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Original Article

Fully Guided vs. Free-Hand Orthognathic Surgery: A Comparative Study on Precision, Advancements, and Clinical Results

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Abstract

With the incorporation of digital innovations, orthognathic surgery has progressed toward greater precision and predictability. Traditional free-hand procedures depend largely on operator skill, often producing inconsistent outcomes. In contrast, fully guided systems utilize computer-assisted techniques such as virtual surgical planning (VSP), CAD/CAM fabrication, and intraoperative navigation to increase accuracy and efficiency. This review contrasts both strategies, evaluating their influence on surgical precision, workflow efficiency, and patient-centered outcomes. A scoping review was performed using PubMed, MEDLINE, Scopus, Cochrane Library, and Embase. Clinical trials and cohort investigations were included. The main parameters of interest were accuracy of skeletal positioning, surgical time, complication incidence, and both functional and esthetic results. Digitally guided surgery achieved near sub-millimeter fidelity, with mean linear deviation ranging between 1.3–2.4 mm and angular variation of 2.29°–3.51°. These approaches also shortened operative duration, averaging 34 minutes to 1.7 hours, while lowering complication rates. Digital protocols improved reproducibility and esthetic predictability. In contrast, free-hand surgery, though less expensive, relied heavily on surgical expertise, generally produced higher variability, and was associated with longer recovery periods. Computer-aided orthognathic methods outperform conventional techniques in accuracy and predictability, enhancing overall efficiency. While manual methods remain acceptable for less complex cases, fully guided surgery represents the optimal standard for complex reconstructions. Future work should explore hybrid models that balance digital accuracy with the adaptability of free-hand execution.

Key words: Guided surgery, Manual techniques, Jaw reconstruction, Computer-assisted surgery, VSP, CAD/CAM, Dynamic navigation

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Introduction

The adoption of digital systems has fundamentally reshaped orthognathic surgery, yielding improved precision, predictability, and clinical outcomes. Historically, skeletal repositioning depended on free-hand procedures, occlusal splints, and intraoperative judgment. Such techniques are inherently influenced by operator variability, contributing to discrepancies in skeletal alignment and extended hospitalization [1, 2].



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The emergence of computer-assisted surgery has further advanced the field, incorporating artificial intelligence (AI), 3D imaging, real-time navigation, augmented reality, and intraoperative visualization to refine accuracy. Preoperative virtual planning enables surgeons to anticipate anatomical variation, reduce soft tissue trauma, and improve safety margins. By integrating VSP with CAD/CAM, customized guides and patient-specific plates can be fabricated, facilitating more predictable execution and superior esthetic and functional results [3-5].

Recent evidence shows that navigation-based approaches significantly enhance vertical control, one of the most challenging dimensions for conventional methods. These systems routinely achieve precision within 2 mm, outperforming occlusal wafers for cranial–caudal alignment [6]. Furthermore, augmented reality–assisted free-hand approaches, which employ electromagnetic tracking and external reference markers, offer enhanced visualization and intraoperative guidance [2].

Nevertheless, manual techniques retain relevance in relatively straightforward cases due to their affordability, though they are frequently associated with longer hospitalization and less predictable outcomes. The hierarchy of surgical stability in orthognathic procedures suggests that maxillary expansion and mandibular rotation are more prone to relapse, emphasizing the importance of advanced preoperative planning [7].

This scoping review therefore aims to comprehensively examine fully guided strategies versus free-hand surgery in orthognathics, weighing their benefits, drawbacks, and clinical implications. By synthesizing available research on virtual planning, navigation, and guide fabrication, the review highlights how digital technologies are reshaping surgical accuracy and patient care.

Materials and Methods

A scoping review methodology was chosen instead of a systematic review due to substantial heterogeneity among studies, including differences in study design, surgical planning, operative execution, and reported outcomes when comparing fully guided and free-hand orthognathic techniques. This approach allows for a broad overview of available evidence, highlighting patterns and gaps without forcing inconsistent data into a meta-analytic framework. The review aims to summarize reproducibility, efficiency, clinical performance, and implementation strategies of both surgical approaches, providing foundational insight for future research and clinical integration of computer-assisted orthognathic procedures. A detailed protocol guided the review process, and all reporting adhered to the PRISMA-ScR checklist (see Supplementary Table S1) [8].

