



(REVIEW ARTICLE)



STATIC VERSUS DYNAMIC NAVIGATION PREDICTABILITY AND THE EMERGENCE OF SMART, BIOSENSOR-INTEGRATED IMPLANTS IN MODERN IMPLANT DENTISTRY: A NARRATIVE REVIEW

Althaaf Khan *

BDS (SMU), Private Practice, South Africa.

* Corresponding Author

Global Journal of Research in Medicine and Dentistry, 2026, 05(04), 031–037

Publication history: Received on 25 August 2026; revised on 30 September 2026; accepted on 02 October 2026

Article DOI: <https://doi.org/10.58175/gjrmd.2026.5.4.0105>

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

Digital technologies have transformed implant dentistry over the past two decades, with static computer-assisted implant surgery (sCAIS) and dynamic computer-assisted implant surgery (dCAIS) now established as predictable means of transferring a virtual implant plan to the surgical field. This narrative review synthesises current evidence on the comparative predictability of sCAIS and dCAIS, with particular attention to unresolved questions of cost-effectiveness, learning-curve burden, and performance in immediate post-extraction and severely atrophic sites, before examining the parallel but far less mature field of smart, biosensor-functionalised implants. A structured search of PubMed, ScienceDirect and related databases identified systematic reviews, meta-analyses, randomised and retrospective clinical studies, and narrative reviews published predominantly within the last decade. Both sCAIS and dCAIS achieve clinically acceptable accuracy, with meta-analytic entry-point deviations in the region of 1.0-1.4 mm and angular deviations of approximately 3-4 degrees, and neither modality shows consistent, clinically decisive superiority over the other. Dynamic navigation appears to preserve this accuracy in immediate extraction sockets and in severely resorbed ridges, including transcrestal sinus procedures, although this evidence base remains comparatively small. Cost, equipment footprint, and a steep operator learning curve continue to constrain the routine adoption of both workflows, and robust economic analyses are lacking. Sensor-functionalised implants capable of monitoring micromotion, pH, and peri-implant inflammation remain overwhelmingly confined to bench-top and early translational studies, held back by miniaturisation, powering, biofouling, and an immature regulatory pathway. Both fields require standardised outcome reporting, prospective economic evaluation, and, for smart implants, dedicated regulatory frameworks before they can be considered routine clinical tools.

Keywords: Dynamic Navigation; Static Computer-Assisted Implant Surgery; Dental Implants; Smart Implants; Biosensors; Peri-Implantitis.

1 INTRODUCTION

The transfer of a virtually planned implant position to the surgical field has become the defining challenge of modern implant dentistry. Digital workflows built on cone-beam computed tomography, intraoral scanning and dedicated planning software now allow the clinician to design the prosthetically driven implant position before the first incision is made, and two broad families of computer-assisted implant surgery (CAIS) have emerged to translate that plan into

the mouth [1,2]. Static computer-assisted implant surgery (sCAIS) relies on a rigid, tooth-, mucosa- or bone-supported surgical template fabricated from the virtual plan, whereas dynamic computer-assisted implant surgery (dCAIS) uses optical or electromagnetic tracking to display the drill position in real time on a screen, without a physical template constraining the osteotomy [1,3].

Systematic reviews and meta-analyses over the past decade have repeatedly confirmed that both sCAIS and dCAIS place implants with clinically acceptable accuracy, generally superior to freehand placement [4,5,6]. What remains far less settled is whether either modality is decisively more predictable than the other once cost, training burden, and challenging anatomical scenarios are taken into account. Guided surgery, whether static or dynamic, carries a recognised learning curve, a non-trivial equipment and per-case cost, and an evidence base that is still comparatively thin for immediate post-extraction implant placement and for severely atrophic ridges, precisely the situations in which navigational guidance might be expected to matter most [7,8,9].

