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ORIGINAL ARTICLE

Risk-Adapted Selection of Minimally Invasive and Navigation-Guided Dental Implantation: An Illustrative Clinical–Radiological Analysis

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Abstract

Background: Minimally invasive implant placement preserves soft-tissue architecture, whereas navigation supports transfer of prosthetically driven plans. Neither approach is universally appropriate because anatomical visibility, bone availability, and registration reliability differ between patients.
Objective: To illustrate how combined clinical and radiological assessment can support differentiated selection of flapless freehand, static-guided, and dynamic-navigation protocols.
Materials and Methods: This methodological demonstration used a constructed dataset representing 60 adults receiving one implant each. No patients were recruited, and the numerical findings are simulated rather than clinical evidence. Three equal groups represented uncomplicated ridges treated flaplessly, intermediate-complexity sites treated using static guides, and anatomically constrained sites treated with dynamic navigation. Selection incorporated cone-beam computed tomography, mucosal characteristics, mouth opening, and prosthetic requirements. Outcomes included angular and apical deviation, operative duration, pain, and early complications.
Results: Simulated mean angular deviations were 4.2°, 2.3°, and 2.0° for flapless freehand, static-guided, and dynamic-navigation placement, respectively. Corresponding apical deviations were 1.5, 1.0, and 0.8 mm. Mean operative durations increased from 22 to 28 and 34 minutes. Early pain scores were low across groups. No neurological injury was represented; three minor wound complications occurred.
Discussion: The constructed pattern illustrates a plausible trade-off between positional control and procedural complexity. However, allocation by anatomical difficulty prevents causal comparisons, and simulated outcomes cannot establish efficacy.
Conclusion: Differentiated planning should prioritize anatomical risk and verification of workflow accuracy rather than routine navigation. Prospective validation with independent outcome assessment is required before adopting quantitative selection thresholds.

Keywords: dental implants, cone-beam computed tomography, flapless surgery, static guidance, dynamic navigation, anatomical risk

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1. Introduction

Dental implant rehabilitation is an established approach to replacing missing teeth, yet favorable outcomes depend on aligning surgical technique with local anatomy, prosthetic requirements, and patient-related risks. Minimally invasive approaches, including flapless placement and limited flap elevation, may reduce surgical trauma and early postoperative discomfort in appropriately selected patients. However, reduced exposure can limit direct assessment of the alveolar contour and complicate the recognition of cortical defects. Consequently, minimizing tissue disruption should not take precedence over anatomical safety or the achievement of a prosthetically appropriate implant position.

Preoperative clinical examination and radiological assessment provide complementary information for selecting an implantation protocol. Clinical evaluation characterizes mucosal conditions, keratinized tissue, ridge morphology, mouth opening, and the need for augmentation. Cone-beam computed tomography enables three-dimensional assessment of available bone, ridge angulation, cortical boundaries, and proximity to structures such as the mandibular canal and maxillary sinus. These findings can support risk stratification, although image quality, artifacts, and the limitations of radiographic bone-density estimates must be considered. Imaging should therefore inform, rather than replace, clinical judgment.

Static computer-assisted guides and dynamic navigation systems translate virtual planning into intraoperative positional guidance through different technical workflows. Both approaches may improve placement accuracy compared with freehand surgery under suitable conditions, but neither eliminates deviations or guarantees superior biological outcomes. Guide stability, registration accuracy, access restrictions, operator experience, and intraoperative changes can influence performance. Moreover, navigation-guided surgery is not synonymous with minimally invasive surgery: guided placement may require flap elevation, whereas selected uncomplicated cases may permit minimally invasive placement without navigation. The clinical value of combining these strategies is therefore likely to vary across anatomical and procedural contexts.

An unresolved practical question is how clinical and radiological characteristics should guide the differentiated use of these protocols rather than their routine application to all patients. Greater technological complexity may be justified near vulnerable anatomical structures or where prosthetic positioning allows little tolerance for error, while simpler approaches may remain appropriate when anatomy and visibility are favorable. This study therefore aimed to evaluate the relationship between preoperative clinical and radiological findings, protocol selection, and implantation outcomes. Particular attention was directed to placement accuracy, perioperative morbidity, and early healing, with the objective of informing a clinically grounded framework for selecting minimally invasive, navigation-guided, or conventional approaches according to individual treatment needs.

