Review

Available online at
www.heca-analitika.com/ijcr

Indonesian Journal of Case Reports

Vol. 4, No. 1, 2026

Dynamic Navigation vs Freehand Dental Implant Placement: A Systematic Review of Surgical Efficiency and Clinical Outcomes

Muhammad Rizqan [1,*] and Muhammad Rizqi Maulana Fatah [2]

[1] Faculty of Dentistry, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia; rizqan6910@gmail.com (M.R.)
[2] General Dentist, Taksim Hospital, Cibarusah, Bekasi, Indonesia; rizkyfatah461@gmail.com (M.R.M.F.)

* Correspondence: rizqan6910@gmail.com

Article History

Received 13 February 2026
Revised 15 April 2026
Accepted 24 April 2026
Available Online 3 May 2026

Keywords:
Dynamic navigation
Dental implant placement
Freehand technique
Surgical accuracy
Implant complications

Abstract

Precise implant positioning is critical for functional, biological, and prosthetic success in dental implant therapy. Dynamic navigation systems provide real-time intraoperative guidance and may enhance placement accuracy compared with conventional freehand techniques. However, their impact on clinical outcomes remains incompletely clarified. To evaluate clinical outcomes, surgical efficiency, and complication rates of dynamic navigation–assisted dental implant placement compared with freehand techniques in adult patients. A systematic search of PubMed, Cochrane Library, and ScienceDirect identified comparative clinical studies evaluating dynamic navigation versus freehand implant placement. Primary outcomes included postoperative pain, operative time, surgical complications, and early implant success. Nine studies were included in the qualitative synthesis. Dynamic navigation consistently demonstrated significantly reduced coronal, apical, and angular deviations compared with freehand placement. Selected studies reported shorter operative times and lower early postoperative pain in navigation groups. Major complications were rare in both techniques, although minor transient neurosensory disturbances were reported more frequently with freehand placement. Early implant survival rates were high and comparable across groups. While dynamic navigation reliably enhances surgical precision and may improve procedural efficiency, its influence on early implant survival appears limited. Improved accuracy may offer greater safety in anatomically complex regions; however, long-term clinical superiority remains uncertain. Dynamic navigation improves implant placement accuracy and may enhance surgical efficiency without increasing complications, but further long-term evidence is needed to establish definitive clinical advantages.

1. Introduction

Dental implant therapy has evolved into one of the most predictable and widely accepted treatment modalities for replacing missing teeth in both partially and fully edentulous patients. Contemporary implant systems demonstrate consistently high survival rates, often exceeding 90–95% over long-term follow-up when appropriate surgical planning and prosthetic execution are achieved [1]. However, long-term survival alone does not fully capture clinical success [2–4]. Optimal outcomes require precise three-dimensional implant positioning that respects biological boundaries, preserves peri-implant tissues, and supports prosthetically driven rehabilitation [5]. Deviations from ideal positioning may compromise soft-tissue stability, biomechanical load distribution, and esthetic integration, and, in anatomically critical regions, may lead to serious complications [6].

Conventional freehand implant placement remains the most commonly performed technique worldwide. Its continued popularity stems from its flexibility, minimal equipment requirements, and adaptability to intraoperative findings. Nevertheless, the freehand approach is inherently operator-dependent. Even with meticulous preoperative cone-beam computed tomography (CBCT) planning, translating virtual planning into accurate intraoperative execution remains challenging [7]. Studies have demonstrated measurable discrepancies between planned and actual implant positions when using conventional techniques, particularly in angular and apical deviations [8]. In the posterior mandibular region, such deviations may increase the risk of inferior alveolar nerve injury. In contrast, in the maxilla, they may predispose to sinus membrane perforation or inadequate primary stability [6].

To address these limitations, computer-assisted implant surgery has progressively gained traction. The introduction of static surgical guides marked a significant milestone in transferring digital planning into clinical reality [9]. Static guides improve positional accuracy compared with freehand techniques by physically constraining drill trajectory according to preoperative planning [10–12]. However, this approach is not without limitations. Static guides may restrict irrigation, reduce surgical visibility, complicate posterior access, and offer limited flexibility once fabricated [13]. In addition, cumulative errors arising from imaging, digital planning, manufacturing tolerances, and intraoral guide positioning may influence final accuracy.

Dynamic navigation systems represent the next evolutionary step in digital implantology. Unlike static guides, dynamic systems provide real-time visual tracking of surgical instruments relative to patient anatomy [14]. By integrating CBCT datasets with optical or infrared tracking technology, the surgeon receives continuous feedback regarding angulation, depth, and spatial orientation during osteotomy preparation. This real-time adaptability enables intraoperative modifications without requiring new guide fabrication, thereby preserving flexibility while maintaining digital precision [15].

From a theoretical perspective, dynamic navigation offers several potential advantages over both freehand and static-guided techniques [2, 10–12, 16]. Enhanced visualization of anatomical landmarks may improve surgical safety in regions with limited bone volume or proximity to critical structures. Improved trajectory control may reduce cortical perforation and ensure prosthetically ideal implant positioning. Furthermore, real-time feedback may shorten operative time by reducing the need for repeated angulation adjustments and intraoperative radiographic verification [14, 15].

Recent clinical investigations have reported that dynamic navigation systems significantly reduce coronal, apical, and angular deviations compared with freehand implant placement [17]. However, most studies to date have concentrated primarily on radiographic accuracy rather than clinically meaningful outcomes. While precision is undeniably important, its true value lies in whether it translates into improved patient-centered outcomes, enhanced surgical efficiency, or reduced complication rates. The relationship between improved angular deviation and tangible clinical benefit remains insufficiently clarified.

Moreover, while static guides have been extensively evaluated through systematic reviews and meta-analyses [9, 13], the body of literature addressing dynamic navigation remains comparatively fragmented. Available studies vary in design, sample size, anatomical focus, and reported endpoints. Some emphasize positional accuracy; others report limited data on operative time, postoperative discomfort, or short-term implant survival. This heterogeneity complicates interpretation and highlights the need for a focused synthesis centered on clinical outcomes rather than solely technical deviation metrics.