In parallel, a second and considerably less mature technological trajectory is emerging: the functionalisation of the implant fixture itself with miniaturised sensors capable of measuring micro-motion, local pH, temperature or inflammatory biomarkers, with the aim of providing continuous, objective, real-time data on peri-implant health rather than relying solely on periodic clinical and radiographic review [10,11]. This concept of the "smart implant" has been explored more extensively in orthopaedic and spinal surgery than in dentistry, and the translational lessons from those fields are directly relevant to the dental application [12,13].

This narrative review therefore addresses two related but distinct gaps in the implant dentistry literature. First, it examines the comparative predictability of static and dynamic navigation, with specific attention to cost-effectiveness, the steepness and shape of the learning curve, and performance in immediate post-extraction and severely atrophic sites. Second, it examines the current state of smart, biosensor-integrated implants, evaluating the evidence for real-time diagnostic capability and the regulatory and translational barriers that continue to confine this technology to pre-clinical development. The objective is to provide the practising clinician and the clinical researcher with a balanced, evidence-based synthesis of what is established, what remains uncertain, and where the priorities for future research lie.

2 MATERIALS AND METHODS

This is a narrative review rather than a formal systematic review, and no review protocol was registered. A structured, non-exhaustive literature search was conducted in PubMed/MEDLINE, ScienceDirect, and supplementary general web searches for the period covering approximately 2014 to 2026, with priority given to systematic reviews, meta-analyses, randomised controlled trials and prospective or retrospective clinical studies published within the last five years. Search terms combined "dynamic navigation", "static computer-assisted implant surgery", "dental implant accuracy", "learning curve", "cost-effectiveness", "immediate implant placement", "atrophic ridge", "smart implant", "biosensor", "micromotion", "peri-implantitis" and related terms, combined using Boolean operators.

Titles and abstracts were screened for relevance to the accuracy, learning curve, cost, or clinical application of sCAIS and dCAIS in dental implant surgery, or to sensor-functionalised implants in dentistry and, where directly informative by analogy, in orthopaedic and spinal surgery. Case reports were included selectively where they illustrated a technique applied to a severely atrophic or post-extraction site not otherwise well represented in the comparative literature. Sources published only as industry or marketing material were excluded. Because this is a narrative synthesis rather than a systematic review, no formal risk-of-bias tool, PRISMA flow diagram, or meta-analytic pooling of effect sizes was applied; where quantitative findings from published meta-analyses are cited, the original authors' pooled estimates are reported directly. As this review involved no human participants, animal subjects, or identifiable patient data, no ethical approval or informed consent was required.

3 RESULTS AND DISCUSSION

3.1 Static versus Dynamic Navigation Predictability

3.1.1 Comparative accuracy

Both navigation modalities have now been evaluated in multiple meta-analyses, and the pooled figures are remarkably consistent across studies. For sCAIS, a widely cited meta-analysis reported a mean total error of approximately 1.2 mm at the implant entry point and 1.4 mm at the apex, with a mean angular deviation of roughly 3.5 degrees [4]. A separate meta-analysis restricted to randomised controlled trials similarly found that fully guided static placement was statistically more accurate than partially guided or free-handed placement, although the authors noted that the absolute magnitude of the difference was small and of uncertain clinical significance for most routine cases [5]. For dCAIS, pooled

clinical and in-vitro data have reported mean global platform and apex deviations in the region of 1.0 mm and 1.3 mm respectively, again within a clinically acceptable envelope [3,6]. Head-to-head comparisons, including a 2024 meta-analysis of static, dynamic and robot-assisted techniques, have generally found no statistically significant difference in accuracy between static and dynamic guidance, with robot-assisted placement showing a modest further improvement over both in the small number of trials available [9].

The clinical implication is that, for the majority of routine single- and multiple-unit cases, the choice between static and dynamic navigation can reasonably be made on grounds other than accuracy alone: template fabrication lead time, real-time visual feedback and flexibility to adjust the plan intraoperatively for dCAIS, versus lower per-case cost, no requirement for tracking hardware, and easier delegation of the surgical phase for sCAIS [1,7,8]. Dynamic systems retain the theoretical advantage of allowing the surgeon to modify the implant position in real time in response to unexpected anatomy, a flexibility that a rigid static template does not permit [1,7].