2. Materials and Methods

A prospective, single-center, risk-stratified clinical study will evaluate the differentiated use of minimally invasive and navigation-guided implant placement in adults with partial edentulism. Recruitment will target 90 participants requiring one implant in a healed site. Eligible patients will be aged 20–75 years, have adequate oral hygiene, and demonstrate sufficient bone volume for placement without simultaneous augmentation. Exclusion criteria will include uncontrolled diabetes, active periodontal disease, previous irradiation involving the jaws, medications associated with substantial osteonecrosis risk, pregnancy, and conditions contraindicating elective implant surgery. Institutional ethics approval and written informed consent will be obtained before enrollment. The study will follow applicable human research and radiation protection requirements.

Baseline assessment will include medical and dental histories, smoking status, periodontal charting, mucosal thickness, keratinized tissue width, and interarch space. Cone-beam computed tomography will be performed using the smallest field of view and exposure settings compatible with diagnostic requirements. Digital intraoral scans will be registered with tomographic data for prosthetically driven planning. Radiological measurements will include ridge height and width, cortical configuration, ridge angulation, and distance to the mandibular canal, mental foramen, adjacent roots, nasal floor, and

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maxillary sinus. Uncalibrated tomographic gray values will not be interpreted as quantitative bone mineral density.

Participants will be assigned to one of three treatment pathways using predefined anatomical and soft-tissue criteria rather than randomization. Minimally invasive freehand placement will be reserved for accessible sites with favorable ridge contours, sufficient keratinized tissue, and a planned circumferential bone envelope of at least 2 mm. Dynamic navigation-guided placement will be selected when restricted access, ridge angulation, or proximity to critical structures increases positional demands, provided that a safe implant trajectory remains feasible. Conventional open-flap freehand placement will be used when direct visualization is necessary because of uncertain ridge morphology or soft-tissue management requirements. Navigation will not replace appropriate anatomical safety margins. Assignment decisions and their rationale will be documented before surgery.

Two experienced implant surgeons will use the same implant system and standardized irrigation, drilling, and postoperative care protocols. Navigation cases will undergo registration and accuracy verification before osteotomy and repeated verification after suspected tracking disturbance. Conversion from flapless to open-flap surgery will be permitted when clinically necessary and recorded with the reason. Operative duration, primary implant stability, intraoperative complications, and postoperative analgesic consumption will be documented. Pain will be measured using a 0–10 numerical rating scale on days 1, 3, and 7.

The primary outcome will be three-dimensional apical deviation from the planned implant position, determined by registering postoperative scan-body intraoral scans with baseline digital models. Coronal and angular deviations will be secondary accuracy outcomes. Clinical follow-up will occur at 1 week and 3, 6, and 12 months. Standardized periapical radiographs obtained at prosthetic loading and 12 months will assess marginal bone-level changes. Implant survival and biological complications will also be recorded.

An assessor blinded to treatment allocation will perform accuracy measurements. Repeat measurements in 20% of cases will estimate intraobserver reliability. Multivariable analyses will adjust for anatomical complexity, implant site, smoking, and surgeon. Enrollment is feasibility-based; effect estimates with 95% confidence intervals will therefore receive priority over definitive superiority claims.

3. Results

The following results describe an illustrative, simulated dataset rather than observed patient outcomes. The analysis included 90 patients receiving one implant each, allocated to three differentiated protocols: minimally invasive flapless placement in favorable anatomy (n = 30), static computer-guided placement in moderately constrained sites (n = 30), and dynamic navigation-guided placement in anatomically complex sites (n = 30). All patients completed the six-month assessment. Mean age was 48.6 ± 11.2 years, and 49 patients (54.4%) were women. Posterior sites accounted for 62 implant placements (68.9%).

Baseline cone-beam computed tomography demonstrated increasing anatomical difficulty across the three groups. Mean residual ridge width was 7.4 ± 0.9 mm in the minimally invasive group, 6.3 ± 0.8 mm in the static-guidance group, and 5.8 ± 0.7 mm in the dynamic-navigation group. The corresponding available bone heights were 12.8 ± 1.7, 10.9 ± 1.6, and 9.7 ± 1.5 mm. These differences reflected anatomy-based protocol selection rather than randomized allocation. Consequently, between-group comparisons were interpreted descriptively and not as estimates of comparative treatment efficacy.

Placement accuracy, operative characteristics, and early clinical outcomes are summarized in Table 1. Deviations were calculated by superimposing the postoperative implant position on the preoperative plan. Both navigation-guided groups showed smaller mean positional discrepancies than the minimally invasive group, despite having more constrained baseline anatomy.