Research question formulation

The review question was constructed using the PICO framework (Population, Intervention, Comparator, Outcome), summarized in **Table 1**:

Table 1.

Component	Description
Population (P)	Patients aged ≥ 18 years undergoing orthognathic surgical procedures
Intervention (I)	Digitally guided surgical methods, including virtual planning, CAD/CAM technology, and 3D imaging techniques
Comparator (C)	Traditional manual surgical approaches
Outcome (O)	Precision of surgery, operational efficiency, aesthetic and functional results, and minimization of complications

“For adult patients (≥ 18 years) undergoing orthognathic surgery, what is the evidence from the past 20 years that fully guided, computer-assisted methods (including virtual surgical planning, CAD/CAM, and 3D imaging) improve surgical accuracy, operative efficiency, functional and aesthetic results, and reduce complication rates, compared to conventional free-hand techniques?”

Search strategy and study identification

On 1 May 2025, a comprehensive search was performed in PubMed, MEDLINE, Scopus, Cochrane Library, and Embase. Search terms combined MeSH headings and free-text keywords relevant to orthognathic surgery and surgical guidance methods.

For PubMed/MEDLINE/Cochrane/Embase:

("orthognathic surgical procedures"[MeSH] OR ("orthognathic"[All Fields] AND "surgical"[All Fields] AND "procedures"[All Fields])

OR "orthognathic surgery"[All Fields] OR "jaw surgery"[All Fields])

AND (("free"[All Fields] AND ("hand"[MeSH] OR "hand"[All Fields]))

OR ("full"[All Fields] AND ("guide"[All Fields] OR "guided"[All Fields] OR "guides"[All Fields] OR "guiding"[All Fields])))

For Scopus:

(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))

Additionally, references of included studies were manually reviewed to identify further relevant publications.

Study selection—Eligibility and screening

This review was confined to complete research articles published in English within peer-reviewed journals. To be considered, studies needed to satisfy the following requirements: participants had to be adults (≥ 18 years) undergoing orthognathic procedures; acceptable study types included clinical trials, retrospective or prospective cohort studies, or case reports; the primary focus had to be a comparison between fully guided (computer-assisted, digital) techniques and traditional free-hand methods in orthognathic surgery, with outcomes addressing surgical precision, efficiency, function, aesthetics, and complication frequency; and the publication date had to fall between 2001 and 2025. Excluded works included duplicate entries, review papers, systematic reviews, meta-analyses, protocols, guidelines, animal-based studies, abstracts from conferences, presentations, preprints, ongoing clinical trials, studies without published findings, and any research deemed irrelevant.

Following these exclusion rules—applied via automated systems and manual researcher checks—the final article pool was obtained. Title and abstract screening was performed independently and in a blinded manner by two reviewers (I.K. and S.T.). Articles that passed this stage underwent full-text examination to confirm eligibility. Any disagreements in screening decisions were resolved with the input of a third reviewer (T.P.).

Data charting

Information from the included studies was systematically collected by the lead reviewers (I.K. and S.T.). Extracted data points consisted of: first author, year of publication, study methodology, sample size, and patient demographics (mean age). Surgical details were also documented, including the type of procedure (mandibular, maxillary, or bimaxillary), the intervention model (fully guided digital workflows using VSP, CAD/CAM, and 3D imaging versus conventional free-hand methods), and perioperative planning protocols. Outcomes were recorded, encompassing measures of surgical precision (linear/angular deviation, occlusal alignment, condylar position), operative details (duration of surgery, ischemia period, and planning time), complication rates, and both functional and cosmetic results (including patient-reported satisfaction when noted). Final study conclusions were summarized to reflect comparative insights between digital fully guided and free-hand techniques.

Collating, summarizing, and reporting results

Collected data were organized into summary tables to allow descriptive examination. Since this work was a scoping review, no meta-analysis was conducted. Instead, a qualitative synthesis of findings was undertaken to evaluate differences between fully guided and conventional free-hand orthognathic approaches. The synthesis emphasized contrasts in surgical precision, efficiency, aesthetic and functional outcomes, and complication rates, thereby outlining the current knowledge base and highlighting research gaps requiring further study.