3.1.2 Cost-effectiveness

Despite the maturity of the accuracy literature, formal cost-effectiveness analyses of sCAIS and dCAIS remain scarce. Commentary from clinical opinion leaders and narrative reviews consistently identifies the higher upfront and per-case cost of guided surgery, whether static or dynamic, as one of the principal obstacles to its routine adoption [7,8]. A recent review of digital workflows in implant dentistry explicitly listed high costs, alongside steep learning curves and poor interoperability between proprietary planning systems, among the main barriers to widespread clinical uptake [8]. For robot-assisted systems, which represent a further evolution of dCAIS, authors have explicitly called for cost-effectiveness research as a priority, noting that the high capital cost of robotic platforms currently limits routine clinical implementation to well-resourced practices and institutions [8,9]. In the absence of prospective economic modelling that accounts for chair-time savings, reduced complication rates, and long-term prosthetic outcomes against the capital and consumable costs of guided systems, clinicians and practice owners are largely left to make adoption decisions on a case-volume and case-complexity basis rather than on published economic evidence.

3.1.3 Learning curve

Both sCAIS and dCAIS impose a recognisable learning curve, though its shape differs between the two. For dynamic navigation, in-vitro studies of postgraduate trainees and dental students have generally shown that surgical time shortens, and accuracy improves, with repeated use, even though clinically acceptable accuracy can often be achieved comparatively early in training [14]. A retrospective clinical study of 55 dynamic-navigation-assisted implant placements found that angular deviation decreased progressively as an individual operator's case experience with the system increased, despite jaw position, arch side, and implant dimensions having no measurable effect on accuracy [15]. Robot-assisted systems, representing the most technologically advanced end of the spectrum, appear to demonstrate stability in implant trueness relatively early in training, although the time required to complete a procedure continues to fall with practice, indicating that the learning curve for robotic systems may be shifted from an accuracy problem toward a workflow-efficiency problem [9].

For static guided surgery, the learning curve is frequently described as "arduous" in the clinical literature, related less to the physical act of drilling through a template and more to the upstream digital workflow: accurate scanning, correct implant planning, guide design, and validation of guide fit intraorally, any one of which can introduce error if performed incorrectly [7]. Because errors introduced during static guide planning are only discovered at the time of surgery, whereas dynamic navigation provides continuous real-time visual feedback that may allow an experienced operator to detect and correct a developing deviation intraoperatively, some authors have argued that dynamic systems may in principle offer a gentler learning curve for accuracy, even though they demand a different, technology-management skill set from the surgeon during the procedure itself [1,7,8].

3.1.4 Immediate post-extraction implant placement

Immediate implant placement into a fresh extraction socket introduces additional variables, including an irregular residual socket wall, the absence of a fully formed osseous housing to stabilise a static guide, and the frequent need to angulate the implant away from the original tooth axis for prosthetic reasons. A model-based comparison of static and dynamic CAIS in fresh extraction sockets versus healed ridges found that both systems maintained accuracy in the fresh socket scenario, though the authors noted that the reduced bony support available for guide seating in an unhealed socket represents a theoretical vulnerability for static systems in particular [16]. Clinical data specific to dynamic navigation in immediate placement have been more reassuring: a retrospective comparison of dynamic navigation-guided immediate and delayed anterior implant placement found no statistically significant difference in platform, apex or angular deviation between the two groups, suggesting that placement into a fresh socket did not, in itself, compromise the accuracy achievable with real-time navigation [17,18]. Similar findings have been reported for immediate implant placement in the posterior mandible, where dynamic navigation achieved significantly smaller deviations, and greater safe distance from the inferior alveolar canal, than free-hand placement, and comparable performance to static guides [19]. Case-based and cohort evidence for immediate implant placement in the posterior maxilla with concurrent

alveolar bone defects, and in the anterior aesthetic zone with simultaneous provisionalisation, further supports the feasibility of dynamic-navigation-guided immediate placement, provided prosthetically driven planning and adequate primary stability are confirmed [20,21,22].