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Table 1. Simulated clinical and radiological outcomes by implantation protocol

Outcome	Minimally invasive, n = 30	Static guidance, n = 30	Dynamic navigation, n = 30
Coronal deviation, mm	1.18 ± 0.42	0.78 ± 0.29	0.71 ± 0.26
Apical deviation, mm	1.54 ± 0.55	1.02 ± 0.37	0.94 ± 0.34
Angular deviation, degrees	4.1 ± 1.5	2.6 ± 1.0	2.3 ± 0.9
Operative time, minutes	24.6 ± 6.2	31.8 ± 7.4	38.5 ± 8.1
Pain at 24 hours, 0–10 scale	2.4 ± 1.3	2.8 ± 1.4	3.1 ± 1.5
Insertion torque, N·cm	38.2 ± 7.1	36.8 ± 6.9	35.4 ± 7.6
Marginal bone change at six months, mm	0.42 ± 0.20	0.45 ± 0.23	0.48 ± 0.24
Implants retained at six months, n/N	30/30	29/30	29/30

Continuous values are presented as mean ± standard deviation. Operative time was measured from the initial incision or mucosal access to completion of wound management; digital planning, guide fabrication, and navigation calibration were excluded. Thus, these times did not represent the total treatment workflow. Marginal bone change was measured on standardized periapical radiographs relative to the immediate postoperative baseline and was calculated only for implants retained at six months.

Apical deviations exceeding 2.0 mm occurred in six minimally invasive cases, one static-guidance case, and one dynamic-navigation case. No implant breached the mandibular canal, entered an adjacent tooth root, or produced a clinically evident neurosensory deficit. Nevertheless, the absence of these events in this small dataset did not establish equivalent safety across protocols. In two static-guidance cases, incomplete guide seating was identified before osteotomy and corrected by adjusting local soft-tissue interference. Dynamic navigation required intraoperative registration verification in three cases.

Early postoperative morbidity was limited. Transient swelling occurred in five minimally invasive, seven static-guidance, and eight dynamic-navigation patients. One superficial wound dehiscence occurred in each navigation-guided group and resolved with local care. No suppurative infection was recorded. Two implants, one in each navigation-guided group, became mobile before loading and were removed, giving an overall six-month retention proportion of 97.8% (88/90).

Among retained implants, mean marginal bone change remained below 0.5 mm in each group. The observed pattern combined shorter surgery and lower early pain scores in favorable sites with smaller placement deviations in guided, anatomically constrained sites. However, protocol selection, anatomical complexity, and tissue-access requirements were interrelated, preventing attribution of these differences to guidance technology alone.

4. Discussion

The clinical and radiological rationale for differentiated implant placement rests on matching surgical access and positional control to the anatomical complexity of each site. Minimally invasive surgery and navigation guidance should not be regarded as competing approaches: the former concerns tissue access, whereas the latter supports execution of a prosthetically driven plan. Their combined or separate application is therefore best understood as a risk-adapted strategy rather than a universal treatment preference. The central implication is that reduced surgical exposure is appropriate only when diagnostic information and intraoperative control compensate adequately for limited direct visualization.

Radiological assessment is fundamental to this selection process. Cone-beam computed tomography permits evaluation of ridge dimensions, cortical configuration, lingual or buccal concavities, and proximity to adjacent roots and neurovascular structures. These characteristics influence both the feasibility of flapless access and the potential value of guidance. However, three-dimensional imaging

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does not eliminate uncertainty. Motion, metallic artifacts, segmentation errors, and limited soft-tissue characterization can affect planning reliability. Moreover, gray values should not be interpreted as standardized measures of bone density across devices. Imaging findings must therefore be integrated with clinical examination, prosthetic requirements, and an appropriate safety margin.

In sites with adequate bone volume, favorable ridge morphology, and sufficient keratinized mucosa, minimally invasive placement may offer a reasonable balance between surgical efficiency and tissue preservation. Avoiding extensive flap elevation can reduce soft-tissue manipulation and may lessen early postoperative discomfort. Nevertheless, these advantages should not be equated automatically with superior osseointegration or long-term peri-implant stability. Flapless access can obscure cortical perforation, unexpected dehiscence, and discrepancies between the planned and actual osteotomy trajectory. Its suitability depends on reliable knowledge of the underlying anatomy and a willingness to convert to open access when uncertainty emerges.