Importantly, the adoption of dynamic navigation systems entails additional costs, equipment acquisition, and a learning curve for clinicians. Therefore, demonstrating superiority in accuracy alone may not be sufficient justification for widespread clinical implementation. Robust evaluation of postoperative pain, intraoperative and early postoperative complications, procedural efficiency, and early implant success is necessary to determine whether dynamic navigation provides meaningful clinical advantages over conventional freehand techniques.

In light of these considerations, the present systematic review aims to evaluate the clinical outcomes, surgical efficiency, and complication rates associated with dynamic navigation–assisted dental implant placement compared with conventional freehand techniques in adult patients undergoing implant therapy. By synthesizing current comparative clinical evidence, this review seeks to clarify whether improved navigational precision translates into measurable clinical benefit.

2. Materials and Methods

2.1. Study Design and Reporting Standards

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The study aimed to synthesize available clinical evidence comparing dynamic navigation–assisted dental implant placement with conventional freehand techniques, focusing on clinical outcomes, surgical efficiency, and early complications. The methodology was predefined prior to study selection to ensure transparency and reproducibility.

2.2. Eligibility Criteria

Studies were considered eligible if they included adult patients undergoing dental implant placement in partially or fully edentulous sites and directly compared dynamic navigation–assisted implant placement with conventional freehand techniques. Only clinical studies were included, encompassing randomized controlled trials, prospective clinical studies, and retrospective comparative studies. Case series were considered only if they provided clinically relevant outcome data and met predefined criteria for implant placement using dynamic navigation systems.

The intervention of interest was real-time dynamic computer-guided implant placement, defined as the use of optical or infrared tracking systems providing intraoperative feedback. Static surgical guide–only studies without a dynamic navigation component were excluded. The comparator was a conventional freehand implant placement performed without intraoperative navigational assistance.

Primary outcomes of interest included postoperative pain, operative time or procedural efficiency, intraoperative and early postoperative surgical complications, and early implant success or failure. Secondary outcomes, such as implant positional accuracy, were recorded when available but were not considered primary endpoints for inclusion.

Non-clinical studies, in vitro investigations, cadaveric studies, technical notes without patient data, and studies lacking relevant outcome reporting were excluded. Only articles published in English were considered.

2.3. Information Sources and Search Strategy

A comprehensive electronic literature search was performed across three databases: PubMed, Cochrane Library, and ScienceDirect. The search strategy combined terms related to dynamic navigation and dental implant placement. Boolean operators were used to broaden and refine the search while maintaining clinical relevance. The final search strategy included combinations of the terms "dynamic navigation," "computer-assisted navigation," "real-time navigation," "dental implant," and "implant placement," along with study design–related keywords such as "clinical," "trial," "retrospective," and "prospective."

The search was conducted without a year restriction to capture all relevant clinical evidence. Reference lists of included studies were manually screened to identify additional eligible articles.

2.4. Study Selection

The initial search identified 1,034 records, including 625 from PubMed, 78 from the Cochrane Library, and 331 from ScienceDirect. After title and abstract screening, 1,023 studies were excluded due to irrelevance, absence of dynamic navigation systems, non-comparative design, or non-clinical methodology.

Eleven records were screened for duplication, and one duplicate was removed. Ten full-text articles were assessed for eligibility. One study was excluded at the full-text stage due to inappropriate participant characteristics and study design not meeting the predefined inclusion criteria. Ultimately, nine studies were included in the qualitative synthesis.

2.5. Data Extraction

Data extraction was performed using a standardized extraction table developed prior to analysis. Extracted variables included study characteristics (author, year, country, design), population demographics, implant site characteristics, number of implants placed, type and brand of dynamic navigation system, comparator details, and reported outcomes.

Clinical outcomes extracted included postoperative pain scores, operative time, intraoperative and early postoperative complications, early implant survival, or failure rates. When available, accuracy parameters such as coronal, apical, and angular deviation were also recorded to provide contextual interpretation of technical precision.

2.6. Risk of Bias Assessment

Risk of bias was assessed qualitatively based on study design, allocation methods, blinding procedures, sample size, and completeness of outcome reporting. Randomized clinical trials were evaluated for allocation concealment and potential performance bias.

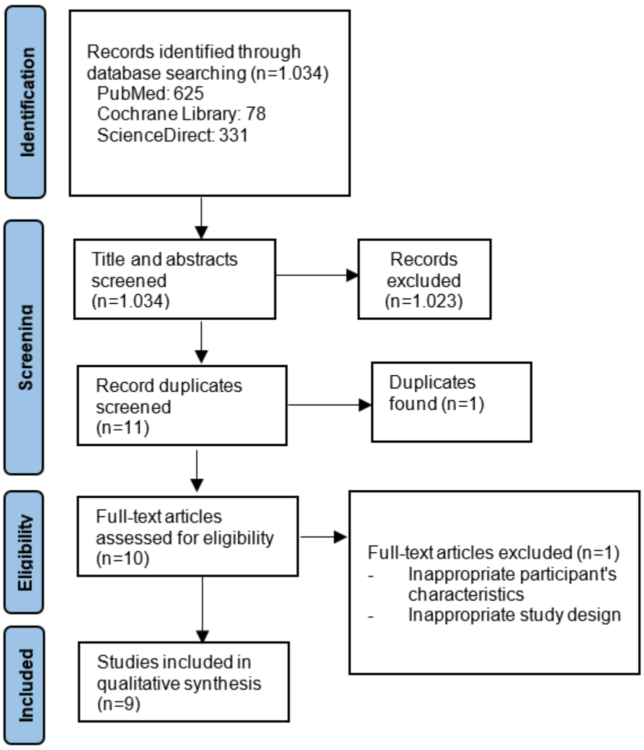

Figure 1. Diagram flow of the literature search strategy for this systematic review.

