models—merging the flexibility of manual techniques with the precision of computer guidance—should represent a key direction for future clinical research.

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Ethics Statement: None

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