Results

The PRISMA flowchart (**Figure 1**) presents the selection and exclusion pathway. An initial 427 records were identified across the databases (PubMed and MEDLINE, $n = 208$; Scopus, $n = 183$; Cochrane and Embase, $n = 36$). Automated screening

removed 319, leaving 108 for closer inspection. From these, 24 duplicates were manually excluded. Next, 73 studies were eliminated during abstract/title screening due to ineligible design. The full-text assessment of 11 remaining papers confirmed all met inclusion criteria. Reference checking contributed 14 more relevant studies. In total, 25 studies were included in this scoping review.

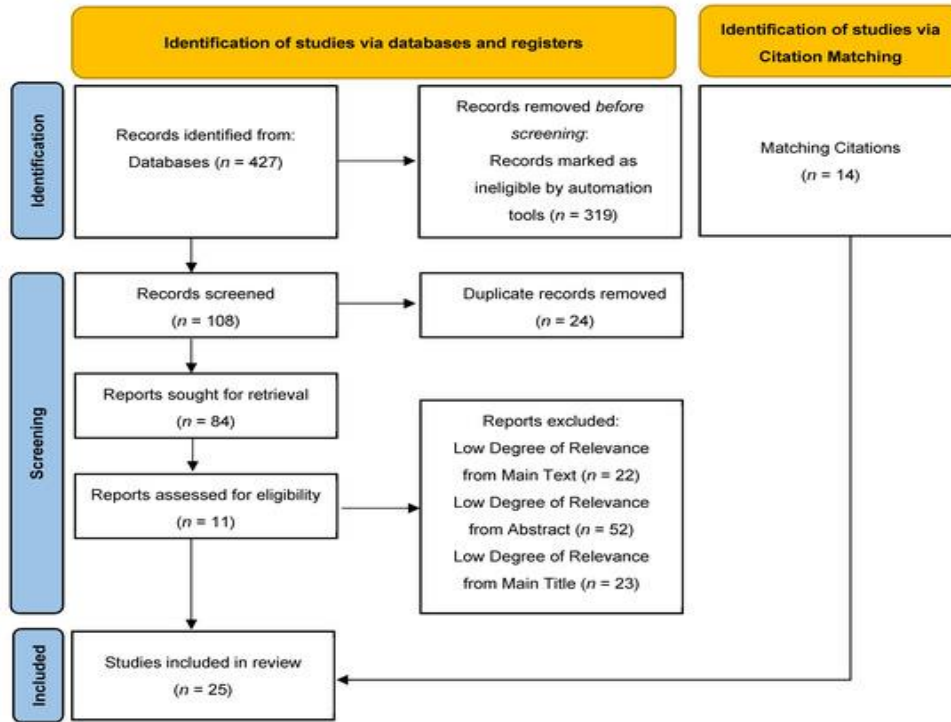


Figure 1. PRISMA Flow Chart

The selected studies were published from 2013 to 2022 (**Table 2**). Across several investigations, fully guided surgical techniques showed higher precision, with intraoperative navigation producing linear deviations between 1.34 mm and 2.4 mm and angular deviations ranging from 2.29° to 3.51°, most notably in vertical alignment. Digital approaches, including virtual surgical planning (VSP) and CAD/CAM, enabled accurate skeletal repositioning, minimizing intraoperative corrections and enhancing postoperative symmetry.

Table 2. Summary of Results from Included Studies

Research, Year	Study Design; Sample Size	Patient Age	Procedure	Method	Planning Approach	Accuracy Measures	Surgical Efficiency	Adverse Events	Clinical and Aesthetic Outcomes	Primary Conclusions
Hanasono MM <i>et al.</i> [9]	Case-Control; 38	51.0 ± 17.4 years	Mandibular reconstruction	Digitally guided (CAD/RPM) vs. manual	Virtual planning with custom guides and pre-shaped hardware vs. intraoperative manual decisions	Reduced positional errors; improved symmetry	Significant time reduction, especially in single-flap cases	Not reported	Enhanced bone alignment and facial aesthetics	Guided techniques offer superior precision and faster surgery.