Retrospective studies were assessed for selection bias and confounding variables.

Given the heterogeneity of study designs and outcome reporting, a formal meta-analysis was not performed. Instead, a narrative synthesis was conducted, emphasizing comparative clinical outcomes and consistency of findings across studies. Risk of bias judgments were categorized as low or moderate; no study was classified as high risk in accordance with predefined interpretative criteria.

2.7. Data Synthesis

Due to heterogeneity in outcome definitions, follow-up duration, and reporting formats, quantitative pooling was deemed inappropriate. A structured narrative synthesis was therefore undertaken. Results were grouped according to predefined primary outcomes: postoperative pain, operative time, surgical complications, and early implant success. Accuracy outcomes were synthesized separately as secondary findings to contextualize clinical implications.

3. Results and Discussion

3.1. Study Selection

Figure 1 illustrates the flow diagram of the literature search strategy for this systematic review. The systematic search identified a total of 1,034 records across three electronic databases, including 625 from PubMed, 78 from the Cochrane Library, and 331 from ScienceDirect. Following removal of clearly irrelevant records during title and abstract screening, 1,023 studies were excluded, primarily due to non-clinical design, absence of dynamic navigation systems, or lack of comparator groups relevant to this review. Eleven records underwent duplicate screening, resulting in the removal of one duplicate entry. Ten full-text articles were subsequently assessed for eligibility based on predefined inclusion criteria. One study was excluded due to inappropriate participant characteristics and incompatible study design. Ultimately, nine studies fulfilled the inclusion criteria and were included in the qualitative synthesis.

The selection process reflects the relatively focused but still emerging body of clinical literature investigating dynamic navigation systems in implant dentistry. Although the initial yield was large, the majority of excluded records consisted of in vitro studies, technical reports, static guide evaluations, or studies lacking clinical outcome data.

3.2. Study Characteristics

The nine included studies demonstrated considerable heterogeneity in design, sample size, and outcome reporting. Study designs included randomized clinical trials, prospective clinical trials, retrospective comparative analyses, and one case series. This diversity reflects the evolving nature of dynamic navigation research, where early investigations often prioritized

Table 1. Characteristics and results table of the included studies.

No.	Author	Design / N	Intervention vs Comparator	Main Outcomes	Findings	Ref.
1	Nirula et al. (India)	Single-centre parallel-group RCT; 60 patients; 120 implants; mean age 48	Navident dynamic navigation using CBCT/STL planning, trace registration, drill calibration, and real-time feedback vs conventional freehand placement	Pain, operative time, patient satisfaction	DN significantly reduced postoperative pain at 0–48h and operative time. VAS: 0.23 ± 0.568 vs 1.73 ± 1.437, p=0.03. Time: 28.3 vs 60 min, p<0.05. Complications and early implant success were not reported.	[18]
2	Ma et al. (China)	Retrospective single-arm clinical study; 55 patients; 55 implants; mean age 53.47 ± 12.83	Dynamic navigation with CBCT/X-Clip registration, DTX Studio planning, real-time guidance, Nobel Active implants, and X-Guide accuracy analysis; no comparator	Implant placement accuracy; learning curve	Mean apex deviation was 1.60 ± 0.94 mm, tip deviation 1.83 ± 1.03 mm, and angular deviation 3.80 ± 2.09°. Tip deviation was significantly greater in anterior sites than in premolar/molar sites. Angular deviation decreased with experience. Pain, operative time, complications, and implant success were not reported.	[19]
3	Aydemir & Arisan (Turkey)	Prospective clinical study; 30 patients, 15 DN / 15 freehand; 60 implants; mean age 46.6 ± 9.4	Navident dynamic navigation with CBCT planning, real-time tracking, drill calibration, and trace registration vs conventional freehand CBCT-guided placement	Implant placement accuracy	DN showed significantly lower angular deviation and improved positional accuracy compared with freehand placement, p<0.05. Coronal and apical deviations were also lower with DN. Pain, operative time, complications, and implant success were not reported.	[17]
4	Younis et al. (China)	Prospective randomized three-arm clinical study; 94 implants total: 34 DN / 30 surgical guide / 30 freehand; mean age 44.5	DCARER dynamic navigation with CBCT/fiducial registration, prosthetically oriented planning, handpiece calibration, and real-time infrared tracking vs freehand CBCT-based "mental navigation"	Implant placement accuracy	DN was significantly more accurate than freehand for most deviations. DN vs freehand: platform deviation 0.99 ± 0.52 vs 1.36 ± 0.62 mm; apical deviation 1.14 ± 0.56 vs 1.73 ± 0.66 mm; angular deviation 3.66° ± 1.64° vs 5.82° ± 2.79°. No significant difference for depth deviations; no learning curve observed. Pain, operative time, complications, and implant success were not reported.	[20]
5	Deng (China)	Retrospective comparative study; 72 posterior maxillary implants, 38 DN / 34 freehand; 55 patients; mean age 52.31 ± 16.74	Iris-100 dynamic navigation with CBCT planning, infrared tracking, tilted implant placement, and NobelActive implants vs conventional freehand immediate placement; bone grafting when required	Primary stability, implant deviation, complications, and implant success	DN significantly improved primary stability and implant positioning accuracy compared with freehand. No serious complications, maxillary sinus perforation, or postoperative sinusitis occurred. Implant success was 100% in both groups over a median 29.6 ± 11.2 months of follow-up.	[21]
6	Zhang (China)	Retrospective three-arm comparative study; 96 posterior mandibular implants: 32 DN / 32 static guide / 30 freehand; age not reported	Dynamic real-time navigation–assisted flapless implant placement with CBCT planning and intraoperative visualization vs conventional freehand flapless placement; static guide also included	Implant accuracy, residual bone volume, marginal bone loss, peri-implant health, and implant success	DN significantly reduced neck, apex, and angular deviation compared with freehand, p<0.05. Apex and angular deviations were also smaller than those of the static guide, p<0.05. Residual bone volume was greater than freehand. Marginal bone loss and peri-implant gingival health did not differ among groups. Pain, operative time, and follow-up	[22]

