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КЛИНИЧЕСКИЕ РЕЗУЛЬТАТЫ ИННОВАЦИОННЫХ ПРОТОКОЛОВ СТОМАТОЛОГИЧЕСКОЙ ХИРУРГИИ
CLINICAL OUTCOMES OF INNOVATIVE DENTAL SURGICAL PROTOCOLS

Аннотация. В статье представлен нарративный синтез клинических данных по инновационным протоколам стоматологической хирургии: компьютерно-ассистированная имплантация, динамическая навигация, роботизированное размещение имплантатов, направленная регенерация кости и периоперационные антиинфекционные стратегии. Показано, что клинически приемлемая точность имплантации определяется в первую очередь типом опоры шаблона, стратегией фиксации и уровнем оператора, а не фактом применения цифрового планирования. Регенеративные протоколы обеспечивают значимый прирост костной ткани при условии контроля обнажения мембраны; обогащённый тромбоцитами фибрин демонстрирует наиболее устойчивые преимущества в раннем заживлении. Описан авторский AI-ассистированный рабочий процесс, объединяющий планирование, навигацию и послеоперационную оценку в единой метрической системе. Ключевым условием предсказуемости хирургических исходов является интеграция чётко определённых метрических точек контроля на этапах планирования, исполнения и наблюдения.

Abstract. This article presents a narrative synthesis of clinical evidence on innovative dental surgical protocols, including computer-assisted implant placement, dynamic navigation, robotic surgery, guided bone regeneration, and perioperative anti-infective strategies. Clinical accuracy in implant surgery is determined primarily by guide support type, fixation strategy, and operator experience rather than by digital planning alone. Regenerative protocols achieve meaningful bone gain when membrane exposure is controlled; platelet-rich fibrin shows the most consistent benefits for early healing. An author-developed AI-assisted workflow integrating planning, intraoperative navigation, and postoperative assessment within a shared metric framework is described. Predictability of surgical outcomes depends on the integration of clearly defined metric control points across the stages of planning, execution, and follow-up.

Ключевые слова: Стоматологическая хирургия, точность имплантации, имплантационная хирургия с использованием навигации, динамическая навигация, роботизированная помощь, направленная регенерация кости, обогащенный тромбоцитами фибрин, послеоперационная инфекция, клинические результаты.

Keywords: Dental surgery, implant accuracy, guided implant surgery, dynamic navigation, robotic assistance, guided bone regeneration, platelet-rich fibrin, postoperative infection, clinical outcomes.

Introduction

The clinical literature on dental surgical innovation has become broad enough that novelty alone is no longer a useful descriptor. In contemporary practice, clinicians adopt new protocols because they promise better control over outcomes that matter in daily work: positional accuracy relative to prosthetic intent, predictable healing trajectories, manageable complication rates, and follow-up endpoints that are comparable across operators and settings. This pattern is evident in implant surgery, where digital planning has expanded the ability to formalize safety margins and quantify deviations, and in regenerative surgery, where the success of hard tissue augmentation depends on soft tissue stability, exposure prevention, and delayed assessment at re-entry (Tahmaseb et al., 2018; Garcia et al., 2018; Ng et al., 2025).

The evidence base supports a general premise that guided implant surgery can achieve accuracy within clinically acceptable limits, yet it also shows that accuracy is not an intrinsic feature of planning software. Outcomes reflect a chain of technical constraints, including imaging quality, data registration, guide fabrication, support type, fixation strategy, intraoperative stability, and operator behavior under time and visibility constraints. Systematic reviews and meta-analyses consistently report mean deviations in the low millimeter range, but the dispersion of deviations, the risk tails, and the factors that shift cases into those tails remain central for clinical decision-making (Khaohoen et al., 2024; Tahmaseb et al., 2018; Zhou et al., 2018).

Beyond the choice of tools, surgical protocols differ in how explicitly they define measurement points, timing of assessment, and decision thresholds. A protocol is clinically useful when it specifies what to measure, when to measure it, and how to interpret the measurement in a way that changes decisions. This is aligned with broader surgical innovation frameworks that caution against adoption without evaluation and encourage staged evidence accumulation tied to clearly defined endpoints (Ergina et al., 2009; Hirst et al., 2019). Dental surgery poses an additional challenge because many interventions are bundled. A guided workflow may be coupled to regenerative steps, antimicrobial decisions, and restorative sequencing, so attributing outcomes to a single element is often not realistic.