Ma H <i>et al.</i> [10]	Retrospective; 118	55.8 ± 18 years	Orthognathic/m axillofacial reconstruction	Digital surgery (CAS) vs. manual	3D virtual modeling with tailored templates vs. conventional manual planning	Similar postoperative alignment; no detailed metrics	Decreased surgery duration, ischemia, bleeding, and hospital/ICU stays	Fewer early adverse events in guided group	Comparable bite function; slight patient-reported variations	Digital surgery reduces resource use with similar long-term results.
Liu YF <i>et al.</i> , 2014 [11]	Retrospective; 15	39.8 years	Mandibular reconstruction	Template-guided vs. manual	3D preoperative modeling with guides vs. surgeon's real-time judgment	~2.40 mm length error; ~3.51° angular error	~2 h reduction in surgery time	Fewer early issues (1/15 vs. 2/7)	Minor functional gains; both restored acceptable aesthetics	Guided approach improves accuracy and shortens surgery time.
Ciocca L <i>et al.</i> [12]	Prospective; 10	Not specified	Maxillofacial surgery	CAD/CAM- guided vs. manual pre- planning	Custom CAD- generated guides vs. intraoperative manual adjustments	Better lateral/arch fit; vertical differences not significant	Surgical time not specified	Not reported	Slightly improved consistency with guided method	Guided methods enhance reproducibility, though skilled manual surgery is comparable.
Weitz J <i>et al.</i> [13]	Retrospective; 50	56 years (SD 13) vs. 55 years (SD 16)	Mandibular reconstruction	VSP-guided with 3D models vs. manual	Comprehensive digital planning with custom guides vs. manual intraoperative approach	Smaller mandibular angle errors	~34 min less surgery time; better bone healing	Similar early adverse event rates	Improved bite alignment, symmetry, and bone union	Digital planning improves predictability in complex cases.
Zhang L <i>et al.</i> [14]	Retrospective; 22	35.5 years	Mandibular reconstruction	CAD/CAM- guided vs. manual	Virtual planning with tailored guides vs. manual intraoperative adjustments	~1.34 mm length error; ~2.29° angular error	Reduced ischemia (~52.5 min vs. 94.2 min)	Not reported	Enhanced bite and bone contact; better symmetry	Guided methods reduce errors and surgical duration.
De Maesschalck T <i>et al.</i> [15]	Retrospective; 18	65.8 years vs. 55.9 years	Mandibular reconstruction	CAS- guided vs. manual	3D virtual planning with custom tools vs. traditional manual methods	Length errors 1.3–2.4 mm; angular errors 2.29°– 3.51°	Comparable outcomes; influenced by surgeon skill	Similar adverse event rates	Acceptable shape outcomes; minor guided	CAS enhances consistency, particularly for less

									benefits	experienced surgeons
Sieira Gil R <i>et al.</i> [16]	Prospective; 20	47 years (SD 14) vs. 64 years (SD 13)	Mandibular reconstruction	CAD/RPM-guided vs. manual	CAD-designed custom guides and pre-shaped plates vs. manual plate shaping	Improved mandibular shape replication	42 min to 1.7 h time savings	Reduced early adverse events	Better bite and aesthetics from precise bone contact	Guided methods streamline surgery despite higher planning costs.
Zweifel DF <i>et al.</i> [17]	Prospective; 9	65.9 years vs. 57.5 years	Head/neck free-flap reconstruction (mandibular)	VSP/3D-guided vs. manual	Digital planning for precise flap shaping vs. manual adjustments	Not directly measured	60–102 min time reduction ; ~\$47.50/min savings	Not reported	Indirectly improved function via precision	Guided methods improve efficiency and cost savings.
Tarsitano A <i>et al.</i> [18]	Prospective; 4	Not specified	Mandibular reconstruction	CAD/CAM-guided vs. manual	Virtual planning with custom guides and pre-shaped plates vs. manual plate shaping	Better native shape replication; improved lateral precision	Fibular prep reduced from 26 min to 10 min	Not reported	Enhanced bite function and aesthetics	Guided methods reduce time and improve accuracy.
Wang YY <i>et al.</i> [19]	Retrospective; 56	52 years	Mandibular reconstruction (fibula flap)	Guided vs. manual	Digital planning with custom guides vs. surgeon-driven methods	Higher anatomical precision ; lower errors	~70 min ischemia time; shorter overall surgery	Fewer alignment issues	Better bone healing and bite outcomes	Guided methods enhance plan execution and efficiency.
Culié D <i>et al.</i> [20]	Retrospective; 29	64.8 ± 8.9 years vs. 60.6 ± 10.9 years	Mandibular reconstruction	CAD/CAM-guided vs. manual	Digital guides for precise bone cuts vs. manual intraoperative adjustments	Improved fibular alignment (lateral/vertical)	Faster osteotomies; reduced total surgery time	Not reported	Better mandibular arch restoration and symmetry	Guided methods improve contour reliability.
Bouchet B <i>et al.</i> [21]	Monocentric Retrospective; 25	59.2 years vs. 60.2 years	Mandibular reconstruction	CAD/CAM-assisted vs. manual	Custom guides and pre-shaped plates vs. manual techniques	Reduced chin deviation ; better objective metrics	Surgical time not specified	Not reported	Better range of motion; subjective satisfaction varies	CAD/CAM improves objective functional outcomes.