No.	Author	Design / N	Intervention vs Comparator	Main Outcomes	Findings	Ref.
					duration were not reported in the abstract.	
7	Stefanelli et al. (Italy)	Prospective case series; 13 patients; 77 full-arch implants; mean age 68.15 ± 9.22; no comparator	Navident dynamic navigation using Trace and Place protocol, CBCT/intraoral scan merge, optical tracking, and real-time drill guidance; no freehand control	Implant placement accuracy, complications, and implant survival	Mean deviations were 0.72 mm coronal, 1.00 mm apical, 0.56 mm depth, and 2.7° angular. No postoperative hemorrhage or infection was reported. Four early implant failures occurred during healing; 73/77 implants osseointegrated, giving 94.8% short-term survival at 4 months. Accuracy improved when 5–6 teeth were traced vs 3–4 teeth.	[23]
8	Jorba-García et al. (Spain)	Randomized clinical trial; 40 patients, 20 DN / 20 freehand; 40 implants; mean age 56.4 ± 12.1	Navident dynamic navigation with CBCT-based prosthetically driven planning, real-time drill tracking, and trace registration vs conventional CBCT-planned freehand placement	Implant placement accuracy, surgical time, implant survival, complications	DN significantly improved placement accuracy and reduced surgical time compared with freehand, $p<0.05$. No major intraoperative complications or postoperative infections were reported. Implant survival was 100% in both groups at 6 months. Pain was not reported.	[24]
9	Edelmann et al. (Germany)	Prospective single-arm clinical trial; 20 patients; 20 implants; age not reported; no comparator	Camlog dynamic navigation using a fully digital workflow with CBCT planning, intraoral scan integration, real-time tracking, 3D printed models, and deviation analysis; no freehand control	Implant placement accuracy, clinical effectiveness	Mean angular deviation was 2.7°, and mean 3D shoulder deviation was 1.83 mm. No major complications were reported. No significant accuracy differences were found between upper vs lower jaw or open vs flapless procedures. Implant survival, pain, operative time, and follow-up duration were not explicitly reported.	[25]

feasibility and accuracy before expanding into broader clinical outcome assessments. A detailed overview of the study design, population characteristics, intervention protocols, comparator groups, outcome measures, and key findings of the included studies is presented in Table 1.

Sample sizes ranged from small exploratory cohorts of fewer than 20 patients to larger comparative groups exceeding 70 participants. The number of implants placed varied substantially, from 20 implants in controlled prospective trials to more than 100 implants in larger retrospective analyses. Most studies focused on partially edentulous patients, though at least one investigated full-arch rehabilitation in complex prosthetic scenarios.

Implant placement sites involved both maxillary and mandibular regions, with a notable emphasis on posterior areas where anatomical constraints such as limited bone volume, proximity to the inferior alveolar nerve, and sinus anatomy increase procedural complexity. Several studies specifically highlighted posterior mandibular placement as a high-risk anatomical scenario in which navigation systems may offer enhanced safety and visualization.

Across studies, dynamic navigation systems varied in brand and workflow but shared common technical features. All utilized CBCT-based preoperative planning, digital prosthetically driven positioning, and real-time drill tracking via optical or infrared systems. Many incorporated intraoral scanning and digital workflow integration, reflecting a broader shift toward fully digital implantology. Freehand comparator groups typically relied on CBCT planning and surgical experience without real-time intraoperative guidance.

3.3. Postoperative Pain

Postoperative pain was inconsistently reported across the included studies. Only one randomized clinical trial quantitatively assessed pain using a visual analog scale (VAS) within the early postoperative period. In that study, patients undergoing dynamic navigation–assisted implant placement reported significantly lower pain scores within the first 48 hours compared to those treated with conventional freehand techniques.

The observed reduction in pain may be attributable to improved surgical precision, reduced need for flap elevation in certain protocols, or minimized periosteal trauma due to more controlled osteotomy angulation. However, the absence of pain assessment in the majority of included studies limits the ability to draw definitive conclusions regarding this outcome. The lack of standardized postoperative pain reporting represents an important gap in the literature and highlights the need for more consistent inclusion of patient-reported outcome measures in future trials.

3.4. Operative Time and Procedural Efficiency

Operative time and procedural efficiency were reported in a subset of comparative studies. Where assessed, dynamic navigation–assisted procedures demonstrated significantly reduced surgical time compared with freehand implant placement. In one study, navigation-assisted placement required approximately half the operative duration of conventional techniques. Another trial similarly reported statistically shorter surgical times in the navigation group.

The reduction in operative time may reflect improved intraoperative visualization, reduced need for repeated angulation corrections, and greater confidence in achieving the preplanned trajectory without intraoperative radiographic verification. Nonetheless, it is important to consider the learning curve associated with dynamic navigation systems. While experienced operators may achieve efficiency gains, early adoption phases may initially increase setup and calibration time.

Several studies did not report operative duration, particularly those primarily designed to evaluate placement accuracy. Consequently, while available data suggest a potential efficiency advantage, the evidence remains limited and heterogeneous.

3.5. Surgical Complications

Across the included studies, surgical complication rates were generally low in both dynamic navigation and freehand groups. No major intraoperative complications, such as permanent inferior alveolar nerve injury or significant sinus perforation, were reported in the navigation groups. In at least one comparative study, transient neurosensory disturbance was observed exclusively in the freehand group, suggesting a possible safety advantage of real-time visualization.

Early postoperative complications, such as infection or hemorrhage, were rarely documented and did not demonstrate statistically significant differences between groups. Importantly, some studies explicitly noted preservation of anatomical structures and improved visualization of critical landmarks when dynamic navigation was employed.

Despite these favorable findings, complication reporting lacked standardization across studies. Definitions of “complication” varied, and detailed stratification between intraoperative and early postoperative events was often absent. Therefore, while navigation systems appear safe within the reported cohorts, definitive conclusions regarding complication reduction require larger, standardized comparative trials.