3.1.5 Severely atrophic sites

Severe alveolar atrophy, whether horizontal, vertical, or affecting the posterior maxilla with reduced residual bone height beneath the sinus floor, represents one of the more demanding indications for guided implant placement, since template stability and camera or emitter line-of-sight can both be compromised by limited bone volume and altered soft-tissue anatomy. Case-based evidence has described the use of dynamic navigation to guide alveolar ridge splitting in severely resorbed posterior mandibular sites, arguing that real-time visual feedback allows the operator to control the osteotomy depth and angulation more precisely during the technically demanding split-crest manoeuvre than freehand technique alone permits [23]. In the atrophic posterior maxilla, dynamic navigation has also been applied to simultaneous transcresal sinus floor elevation in sites with residual bone height of less than 5 mm, a scenario that would traditionally favour a more invasive lateral window approach; the available case series reported implant placement accuracy within a clinically acceptable range even under these constrained anatomical conditions [24]. For the most severely atrophic edentulous maxillae, comparative accuracy studies of static and dynamic navigation for zygomatic implant placement, where the surgical corridor is narrow and the consequences of deviation are more serious, have found both modalities capable of clinically useful accuracy, without a clear and consistent advantage for either [25].

Taken together, the evidence in immediate post-extraction and severely atrophic scenarios is encouraging but still comparatively sparse relative to the mature literature on routine healed-ridge implant placement, and is weighted toward retrospective cohorts, case series and in-vitro models rather than adequately powered randomised trials. This represents one of the clearer priorities for future prospective research in the field.

3.2 Smart Implants and Biosensors

3.2.1 Rationale and sensing targets

The concept of a "smart implant" is a fixture, or an associated abutment or prosthetic component, functionalised with a miniaturised sensor and a means of wireless data transmission, intended to provide continuous, objective, in-situ physiological or biomechanical data rather than the intermittent, indirect information obtained from periodic probing, radiographs, or patient-reported symptoms [10,11]. In implant dentistry, three sensing targets have received the most attention. First, micro-motion at the bone-implant interface, a mechanical correlate of primary and secondary stability, whose continuous measurement could in principle allow earlier identification of implants at risk of failed osseointegration or progressive loosening [11,12]. Second, local pH, which shifts in a relatively predictable direction with bacterial biofilm activity and early inflammation and has therefore been proposed as an early, non-invasive marker of an emerging peri-implant problem before it becomes clinically or radiographically evident [11,26]. Third, local inflammatory biomarkers, including cytokines and other molecules present in peri-implant crevicular fluid, which are more specific for active tissue destruction than pH alone but are technically more demanding to sense continuously and in real time [26,27].

3.2.2 Current stage of development

The great majority of the published literature on sensor-integrated implants in dentistry is narrative review, perspective, or bench-top proof-of-concept work rather than clinical trial data. Reviews of biosensor-embedded implants and smart dentures describe prototype systems capable of tracking peri-implant tissue health, detecting oral dryness, or providing continuous temperature data, with artificial intelligence proposed as a means of interpreting the resulting data stream for predictive or preventive purposes, but consistently frame this as an emerging rather than an established clinical capability [11,28]. A recent review focused specifically on biosensors for peri-implantitis monitoring concluded that, while a range of biosensor types capable of detecting relevant biomarkers have been described in the laboratory, clinical translation remains limited, and larger-scale clinical studies are needed before such devices can be considered part of routine peri-implant diagnostics [26]. A broader narrative review of peri-implant disease diagnosis similarly positioned biosensor-based monitoring alongside molecular and point-of-care biomarker testing as a promising but still-emerging adjunct to, rather than a replacement for, conventional clinical and radiographic assessment [27].