Bartier S <i>et al.</i> [22]	Retrospective; 33	55.9 ± 12.7 years	Mandibular reconstruction (fibula flap)	CAD/CAM/VSP-guided vs. manual	VSP with anatomical checkpoints and custom guides vs. manual adjustments	Better sagittal/coronal symmetry and condyle placement	No notable time difference	Not reported	Superior aesthetics and functional consistency	Guided methods enhance skeletal symmetry and outcomes.
Kwon TG <i>et al.</i> [23]	Retrospective; 42	21.9 ± 3.0 years vs. 23.1 ± 5.2 years	Maxillary (Le Fort I osteotomy)	Digital VMS vs. manual AMS	3D dental/cephalometric data vs. traditional impressions	63.2% VMS vs. 26% AMS with <1 mm error	Reduced lab time; streamlined digital process	Not reported	Comparable reliability; better precision	Digital VMS improves workflow without sacrificing accuracy
Schwarz HC, [24]	Retrospective; 30	28.3 years	Bimaxillary orthognathic surgery	CASS-guided vs. manual	Comprehensive digital planning vs. traditional cast-based planning	Not applicable—focus on time/resources	~60 min saved (865 min to 805 min)	Not reported	Improved efficiency; potential for higher throughput	CASS reduces planning time and resource use.
Van Hemelen G <i>et al.</i> [25]	Randomized Prospective; 66	19.78 years	Orthognathic surgery	3D-guided vs. 2D manual	3D digital modeling vs. 2D cephalometric analysis	Better soft tissue prediction; <2 mm hard tissue errors	Focus on planning predictability; time not detailed	Not reported	Improved facial symmetry and soft tissue results	3D planning enhances soft tissue outcome prediction.
Resnick CM <i>et al.</i> [26]	Retrospective; 43	Not specified	Bimaxillary orthognathic surgery	VSP/3D-printed splints vs. manual	Digital workflow with 3D-printed splints vs. plaster model surgery	Not applicable—focus on cost	~\$650–\$930 savings; ~25 days saved annually	Not reported	Comparable outcomes; better predictability	VSP improves time and cost efficiency.
Wrzosek MK <i>et al.</i> [27]	Prospective; 41	Not specified	Bimaxillary orthognathic surgery	VSP/3D-printed splints vs. manual	Digital office-based planning vs. manual lab-intensive prep	Enhanced consistency	~2.2 h planning time reduction; less resident workload	Not reported	Maintained or improved bite/skeletal precision	VSP reduces planning time and labor.
Ritto FG <i>et al.</i> [28]	Retrospective; 30	Not specified	Maxillary repositioning	VSP-guided vs. CMS	Cone-beam CT/digital simulation vs. articulator-based model surgery	~1.20 mm VSP vs. 1.27 mm CMS error	Improved workflow; time not specified	Not reported	Comparable function; better planning	VSP matches accuracy with streamlined planning