3.6. Early Implant Success and Survival

Short-term implant survival was consistently high across all studies. Comparative trials frequently reported 100% survival rates in both dynamic navigation and freehand groups during early follow-up periods. In the single case series, a small number of early failures during the healing phase were documented; however, this study lacked a comparator and represented a distinct clinical scenario.

Follow-up durations varied widely, ranging from immediate postoperative radiographic evaluation to approximately 30 months in retrospective cohorts. No statistically significant differences in early implant success between navigation-assisted and freehand techniques were identified in comparative studies.

These findings suggest that while dynamic navigation may enhance precision, short-term biological integration outcomes appear comparable between techniques. However, long-term survival beyond the early healing phase remains insufficiently reported in the current body of literature.

3.7. Accuracy Outcomes

Although not predefined as primary endpoints in this review, accuracy outcomes were consistently reported across nearly all included studies. Dynamic navigation systems demonstrated statistically significant reductions in coronal, apical, and angular deviations compared with freehand placement. Mean angular deviations in navigation groups generally ranged between approximately 1.4° and 3.8°, whereas freehand techniques frequently demonstrated larger deviations.

Linear deviations at the implant platform and apex were likewise reduced with navigation systems, often by clinically meaningful margins. Some studies further reported improved residual bone preservation and enhanced primary stability when navigation systems were employed.

Importantly, accuracy improvements were observed across both maxillary and mandibular placements and in both flap and flapless procedures. However, certain anatomical regions exhibited greater deviation variability, emphasizing the influence of site-specific anatomical complexity.

3.8. Overall Synthesis of Clinical Findings

Taken together, the included studies suggest that dynamic navigation–assisted implant placement improves placement accuracy and may enhance procedural efficiency compared with conventional freehand techniques. Limited evidence also indicates potential reductions in immediate postoperative pain and transient neurosensory disturbances.

However, reporting of patient-centered outcomes remains inconsistent. Most studies prioritized deviation analysis over comprehensive clinical endpoints. Early implant survival appears high and comparable between techniques, but robust long-term comparative survival data are lacking.

The existing evidence supports the technical precision and safety of dynamic navigation systems. Nevertheless, the translation of improved accuracy into clearly superior long-term clinical outcomes remains an area requiring further high-quality randomized investigations.

3.9. Discussion

This systematic review synthesized contemporary clinical evidence comparing dynamic navigation–assisted dental implant placement with conventional freehand techniques. Across the nine included studies, dynamic navigation consistently demonstrated superior three-dimensional accuracy and, in selected trials, improved surgical efficiency and reduced early postoperative discomfort. Surgical complication rates were low in both techniques, although minor neurosensory disturbances were reported more frequently in freehand groups. Importantly, early implant survival rates were high and comparable between approaches.

The most consistent finding across studies was the reduction in angular and linear deviation achieved with dynamic navigation. While improved accuracy may initially appear to be a purely technical parameter, it carries important biological and prosthetic implications. Implant malposition can influence stress distribution, marginal bone remodeling, and prosthetic emergence profile [5]. Thus, precision is not merely aesthetic or radiographic; it is biomechanically consequential.

At the same time, the present review highlights a nuanced conclusion: improved positional accuracy does not automatically translate into superior short-term implant survival. Osseointegration appears robust in both navigation and freehand cohorts, suggesting that experienced clinicians can achieve acceptable biological outcomes even without navigational assistance. The value of dynamic navigation may therefore lie more in risk mitigation, procedural predictability, and complex case management than in altering baseline survival rates.

Freehand implant placement depends on the clinician's ability to mentally map preoperative CBCT planning into intraoperative execution. Even with careful planning, small errors in angulation at the coronal level may amplify apically, leading to clinically relevant deviation [8]. Posterior regions further complicate this process due to limited visibility, restricted mouth opening, and proximity to critical anatomical structures [6].

Dynamic navigation systems address this limitation by integrating CBCT datasets with optical tracking technology to provide real-time feedback during osteotomy preparation [14]. The surgeon can visualize angulation, depth, and spatial orientation simultaneously, allowing immediate correction before deviation becomes irreversible. This mechanism explains the consistent reduction in coronal, apical, and angular deviation observed in comparative trials [17, 26].

Unlike static guides, which constrain drill trajectory mechanically, dynamic navigation preserves intraoperative flexibility [9, 13]. If unexpected anatomical conditions arise, the surgeon can adjust the trajectory without discarding a physical template. This combination of flexibility and precision represents a conceptual advantage over both freehand and static-guided techniques.

Operative time was reduced in several comparative studies included. Although dynamic navigation requires calibration and setup, real-time visualization may reduce repeated angulation corrections and intraoperative verification steps. In experienced hands, this may streamline surgical flow.

Previous literature suggests that the efficiency of computer-assisted systems is influenced by operator learning curves [27]. Early adoption phases may involve longer setup time, but with repeated use, procedural confidence increases and time savings become more apparent. The included studies did not uniformly assess learning curve progression, yet the reported reductions in operative time indicate that navigation may enhance workflow efficiency once proficiency is achieved.

From a systems perspective, procedural efficiency has broader implications. Reduced operative duration may lower patient discomfort, minimize anesthetic exposure, and potentially improve clinic throughput. However, these advantages must be weighed against the financial investment required for navigation equipment.

Only limited data addressed postoperative pain, yet available evidence suggested lower early VAS scores in navigation-assisted groups. Reduced pain may reflect minimized soft tissue manipulation and more controlled osteotomy depth. Computer-guided systems may facilitate flapless protocols, which have been associated with reduced postoperative inflammation and faster recovery [28].

Pain is a patient-centered outcome that significantly influences satisfaction and perception of treatment quality. Despite its importance, most implant navigation studies have prioritized radiographic accuracy over patient-reported outcomes. The scarcity of standardized pain reporting in the current literature underscores a critical methodological gap. Future trials should incorporate validated pain scales and quality-of-life measures to better characterize the experiential impact of navigation systems.