Within this context, the present article synthesizes clinical outcomes across several innovative dental surgical protocol families, with particular attention to whether outcome definitions, measurement timing, and corrective thresholds are explicitly specified. In addition, the article describes an author-developed AI-assisted planning and navigation workflow as a personal technical development intended to align planning, intraoperative guidance, and postoperative measurement under a single metric-driven logic.

Materials and Methods

A focused narrative clinical evidence synthesis was conducted, searches were performed in PubMed/MEDLINE, Embase, Scopus, and Cochrane Central for publications from January 2018 to January 2026 using combinations of terms relating to guided implant surgery, dynamic navigation, robotic implant placement, guided bone regeneration, titanium mesh and membrane barriers, platelet-rich fibrin, socket preservation, postoperative infection, and clinical outcomes. Reference lists of key systematic reviews were hand-screened to identify additional clinical trials and high-quality cohorts. Seminal clinical trials published before 2018 were additionally included when they defined protocol comparisons that remain clinically referenced, particularly for edentulous guide support and fixation strategies.

Eligible evidence included systematic reviews with transparent methods, randomized controlled clinical trials where available, and prospective observational studies with explicit outcome definitions. In vitro-only studies were excluded from primary synthesis unless the study addressed a measurement property relevant to clinical interpretation, such as registration drift quantification. Given the heterogeneity of interventions and endpoints, results were synthesized narratively, with attention to reported effect directions, complication drivers, and factors limiting transferability to routine clinical practice. Particular attention was paid to how studies reported measurement timing, definitions of early versus late complications, and the presence of long-term follow-up.

Screening was performed in two stages. Titles and abstracts were first evaluated for clinical relevance and explicit outcome reporting, followed by full-text assessment to confirm population, intervention definition, and endpoint timing. Given the heterogeneity of protocols and reporting conventions, synthesis was qualitative and structured around outcome domains rather than pooled effect estimation, while explicitly identifying sources of variability that may influence transferability to routine clinical practice.

Results

Across clinical domains, the results of innovative protocols can be organized according to protocol-specific measurement points reported in clinical studies. In implant placement, the control point is deviation from the planned position relative to a safety margin. In regenerative surgery, it is the maintenance of a protected space and wound stability over months rather than days. In extraction and socket management, it is the stability of early soft tissue closure and the mitigation of short-term morbidity that can compromise subsequent restorative steps.

Computer-assisted implant placement has the most mature outcome language because deviations are quantifiable. Meta-analytic evidence suggests mean coronal and apical deviations around the 1 mm range with angular deviations around a few degrees across computerized systems, with robotic approaches trending toward lower deviations in pooled analyses (Khaohoen et al., 2024; Luo et al., 2025). While pooled mean values fall within clinically acceptable ranges, they may obscure wider deviation distributions observed in specific clinical scenarios, particularly in fully edentulous cases, mucosa-supported guides, and situations with reduced guide stability. Support type and fixation strategy directly influence the variability of observed deviations. It defines whether the measured deviation distribution remains tight or becomes wide enough that safety margins are challenged.

Clinical trials and prospective cohorts add practical constraints to the meta-analytic picture. A randomized clinical trial in edentulous patients comparing bone-supported and mucosa-supported guided surgery with mental navigation and pilot template approaches found that guided methods improve accuracy, but also that support type influences the consistency of outcomes (Vercruyssen et al., 2014). A prospective cohort study focusing on tooth-supported drill guides based on CBCT and intraoral scanning showed that a digitally integrated workflow can deliver high accuracy, but also emphasized that guide seating and intraoperative control remain decisive even in apparently straightforward partially edentulous cases (Derksen et al., 2019). Complementary work has shown that bone density, surgical experience, and half-guided protocols can shift accuracy outcomes in edentulous jaws, reinforcing the need to interpret a planning-derived target within the constraints of support and intraoperative execution (Kivovics et al., 2020).

Dynamic navigation and robotic assistance introduce a different type of constraint: rather than relying on a physical template, they depend on registration stability and on the operator's ability to act on continuous feedback without losing tactile control. Studies on dynamic navigation accuracy highlight that outcomes depend on tracking stability, reference marker security, and the learning curve. A controlled evaluation of young operators using dynamic navigation demonstrated measurable learning effects, indicating that early performance metrics differ from those observed after operator familiarization (Spille et al., 2022). Clinical retrospective data similarly note that deviations and procedure time evolve with operator experience and with factors such as edentulous segments and limited reference stability (Ma et al., 2023). Robotic systems show low mean deviations in clinical series and meta-analyses, but the current evidence base remains characterized by limited randomized comparisons and scarce long-term endpoints, so the translation to durable clinical outcomes requires careful separation of accuracy metrics from long-term complication profiles (Luo et al., 2025).