										efficiency
Steinhuber <i>T et al.</i> [29]	Prospective Control; 40	24.6 years	Orthognathic surgery (single/double-jaw)	Office-based VSP vs. manual	Digital planning by technicians vs. manual lab prep	Not reported—focus on planning time	36 min (single-jaw), 74 min (double-jaw) saved	Not reported	Maintained outcomes; better workflow	VSP reduces planning time and resident workload.
Schneider <i>D et al.</i> [30]	Randomized Controlled Trial; 21	31.1 years	Orthognathic surgery	VSP/CAD/CAM/3D printing vs. manual	Advanced digital workflow vs. cephalometric/stone model adjustments	Reduced angular errors (SNA, SNB, ANB); better splint fit	~31% less time for splint interventions	Not reported	Improved function and symmetry	VSP enhances precision and surgical efficiency.
Al-Sabahi <i>ME et al.</i> [31]	Prospective Randomized Control Trial; 22	41 ± 18.5 years vs. 47.8 ± 13.6 years	Mandibular reconstruction	CAD/CAM-assisted (COG) vs. manual (MB)	Digital planning with custom guides/plates vs. manual reconstruction	Better contour symmetry; reduced angular errors	Shorter surgery/ischemia times	Not reported	Higher satisfaction (VAS, PSS); better aesthetics	Guided methods improve symmetry and efficiency.
Bao <i>T et al.</i> [32]	Retrospective; 35	Not specified	Mandibular reconstruction	CAD/CAM-guided vs. manual	3D modeling with custom guides/plates vs. intraoperative judgment	Improved osteotomy angles, segment lengths, positioning	~70 min vs. 120–180 min ischemia; shorter surgery	Not reported	Better bite, symmetry; less trauma	CAD/CAM enhances accuracy and reduces time.
Ritschl <i>LM et al.</i> [33]	Retrospective; 30	63.07 ± 8.08 years vs. 61.94 ± 11.64 years	Mandibular reconstruction	CAD/CAM/VSP-guided vs. manual	3D modeling with custom guides/plates vs. manual adjustments	Better native anatomy replication; similar function	~35 min surgery time savings	No significant difference	Comparable function; better predictability in complex cases	Guided methods improve contour replication and reduce time.

Regarding surgical efficiency, computer-assisted methods consistently shortened operative duration compared with conventional free-hand approaches, with time savings ranging from 34 minutes to 1.7 hours. The integration of pre-bent fixation plates and customized cutting guides streamlined intraoperative steps, and multiple reports noted a decrease in overall operative time. Additionally, improved preoperative simulation contributed to faster execution in the operating room and fewer intraoperative modifications.

Post-surgical findings showed that patients treated with fully guided approaches had shorter hospitalizations and a lower incidence of complications. Digital planning accuracy translated into higher satisfaction ratings, with measurable improvements in both functional recovery and cosmetic outcomes compared to traditional methods.

Table 2 outlines the comparative performance of guided versus free-hand techniques, detailing findings on accuracy, efficiency, postoperative recovery, and complication incidence.

Discussion

Orthognathic procedures require exact skeletal repositioning to achieve both functional correction and facial harmony. A growing body of research has examined the advantages and drawbacks of digital, fully guided surgery relative to conventional free-hand methods. Computer-assisted workflows employ VSP, 3D imaging, CAD/CAM, and rapid prototyping to fabricate customized guides, pre-shaped fixation plates, and splints, creating a process that allows accurate virtual planning, reproducible intraoperative transfer, and predictable results. In contrast, free-hand techniques utilize two-dimensional cephalometric analyses, dental model surgery, and manually constructed splints, methods that are more dependent on surgeon skill and subject to both inter- and intra-operator variability.

Digital workflows have transformed preoperative preparation through 3D visualization, VSP, CAD/CAM, and prototyping, generating patient-specific templates and guides that allow skeletal repositioning to be simulated with sub-millimetric precision. These carefully designed virtual plans can then be executed in the operating room [9, 13, 30]. Conversely, free-hand strategies rely on 2D tracings, model surgery, and manual splint construction, involving several laboratory steps [23, 24]. While such methods may yield acceptable outcomes in expert hands, they carry higher risks of error due to the limitations of 2D data in representing complex 3D structures [12, 25].