Major intraoperative complications were rare across all studies, regardless of technique. However, transient neurosensory disturbances were reported primarily in freehand groups [10, 11, 16, 29, 30]. In posterior mandibular regions, millimetric deviations may result in inferior alveolar nerve proximity [6]. Dynamic navigation offers continuous visualization of drill trajectory relative to anatomical landmarks, potentially reducing the likelihood of cortical perforation or canal violation.

Earlier reviews of computer-guided surgery reported improved accuracy but inconsistent evidence regarding complication reduction [9, 13]. The present synthesis suggests that dynamic navigation may enhance anatomical safety, particularly in high-risk regions. Nevertheless, complication definitions and reporting methods varied across studies, limiting the strength of comparative inference.

The absence of major complications in navigation groups across included studies reinforces the safety profile of these systems [10, 16, 29, 30]. However, larger multicenter trials with standardized adverse event reporting are required to establish definitive risk reduction.

Early implant survival rates were consistently high in both navigation and freehand cohorts. These findings align with long-term survival data for contemporary implant systems [1]. Osseointegration depends primarily on atraumatic surgical technique, adequate primary stability, and host-related biological factors rather than navigation assistance per se.

However, accurate implant positioning may indirectly influence long-term peri-implant health. Malpositioned implants can compromise load distribution, increase cantilever forces, and affect peri-implant bone remodeling [5, 31]. Although short-term survival does not differ significantly between techniques, improved prosthetically driven positioning may yield advantages in marginal bone stability over time.

At present, long-term data comparing navigation and freehand techniques remain limited. Therefore, while early survival equivalence is reassuring, it does not exclude potential long-term biomechanical benefits of enhanced accuracy.

Static guides have been extensively evaluated through systematic reviews and meta-analyses demonstrating improved positional accuracy over freehand placement [9, 13]. Dynamic navigation, as a newer technology, has received comparatively less systematic synthesis. Randomized clinical trials have confirmed superior angular and coronal accuracy with navigation systems [15, 17, 26], yet few reviews have emphasized clinical endpoints beyond deviation metrics.

By focusing on operative time, complications, pain, and early survival, the present review extends beyond purely technical evaluation [32–35]. It situates dynamic navigation within a clinically meaningful framework, aligning technical precision with patient-centered and procedural outcomes.

The decision to implement dynamic navigation systems involves consideration of cost, training, and anticipated benefit. Based on current evidence, navigation appears most advantageous in anatomically complex cases, posterior mandibular placements, full-arch rehabilitations, or scenarios requiring prosthetically exact positioning.

For straightforward cases managed by experienced clinicians, freehand placement may remain clinically acceptable, particularly when anatomical risk is minimal. Thus, navigation should be viewed not as a universal replacement but as a precision-enhancing adjunct tailored to case complexity.

Cost-effectiveness analyses remain sparse. Given the substantial investment required for navigation systems, future research should evaluate whether reduced operative time, improved safety margins, or decreased complication risk justifies economic expenditure.

The included studies exhibited heterogeneity in design, sample size, and outcome definitions. Pain and complication reporting were inconsistent. Follow-up durations were generally short to medium term, limiting assessment of long-term survival and peri-implant bone changes.

Most studies were single-center investigations with modest sample sizes, increasing susceptibility to selection bias and limiting external validity. Additionally, the absence of standardized reporting frameworks complicates quantitative pooling.

Despite these limitations, the consistency of accuracy improvement across diverse settings strengthens the reliability of the core finding.

Future randomized controlled trials should incorporate standardized reporting of patient-reported outcomes, complication stratification, and long-term peri-implant bone stability. Comparative evaluations of learning curves and operator experience would clarify how navigation performance evolves over time [27].

Longitudinal cohort studies examining prosthetic outcomes, marginal bone remodeling, and peri-implant disease incidence may determine whether enhanced accuracy yields sustained biological benefit [28, 31, 36]. Cost-effectiveness analyses are also essential to guide adoption decisions within clinical practice.

Dynamic navigation–assisted implant placement consistently improves three-dimensional accuracy and may enhance surgical efficiency while maintaining a favorable safety profile. Early implant survival remains comparable to conventional freehand techniques. Although improved technical precision is well established, definitive evidence linking navigation to superior long-term clinical outcomes remains limited.

Dynamic navigation should therefore be considered a precision-enhancing tool that augments surgical control, particularly in complex anatomical scenarios, rather than a replacement for sound surgical principles.

4. Conclusions

Dynamic navigation–assisted dental implant placement consistently improves three-dimensional positional accuracy compared with conventional freehand techniques. Available evidence suggests potential advantages in operative efficiency and early postoperative comfort without increasing complication rates. However, early implant survival appears comparable between techniques. While enhanced precision may improve surgical predictability and anatomical safety, particularly in complex posterior regions, further high-quality randomized trials with long-term follow-up are required to confirm whether these technical improvements translate into sustained clinical benefits.

Author Contributions: M.R. and M.R.M.F.; methodology, M.R. and M.R.M.F.; software, M.R. and M.R.M.F.; validation, M.R. and M.R.M.F.; formal analysis, M.R. and M.R.M.F.; investigation, M.R. and M.R.M.F.; resources, M.R. and M.R.M.F.; data curation, M.R. and M.R.M.F.; writing—original draft preparation, M.R. and M.R.M.F.; writing—review and editing, M.R. and M.R.M.F.; visualization, M.R. and M.R.M.F.; supervision, M.R.; project administration, M.R..; funding acquisition, M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This study does not receive external funding.

Ethical Clearance: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: All the authors declare no conflicts of interest.