Navigation-guided protocols become particularly relevant when the acceptable positional tolerance is narrow. Examples include restricted mesiodistal spaces, proximity to vital structures, demanding restorative trajectories, and rehabilitation requiring coordinated placement of multiple implants. Static guides provide mechanical transfer of a predefined plan, while dynamic navigation allows real-time monitoring and potential adjustment. Neither modality guarantees exact placement. Registration accuracy, guide support, fixation, instrument calibration, mouth opening, and operator experience can influence the final result. Guidance should consequently be viewed as an additional control mechanism, not as a substitute for anatomical judgment or surgical competence.

The distinction between technical accuracy and clinical benefit is especially important. Smaller angular or linear deviations may improve prosthetic feasibility and reduce the likelihood of an anatomically unfavorable position, but these improvements do not necessarily translate into measurable differences in implant survival. Survival is also influenced by host health, plaque control, smoking, loading conditions, and maintenance. Radiological deviations should therefore be interpreted alongside patient-centered outcomes, peri-implant tissue health, prosthetic complications, and the need for corrective procedures. A technically precise intervention may still be clinically suboptimal if it compromises cleansability or soft-tissue architecture.

Differentiated selection also requires recognition that more complex cases are often preferentially assigned to guided procedures. This creates a potential indication bias in comparative research. Similar outcomes between protocols may reflect successful risk management in the guided group rather than equivalence under identical conditions. Conversely, favorable recovery after minimally invasive treatment may partly reflect selection of anatomically uncomplicated sites. Without adequate adjustment for baseline anatomy, augmentation requirements, implant location, and operator experience, causal claims about protocol superiority would be premature. Analyses should also account for clustering when individual patients receive multiple implants.

A further practical consideration is the threshold for abandoning the planned minimally invasive pathway. Unstable guide seating, unexpected bone resistance, inadequate irrigation, or concern about cortical integrity should prompt reassessment rather than strict adherence to the digital plan. Where augmentation or direct evaluation of a defect is necessary, flap elevation may offer greater control despite increased tissue manipulation. The objective is not the smallest possible incision, but the least invasive procedure compatible with safe placement and a maintainable restoration. Additional imaging should likewise be justified by its expected diagnostic contribution and radiation burden.

The interpretation of differentiated protocols remains constrained by heterogeneous anatomical presentations, operator-dependent performance, and the duration of observation. Early healing and satisfactory postoperative positioning cannot establish long-term biological superiority. Future prospective comparisons should use explicit selection criteria, standardized deviation measurements, validated patient-reported outcomes, and sufficiently long follow-up to assess peri-implant health and prosthetic maintenance. Economic evaluation would also clarify whether additional planning and equipment costs are justified in different risk categories. Overall, clinical examination and three-dimensional anatomical assessment support individualized protocol selection, with navigation

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and minimally invasive access deployed selectively according to the demands of safe, prosthetically appropriate implant rehabilitation.

5. Conclusion

The clinical and radiological assessment supports a differentiated approach to minimally invasive and navigation-guided dental implantation rather than the routine use of a single surgical protocol. Treatment selection should integrate alveolar bone dimensions, anatomical limitations, soft-tissue characteristics, prosthetically driven implant positioning, and the feasibility of achieving adequate primary stability. Within this framework, minimally invasive placement appears most appropriate for carefully selected sites with favorable anatomy and sufficient keratinized tissue, where reduced surgical exposure does not compromise anatomical assessment or implant positioning.

Navigation-guided protocols may offer particular value when the available bone volume is limited, critical structures are nearby, or implant angulation requires precise prosthetic coordination. However, their potential benefits depend on imaging quality, accurate registration, guide stability or tracking reliability, and operator experience. Digital planning should therefore complement, rather than replace, clinical judgment and intraoperative verification. Conversion to an open approach remains justified when unexpected bone defects, inadequate visualization, or uncertainty regarding implant stability arises.

Taken together, these considerations indicate that the principal justification for protocol selection is the balance between surgical morbidity, positional accuracy, and anatomical safety. Favorable early clinical healing and acceptable radiological positioning should not be interpreted as evidence of superior long-term implant survival or peri-implant tissue stability. The observational nature of this evaluation and possible differences in baseline case complexity limit causal comparisons between techniques.

Further prospective studies using standardized accuracy measurements, patient-reported outcomes, peri-implant tissue assessments, and longer follow-up are needed to clarify comparative effectiveness. An individualized, risk-adapted workflow remains a clinically reasonable basis for selecting the least invasive approach compatible with safe, prosthetically appropriate implant placement.

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