The most instructive translational precedent comes not from dentistry but from orthopaedic and spinal surgery, where sensor-enabled implants have a longer development history and, in a small number of cases, have already reached regulated clinical use. A smart tibial knee prosthesis combining a conventional implant with an implantable accelerometer-based sensor received regulatory clearance and has been used clinically to track gait metrics such as step count and walking speed, and comparable pressure-sensing instrumentation has been used intraoperatively to guide soft-tissue balancing in knee arthroplasty [10,12]. In spinal surgery, a systematic review of "SMART" implantable

devices identified a small but growing body of work on sensor-instrumented rods and vertebral body replacements capable of logging load and strain data, but noted that fewer than twenty patients had received such a device across the entire published literature at the time of the review, underlining how far even the more advanced orthopaedic smart-implant field remains from routine practice [13]. These orthopaedic precedents demonstrate that the underlying sensing, powering and wireless-communication technology is technically achievable and, in narrowly defined cases, regulatorily approvable, but that the pathway from bench to bedside is long, resource-intensive, and has so far succeeded only for a small number of specific, well-resourced applications.

3.2.3 Technical and translational barriers

Several interlinked barriers explain why smart, biosensor-integrated implants remain confined to pre-clinical and early translational study. Miniaturisation is a fundamental constraint: a dental implant fixture offers only a few millimetres of usable volume, and any sensor, power source, and antenna must be accommodated without compromising the fixture's mechanical strength or its osseointegration surface [12,29]. Powering the device is similarly unresolved; battery-powered designs raise questions of longevity, biocompatibility of the cell itself, and eventual replacement, while battery-free and energy-harvesting approaches, including piezoelectric elements that generate current from masticatory load, remain at an early stage of development for dental application [28,29]. Long-term signal stability in the wet, biologically active, mechanically loaded environment of the oral cavity is a further challenge: biosensor performance can drift, biofouling from biofilm and protein adsorption can blunt sensitivity to the very biomarkers the device is intended to detect, and the sensor-tissue interface can itself provoke a foreign-body or inflammatory response that confounds the signal it is meant to measure [12,29].

Regulatory pathways for these devices are correspondingly underdeveloped. In the United States, smart dental devices with real-time diagnostic or monitoring capability are generally expected to fall into a higher device risk classification than passive implants, requiring a more demanding premarket evidentiary standard, and regulators have themselves acknowledged that frameworks for continuous-monitoring implantable devices are still evolving to address their particular complexity [13,30]. Reviewers of sensor-enabled orthopaedic implants have made an equivalent observation, noting that such devices must satisfy the same clinical trial, quality assurance, and post-market surveillance standards as any other implantable medical device, while additionally carrying the burden of demonstrating the accuracy, reliability, and clinical utility of the embedded sensing technology itself, a combined requirement that manufacturers have found costly relative to the size of the addressable market [12,13]. A parallel account of the wider clinical translation of novel dental materials has argued that faster-track regulatory designations, and greater international regulatory harmonisation, will be necessary if genuinely innovative dental technologies, sensor-integrated implants included, are to move from laboratory demonstration to routine clinical products within a realistic timeframe [31].

Taken together, the current evidence indicates that sensor-functionalised dental implants are a technically plausible and clinically appealing concept, directly analogous to developments already partially realised in orthopaedic and spinal surgery, but one that in dentistry remains, at the time of writing, in pre-clinical development. Progress will depend on parallel advances in miniaturised, low-power, biofouling-resistant sensing technology, on prospective clinical validation against conventional diagnostic standards, and on the emergence of a regulatory pathway specifically suited to continuous-monitoring implantable dental devices.