References

1. Moraschini, V., Poubel, L. A. da C., Ferreira, V. F., and Barboza, E. dos S. P. (2015). Evaluation of Survival and Success Rates of Dental Implants Reported in Longitudinal Studies with a Follow-up Period of at Least 10 Years: A Systematic Review, *International Journal of Oral and Maxillofacial Surgery*, Vol. 44, No. 3, 377–388. doi:10.1016/j.ijom.2014.10.023.
2. Zhou, W., Liu, Z., Song, L., Kuo, C., and Shafer, D. M. (2018). Clinical Factors Affecting the Accuracy of Guided Implant Surgery—A Systematic Review and Meta-Analysis, *Journal of Evidence Based Dental Practice*, Vol. 18, No. 1, 28–40. doi:10.1016/j.jebdp.2017.07.007.
3. Vercruyssen, M., Cox, C., Coucke, W., Naert, I., Jacobs, R., and Quirynen, M. (2014). A Randomized Clinical Trial Comparing Guided Implant Surgery (Bone- or Mucosa-supported) with Mental Navigation or the Use of a Pilot-drill Template, *Journal of Clinical Periodontology*, Vol. 41, No. 7, 717–723. doi:10.1111/jcpe.12231.
4. D'haese, J., Ackhurst, J., Wismeijer, D., De Bruyn, H., and Tahmaseb, A. (2017). Current State of the Art of Computer-guided Implant Surgery, *Periodontology 2000*, Vol. 73, No. 1, 121–133. doi:10.1111/prd.12175.
5. Derks, J., and Tomasi, C. (2015). Peri-implant Health and Disease. A Systematic Review of Current Epidemiology, *Journal of Clinical Periodontology*, Vol. 42, No. S16, S158–S171. doi:10.1111/jcpe.12334.
6. Shiba, T., Komatsu, K., Takeuchi, Y., Koyanagi, T., Taniguchi, Y., Takagi, T., Maekawa, S., Nagai, T., Kobayashi, R., Matsumura, S., Katagiri, S., Izumi, Y., Aoki, A., and Iwata, T. (2024). Novel Flowchart Guiding the Non-Surgical and Surgical Management of Peri-Implant Complications: A Narrative Review, *Bioengineering*, Vol. 11, No. 2, 118. doi:10.3390/bioengineering11020118.
7. Vercruyssen, M., Laleman, I., Jacobs, R., and Quirynen, M. (2015). Computer-supported Implant Planning and Guided Surgery: A Narrative Review, *Clinical Oral Implants Research*, Vol. 26, No. S11, 69–76. doi:10.1111/clr.12638.
8. Tahmaseb, A., Wismeijer, D., Coucke, W., and Derksen, W.

(2014). Computer Technology Applications in Surgical Implant Dentistry: A Systematic Review, *The International Journal of Oral & Maxillofacial Implants*, Vol. 29, No. Supplement, 25–42. doi:10.11607/jomi.2014suppl.g1.2.

9. Khaohoen, A., Powcharoen, W., Yoda, N., Rungsiyakull, C., and Rungsiyakull, P. (2025). Accuracy in Dental Implant Placement: A Systematic Review and Meta-Analysis Comparing Computer-Assisted (Static, Dynamic, Robotics) and Noncomputer-Assisted (Freehand, Conventional Guide) Approaches, *The Journal of Prosthetic Dentistry*, Vol. 134, No. 1, 91.e1-91.e25. doi:10.1016/j.prosdent.2025.03.038.

10. Joda, T., Ferrari, M., Gallucci, G. O., Wittneben, J., and Brägger, U. (2017). Digital Technology in Fixed Implant Prosthodontics, *Periodontology 2000*, Vol. 73, No. 1, 178–192. doi:10.1111/prd.12164.

11. Tahmaseb, A., De Clerck, R., and Wismeijer, D. (2009). Computer-Guided Implant Placement: 3D Planning Software, Fixed Intraoral Reference Points, and CAD/CAM Technology. A Case Report, *International Journal of Oral and Maxillofacial Implants*, Vol. 24, No. 3, 541–546.

12. Lin, G., Chan, H., and Wang, H. (2014). Effects of Currently Available Surgical and Restorative Interventions on Reducing Midfacial Mucosal Recession of Immediately Placed Single-Tooth Implants: A Systematic Review, *Journal of Periodontology*, Vol. 85, No. 1, 92–102. doi:10.1902/jop.2013.130064.

13. Schneider, D., Marquardt, P., Zwahlen, M., and Jung, R. E. (2009). A Systematic Review on the Accuracy and the Clinical Outcome of Computer-guided Template-based Implant Dentistry, *Clinical Oral Implants Research*, Vol. 20, No. s4, 73–86. doi:10.1111/j.1600-0501.2009.01788.x.

14. Block, M. S., and Emery, R. W. (2016). Static or Dynamic Navigation for Implant Placement—Choosing the Method of Guidance, *Journal of Oral and Maxillofacial Surgery*, Vol. 74, No. 2, 269–277. doi:10.1016/j.joms.2015.09.022.

15. Widmann, G., and Bale, R. J. (2006). Accuracy in Computer-Aided Implant Surgery--a Review, *International Journal of Oral and Maxillofacial Implants*, Vol. 21, No. 2, 305–313.

16. Solow, R. A. (2015). Clinical Considerations for Selecting Implant Abutments for Fixed Prosthodontics, *General Dentistry*, Vol. 63, No. 1, 30–36.

17. Aydemir, C. A., and Arısan, V. (2020). Accuracy of Dental Implant Placement via Dynamic Navigation or the Freehand Method: A Split-mouth Randomized Controlled Clinical Trial, *Clinical Oral Implants Research*, Vol. 31, No. 3, 255–263. doi:10.1111/clr.13563.

18. Nirula, P. (2023). Feedback on Dental Implants with Dynamic Navigation versus Freehand, *Bioinformation*, Vol. 19, No. 3, 290–294. doi:10.6026/97320630019290.

19. Ma, L., Ye, M., Wu, M., Chen, X., and Shen, S. (2023). A Retrospective Study of Dynamic Navigation System-Assisted Implant Placement, *BMC Oral Health*, Vol. 23, No. 1, 759. doi:10.1186/s12903-023-03481-2.