Regenerative protocols demonstrate an analogous pattern. Form-stable barriers such as titanium mesh can achieve clinically relevant vertical and horizontal bone gain, with umbrella-level synthesis reporting mean gains in the range of a few millimeters and exposure rates that remain substantial, often around one quarter of cases in aggregated analyses (Ng et al., 2025). A systematic review and meta-analysis indicates that membrane exposure has a detrimental influence on guided bone regeneration outcomes, suggesting clinically meaningful reductions in bone gain when exposure occurs (Garcia et al., 2018). Clinical studies of GBR protocols incorporating platelet concentrates and staged membrane strategies report promising bone gain, but they also reinforce that wound stability over months is the limiting step, and that clinical success depends on phenotype, flap design, and tension control as much as on biomaterial selection (Castro et al., 2020).

Platelet concentrates, including PRF variants, are often positioned as biologic adjuncts that improve early healing and reduce morbidity. Clinical trials in extraction sockets and preserved sites indicate potential benefits in early pain reduction and short-term soft tissue healing, including in higher-risk groups such as smokers, although results vary by preparation protocol and comparator (Alrayyes et al., 2022). A more recent controlled clinical study evaluating PRF in post-extraction healing likewise emphasizes symptom relief and early tissue response as the most consistent advantages, while the impact on hard tissue outcomes is more variable and more sensitive to socket morphology and co-interventions (Hajibagheri et al., 2025). For clinical protocol design, these findings indicate that PRF primarily functions as an adjunct influencing early healing parameters within a broader wound-management strategy.

Perioperative anti-infective protocols illustrate a particularly important outcome-control dilemma. While antibiotic prophylaxis may reduce postoperative infections, indiscriminate use conflicts with antimicrobial stewardship and can create adverse effects. A recent randomized controlled clinical trial comparing a single 2 g amoxicillin dose one hour before implant placement versus placebo reported no statistically significant difference in early implant failure, while showing a higher infection rate in the placebo group, a nuance that underscores the need to distinguish early failure endpoints from infection endpoints and to interpret both through patient and procedure risk profiles (Bravo-Olmedo et al., 2025). These findings support a move toward risk-stratified decision rules where the protocol specifies the infection endpoints that justify prophylaxis and the follow-up timing used to validate that decision.

The outcome-control lens can be extended to soft tissue determinants of long-term implant health. The literature on peri-implant keratinized mucosa suggests associations between inadequate keratinized mucosa and adverse peri-implant inflammatory parameters and disease prevalence, although causality and confounding remain topics of debate. A meta-analysis reports increased peri-implantitis prevalence in the absence of keratinized mucosa, indicating that soft tissue phenotype should be treated as an outcome-relevant variable rather than a background characteristic (Mahardawi et al., 2023). For innovative protocols, this implies that long-term outcome control requires integrating surgical soft tissue decisions with postoperative hygiene and maintenance, and that accuracy and early healing metrics should be interpreted within the broader peri-implant risk landscape.

Discussion

Across the reviewed studies, consistent patterns are observed: the most effective innovations are those that specify measurable checkpoints at points where error and variability are most likely to emerge. This approach allows protocols to be compared based on defined measurement and control steps. It also provides a rationale for why some technically advanced approaches do not reliably translate into improved outcomes when the measurement logic is weak, when endpoint timing is inappropriate, or when the protocol does not define corrective actions triggered by the measurements.

In guided implant surgery, the central measurement is deviation, but the clinically meaningful construct is risk. Mean deviation values across studies can be interpreted as evidence that guided approaches are broadly accurate, yet the clinical decision is driven by whether the protocol keeps the risk tail within the safety margin. This is why support type, fixation, and case complexity remain decisive. Tooth-supported guides can achieve high accuracy under favorable conditions, while mucosa-supported guides in long-span edentulism can become sensitive to compressibility, seating errors, and the dynamics of the mandible, producing wider deviation distributions. Several systematic and clinical studies converge on the practical recommendation of maintaining a safety margin of at least 2 mm from critical structures, a recommendation that reflects a conservative safety margin intended to account for deviation variability rather than typical mean performance (Tahmaseb et al., 2018; Zhou et al., 2018).