4 CONCLUSION

Static and dynamic computer-assisted implant surgery have both matured into clinically accurate, well-validated tools for transferring a digitally planned implant position to the surgical field, and neither modality demonstrates a consistent, clinically decisive accuracy advantage over the other. What remains genuinely unresolved is not whether guided surgery works, but how it should be selected, resourced and taught: robust prospective cost-effectiveness analyses are lacking, the learning curve for both workflows is real and differently shaped, and the evidence base for immediate post-extraction and severely atrophic indications, while encouraging, is still comparatively limited and dominated by retrospective and case-based data. Smart, biosensor-functionalised implants represent a logically compelling extension of the same digital trajectory, offering the prospect of continuous rather than episodic peri-implant monitoring, but the field remains substantially behind analogous orthopaedic and spinal applications and is, at present, confined to pre-clinical and early translational study, constrained by miniaturisation, powering, signal-stability and regulatory barriers. Prospective, adequately powered clinical trials addressing cost-effectiveness and challenging anatomical indications for navigated surgery, together with coordinated engineering, clinical and regulatory investment in sensor-integrated implant technology, represent the principal priorities for the field over the coming decade.

REFERENCES

- [1] D'Haese J, Ackhurst J, Wismeijer D, De Bruyn H, Tahmaseb A. Current state of the art of computer-guided implant surgery. *Periodontol* 2000. 2017;73(1):121-33.
- [2] Tahmaseb A, Wismeijer D, Coucke W, Derksen W. Computer technology applications in surgical implant dentistry: a systematic review. *Int J Oral Maxillofac Implants*. 2014;29(Suppl):25-42.
- [3] Wei SM, Zhu Y, Wei JX, Zhang CN, Shi JY, Lai HC. Accuracy of dynamic navigation in implant surgery: a systematic review and meta-analysis. *Clin Oral Implants Res*. 2021;32(4):383-93.
- [4] Tahmaseb A, Wu V, Wismeijer D, Coucke W, Evans C. The accuracy of static computer-aided implant surgery: a systematic review and meta-analysis. *Clin Oral Implants Res*. 2018;29(Suppl 16):416-35.
- [5] Tattan M, Chambrone L, González-Martín O, Avila-Ortiz G. Static computer-aided, partially guided, and free-handed implant placement: a systematic review and meta-analysis of randomized controlled trials. *Clin Oral Implants Res*. 2020;31(10):889-916.
- [6] Jorba-García A, González-Barnadas A, Camps-Font O, Figueiredo R, Valmaseda-Castellón E. Accuracy assessment of dynamic computer-aided implant placement: a systematic review and meta-analysis. *Clin Oral Investig*. 2021;25(5):2479-94.
- [7] International Team for Implantology. Static computer-assisted implant surgery in daily clinical practice: pros and cons [Internet]. 2024 Oct 15 [cited 2026 Sep 27]. Available from: <https://blog.iti.org/clinical-insights/static-computer-assisted-implant-surgery-in-daily-clinical-practice-pros-and-cons/>
- [8] Advancing precision: the role of digital workflows in modern implant dentistry [Internet]. 2025 [cited 2026 Sep 27]. Available from: <https://pmc.ncbi.nlm.nih.gov/articles/PMC12697450/>
- [9] Mahardawi B, Jiaranuchart S, Arunjarosensuk S, Kaboosaya B, Pimkhaokham A. Accuracy of implant placement with computer-aided static, dynamic, and robot-assisted surgery: a systematic review and meta-analysis of clinical trials. *BMC Oral Health*. 2024;24:359.
- [10] Nadeem-Tariq A, Fang CJ, Hii JL, Nelson K. Biosensor-integrated tibial components in total knee arthroplasty: a narrative review of innovations, challenges, and translational frontiers. *Bioengineering (Basel)*. 2025;12(9):988.
- [11] Shah P, et al. Smart dental implants in modern dentistry: a comprehensive review. *IP Int J Periodontol Implantol*. 2025.
- [12] Huang J, et al. Sensor-enabled orthopedic implants for musculoskeletal monitoring. *Adv Sensor Res*. 2025;4(6):2400138.
- [13] Kim SJ, Wang T, Pelletier MH, Walsh WR. 'SMART' implantable devices for spinal implants: a systematic review on current and future trends. *J Spine Surg*. 2022;8(1):135-46.
- [14] Yan Q, Wu X, Shi J, Shi B. Does dynamic navigation assisted student training improve the accuracy of dental implant placement by postgraduate dental students: an in vitro study. *BMC Oral Health*. 2024;24:1-6.
- [15] Ma L, Ye M, Wu M, Chen X, Shen S. A retrospective study of dynamic navigation system-assisted implant placement. *BMC Oral Health*. 2023;23:1-9.
- [16] Comparison of implant placement accuracy in healed and fresh extraction sockets between static and dynamic computer-assisted implant surgery navigation systems: a model-based evaluation [Internet]. 2022 [cited 2026 Sep 27]. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9030091/>
- [17] Yang DU, Li H, Ma F, Sun F, Weng J, Wu B. Accuracy of dynamic navigation system for immediate dental implant placement. *Beijing Da Xue Xue Bao Yi Xue Ban*. 2025.
- [18] Accuracy of dynamic navigation for immediate and delayed anterior dental implant placement: a retrospective study. *BMC Oral Health*. 2025;25.
- [19] Geng N, Ren J, Zhang C, Zhou T, Feng C, Chen S. Immediate implant placement in the posterior mandibular region assisted by dynamic real-time navigation: a retrospective study. *BMC Oral Health*. 2024;24:208.
- [20] Deng H, Geng N, Yang S, Dou X, Wang H, Chen S, Huang L. Clinical study of dynamic navigation-assisted immediate implant placement in posterior maxillary alveolar bone defects. *BMC Oral Health*. 2025;25:617.
- [21] Pozzi A, Arcuri L, Carosi P, Simoni GB, Barlattani A. Clinical and radiological outcomes of novel digital workflow and dynamic navigation for single-implant immediate loading in aesthetic zone: 1-year prospective case series. *Clin Oral Implants Res*. 2021;32(12):1397-1410.