The literature consistently demonstrates that guided surgery provides superior reproducibility and accuracy. For example, Zhang *et al.* reported digitally designed osteotomies with mean linear errors of ~ 1.34 mm and angular deviations of $\sim 2.29^\circ$, values that were more consistent than those from free-hand surgery [14]. Likewise, other studies [11, 15, 20] highlight that guided approaches achieve better replication of preoperative plans, with improved control of fibular positioning and mandibular alignment. Although De Maesschalck T. *et al.* acknowledged that highly skilled free-hand surgeons can sometimes reach similar outcomes, digital workflows minimize inter-surgeon variability and establish standardized, quantifiable outcomes, supporting greater consistency across diverse cases [15].

One of the most notable benefits of guided methods is the reduction in operating time and ischemia duration. Numerous reports [9, 10, 17, 18] confirm that the use of customized guides and preformed plates significantly decreases surgery duration. The guided technique avoids labor-intensive intraoperative adjustments, such as manual plate bending and repeated fragment repositioning, thus optimizing efficiency in the operating theater. As a result, both total operative time and flap ischemia intervals are shortened. Additionally, research on preoperative preparation [24, 27, 29] has shown that digital planning reduces laboratory workload and decreases total planning time, while also easing the demands on surgical training programs. The clear gains in both functional and cosmetic results highlight the accuracy achievable with digital planning systems. Numerous reports confirm that fully guided surgery enhances mandibular balance, produces more stable occlusion, and optimizes condylar seating—factors closely tied to effective chewing and overall facial harmony [13, 21, 31, 32]. Even in situations where patients express satisfaction with free-hand operations [21], quantitative measures such as soft tissue forecasting and reference point accuracy [22, 25] tend to favor guided approaches. Such refinements are particularly critical in complex reconstructions, where small positional errors can eventually cause asymmetry or impaired function.

Although the digital route involves higher start-up costs due to specialized hardware, software, and custom fabrication [16, 26, 30], multiple cost-benefit analyses argue that these are balanced by downstream savings. In high-throughput surgical centers, cost-effectiveness emerges through shortened procedures, reduced ischemia intervals, and fewer revision cases [17, 26]. When indirect expenditures such as operative room occupancy and surgeon hours are included, yearly savings and departmental efficiency improve considerably.

Training implications are also significant. Digital planning offers novice surgeons a reproducible roadmap, helping shorten the learning curve [11, 27]. At the same time, concerns exist that dependence on computer-generated guides may limit the development of manual dexterity needed in unexpected intraoperative situations [12, 18]. By contrast, the free-hand style allows immediate modifications during surgery, though this adaptability often leads to longer operations and less consistency [9, 19].

For maxillary repositioning and double-jaw surgeries, both strategies produce acceptable results. For example, Kwon TG *et al.* (2014) and Ritto FG *et al.* [23, 28] reported error margins of 1–2 mm when using digital planning, sometimes with superior

occlusion and skeletal alignment. Further, Schwartz [24] and Van Hemelen [25] demonstrated that 3D-guided planning improves soft tissue projection and overall facial symmetry—essential for balanced outcomes in bimaxillary cases. Looking ahead, newer innovations such as intraoral digital scanning and office-based 3D printing are expected to make guided surgery faster and more affordable [26, 30]. However, broader validation through large-scale, prospective studies is still required to confirm benefits for long-term function, aesthetics, patient-reported outcomes, and surgical education. Despite strong evidence in favor of guided systems, several constraints remain. The diversity of methodologies, patient cohorts, and assessment metrics across published studies complicates direct comparison. Furthermore, real-world adoption requires substantial infrastructure, upfront financial investment, and specialized training, which may limit feasibility in low-resource settings. This highlights the need for unified protocols, scalable cost-management strategies, and training models that integrate both digital and traditional skills. Future work should prioritize multicenter trials with standardized designs to clarify clinical impact and to support wider integration into surgical practice.

Conclusions

Digitally guided orthognathic surgery clearly surpasses traditional free-hand methods in terms of accuracy, reproducibility, and operative efficiency. Patient-specific planning tools allow near-perfect transfer of virtual simulations into the operating room, yielding improved function, better symmetry, and shorter surgical times. The benefits—including lower variability and possible long-term cost savings in busy clinical environments—point to its transformative role. Nonetheless, initial costs and reduced flexibility during surgery remain obstacles. Future research should emphasize long-term validation and investigate hybrid workflows that merge the adaptability of free-hand surgery with the precision of digital systems.

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