Dynamic navigation shifts the source of risk from physical guide stability to registration stability and operator performance under feedback. Learning curve data indicate that early outcomes can be misleading if adopted as representative of routine performance, and retrospective clinical observations suggest that deviations can vary meaningfully with case selection and reference stability (Spille et al., 2022; Ma et al., 2023). These observations support the inclusion of explicit registration verification steps and predefined thresholds for re-registration or conversion to alternative strategies when tracking quality degrades.

Robotic systems appear promising in accuracy metrics, but the clinical interpretation should remain cautious. Accuracy is a proximal endpoint, while the endpoints that matter to patients and to long-term implant success include biologic complications, peri-implant inflammatory status, prosthetic complications, and radiographic stability over years. The current evidence base for robotic assistance remains relatively limited in randomized and long-term designs, which is consistent with the IDEAL framework expectation that many innovations reach broad use before their long-term monitoring phase is mature (Ergina et al., 2009; Hirst et al., 2019).

Regenerative protocols reinforce an analogous point. The use of titanium mesh or reinforced barriers can provide space maintenance and yield measurable bone gain, but exposure remains the dominant predictor of variability. The systematic evidence that exposure reduces bone gain should translate into protocol emphasis on soft tissue management, including flap design, tension release, and phenotype modification when indicated (Garcia et al., 2018; Ng et al., 2025). In this domain, innovation that is framed only in terms of biomaterial selection is incomplete, because the most important controllable variable is often wound stability.

Biologic adjuncts such as PRF are clinically attractive because they can improve early postoperative experience and potentially stabilize early healing. The most consistent evidence supports short-term symptom relief and early soft tissue response, while long-term structural outcomes are more heterogeneous and depend on site-specific conditions and co-interventions (Alrayyes et al., 2022; Hajibagheri et al., 2025).

Antibiotic prophylaxis illustrates how protocol innovation can align clinical pragmatism with stewardship. The recent randomized trial comparing single-dose amoxicillin with placebo suggests that infection endpoints and early failure endpoints can diverge, and that antibiotic use decisions should be linked to the endpoint the protocol aims to control (Bravo-Olmedo et al., 2025). A similar logic applies to antiseptic measures, decontamination steps, and postoperative maintenance. Protocols that specify who is at risk, what adverse event is being prevented, and what follow-up window will confirm benefit are more likely to produce reproducible outcomes and more defensible prescribing patterns.

The author-developed AI-assisted planning and navigation workflow, created as a personal technical solution, can be situated within this outcome-control framing without overstatement. The workflow provides an integrated measurement architecture in which planning data, intraoperative guidance, and postoperative assessment are linked by shared spatial and metric references. In practical terms, such a workflow can be used to enforce registration verification, to log intraoperative deviations and corrective actions, and to structure follow-up imaging and clinical indices so that long-term outcomes are assessed on the same coordinate and metric logic used during planning. Accordingly, the personal technical development functions as an implementation scaffold for measurement consistency and auditability, without implying superiority over established approaches. This positioning is consistent with the broader literature in which digital innovation is most credible when it reduces ambiguity in what is measured and how the measurement changes decisions.

Long-term outcomes require direct longitudinal evaluation and should not be inferred from early healing parameters or immediate positional accuracy. For clinical translation, long-term is most defensibly defined as at least 12 to 36 months of follow-up, because peri-implant tissue adaptation, prosthetic loading effects, and maintenance-related confounding accumulate over this interval. Protocols that report only short-term closure and deviation metrics can establish feasibility and process control, whereas durability requires follow-up designs that capture biological stability and functional performance under routine load.

Conclusion

Clinical evidence indicates that dental surgical protocols achieve greater reproducibility when they are designed around measurable outcome control rather than around tools. The current clinical evidence supports the accuracy of computerized implant placement methods within clinically acceptable ranges, while emphasizing that support type, fixation, registration stability, and operator learning dynamics define variability. Regenerative protocols can deliver clinically meaningful bone gain, but exposure control and soft tissue management remain the dominant determinants of predictability. Biologic adjuncts such as PRF show the most consistent benefits in early healing and symptom control, while long-term structural outcomes require more standardized reporting and careful interpretation. Risk-stratified perioperative anti-infective protocols illustrate how explicit endpoint selection can improve clinical decision-making. An author-developed AI-assisted workflow is presented as a practical means of aligning planning, intraoperative guidance, and postoperative measurement, thereby enabling structured evaluation of surgical outcomes across planning, execution, and follow-up.

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