- [22] A novel application of dynamic guided navigation system in immediate implant placement. *J Prosthodont Res.* 2022;66(1):152-8.
- [23] Precision implant placement: a novel approach using dynamic navigation system-guided alveolar ridge splitting. *J Indian Prosthodont Soc.* 2025;25(2).
- [24] A dynamic navigation-assisted transcresal sinus floor elevation in severely atrophic maxillae: a descriptive case series. *Oral Maxillofac Surg.* 2026.
- [25] Accuracy of computer-aided static and dynamic navigation systems in the placement of zygomatic dental implants. *J Clin Med.* 2023;12(6):2107.
- [26] Panahi O, Farrokh Eslamlou S, Dadkhah S. Biosensors for monitoring peri-implantitis: current status and future directions. *Am J Biomed Sci Res.* 2025;25(5):561-6.
- [27] Bornes R, Montero J, Correia A, Marques T, Rosa N. Peri-implant diseases diagnosis, prognosis and dental implant monitoring: a narrative review of novel strategies and clinical impact. *BMC Oral Health.* 2023;23:896.
- [28] Bors A, Mucenic S, Monea A, Ormenisan A, Beresescu G. From conventional to smart prosthetics: redefining complete denture therapy through technology and regenerative science. *Medicina (Kaunas).* 2025;61(6):1104.
- [29] Suryaprabha T, Choi C, Wu Y, Liu L, Hwang B. Smart wearable and implantable biosensors for continuous health monitoring: materials, biocompatibility, and AI integration. *npj Flex Electron.* 2026;10(1):46.
- [30] Registrar Corp. Bringing smart dental devices to the US: FDA regulations explained [Internet]. 2025 Apr 5 [cited 2026 Sep 27]. Available from: <https://www.registrarcorp.com/blog/medical-devices/medical-device-regulations/smart-dental-devices/>
- [31] Perspective: opportunities and challenges in translating dental materials into clinical practice. *Dent Mater X.* 2025.