20. Younis, H., Lv, C., Xu, B., Zhou, H., Du, L., Liao, L., Zhao, N., Long, W., Elayah, S. A., Chang, X., and He, L. (2024). Accuracy of Dynamic Navigation Compared to Static Surgical Guides and the Freehand Approach in Implant Placement: A Prospective Clinical Study, *Head & Face Medicine*, Vol. 20, No. 1, 30. doi:10.1186/s13005-024-00433-1.

21. Deng, H., Geng, N., Yang, S., Dou, X., Wang, H., Chen, S., and Huang, L. (2025). Clinical Study of Dynamic Navigation-Assisted Immediate Implant Placement in Posterior Maxillary Alveolar Bone Defects, *BMC Oral Health*, Vol. 25, No. 1, 617. doi:10.1186/s12903-025-05976-6.

22. Zhang, C., AL-Awadhi, Z. A., Geng, N., Mo, S., and Chen, S. (2025). Dynamic Navigation-Assisted Flapless Implant Placement in the Posterior Mandible: A Retrospective and Comparative Study, *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology*, Vol. 139, No. 6, 670–683. doi:10.1016/j.oooo.2024.12.018.

23. Stefanelli, L. V., Mandelaris, G. A., Franchina, A., Pranno, N., Pagliarulo, M., Cera, F., Maltese, F., De Angelis, F., and Di Carlo, S. (2020). Accuracy of Dynamic Navigation System Workflow for Implant Supported Full Arch Prosthesis: A Case Series, *International Journal of Environmental Research and Public Health*, Vol. 17, No. 14, 5038. doi:10.3390/ijerph17145038.

24. Jorba-García, A., Bara-Casaus, J. J., Camps-Font, O., Sánchez-Garcés, M. Á., Figueiredo, R., and Valmaseda-Castellón, E. (2023). Accuracy of Dental Implant Placement with or without the Use of a Dynamic Navigation Assisted System: A Randomized Clinical Trial, *Clinical Oral Implants Research*, Vol. 34, No. 5, 438–449. doi:10.1111/clr.14050.

25. Edelmann, C., Wetzel, M., Knipper, A., Luthardt, R. G., and Schnutenhaus, S. (2021). Accuracy of Computer-Assisted Dynamic Navigation in Implant Placement with a Fully Digital Approach: A Prospective Clinical Trial, *Journal of Clinical Medicine*, Vol. 10, No. 9, 1808. doi:10.3390/jcm10091808.

26. Pinter, G. T., Decker, R., Szenasi, G., Barabas, P., and Huszar, T. (2022). Dynamic Navigation for Dental Implant Placement, *Journal of Visualized Experiments*, No. 187. doi:10.3791/63400.

27. Pellegrino, G., Ferri, A., Del Fabbro, M., Prati, C., Gandolfi, M., and Marchetti, C. (2021). Dynamic Navigation in Implant Dentistry: A Systematic Review and Meta-Analysis, *The International Journal of Oral & Maxillofacial Implants*, Vol. 36, No. 5, e121–e140. doi:10.11607/jomi.8770.

28. Fortin, T., Isidori, M., and Bouchet, H. (2009). Placement of Posterior Maxillary Implants in Partially Edentulous Patients with Severe Bone Deficiency Using CAD/CAM Guidance to Avoid Sinus Grafting: A Clinical Report of Procedure, *International Journal of Oral and Maxillofacial Implants*, Vol. 24, No. 1, 96–102.

29. Block, M., Emery, R., Lank, K., and Ryan, J. (2017). Implant Placement Accuracy Using Dynamic Navigation, *The International Journal of Oral & Maxillofacial Implants*, Vol. 32, No. 1, 92–99. doi:10.11607/jomi.5004.

30. Esposito, M., Grusovin, M. G., Felice, P., Karatzopoulos, G., Worthington, H. V, and Coulthard, P. (2009). The Efficacy of Horizontal and Vertical Bone Augmentation Procedures for Dental Implants - a Cochrane Systematic Review, *European Journal of Oral Implantology*, Vol. 2, No. 3, 167–184.

31. Ma, S., and Fenton, A. (2015). Screw- Versus Cement-Retained Implant Prostheses: A Systematic Review of Prosthodontic Maintenance and Complications, *International Journal of Prosthodontics*, Vol. 28, No. 2, 127–145. doi:10.11607/ijp.3947.

32. Albrektsson, T., Dahlin, C., Jemt, T., Sennerby, L., Turri, A., and Wennerberg, A. (2014). Is Marginal Bone Loss around Oral Implants the Result of a Provoked Foreign Body Reaction?, *Clinical Implant Dentistry and Related Research*, Vol. 16, No. 2, 155–165. doi:10.1111/cid.12142.

33. Widmann, G., Stoffner, R., and Bale, R. (2009). Errors and Error Management in Image-Guided Craniomaxillofacial Surgery, *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, Vol. 107, No. 5, 701–715. doi:10.1016/j.tripleo.2009.02.011.

34. Chen, Y., and Su, B. (2022). Accuracy of Computer-Guided Oral Implant Placement and Influencing Factors, *Sheng Wu Yi Xue Gong Cheng Xue Za Zhi*, Vol. 39, No. 4, 841–847. doi:10.7507/1001-5515.202110070.

35. Xu, Z., Zhou, L., Zheng, M., Lin, Y., Huang, W., Chen, J., Li, Y., and Wu, D. (2023). The Effect of Implant Surgery Experience on the Learning Curve of a Dynamic Navigation System: An in Vitro Study, *BMC Oral Health*, Vol. 23, No. 1, 89. doi:10.1186/s12903-023-02792-8.

36. Papaspyridakos, P., Chen, C.-J., Singh, M., Weber, H.-P., and Gallucci, G. O. (2012). Success Criteria in Implant Dentistry, *Journal of Dental Research*, Vol. 91, No. 3, 242–248. doi:10.1177/0022034511431252.