



Robot-Assisted Dental Implant Surgery: From Digital Precision to Human–Robot Partnership

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Dental implantology has undergone a remarkable transformation with the integration of digital planning, three-dimensional imaging, computer-assisted navigation, and, more recently, robotic technology. The emergence of robot-assisted dental implant surgery represents an important step in this evolution, promising greater precision, reproducibility, and intraoperative control. Robot-assisted systems have been developed to address some of the limitations associated with conventional free-hand surgery, including operator fatigue, physiological hand tremor, limited visibility, and variability related to surgical experience [1,2].

The rationale for robotic assistance is particularly compelling because implant placement is a precision-dependent surgical procedure. Small deviations in implant position, angulation, or depth can influence prosthetic emergence, biomechanics, aesthetics, and the relationship of the implant to vital anatomical structures. Inaccurate placement may contribute to complications

such as nerve injury, bleeding, and prosthetic difficulties [1,3]. Therefore, robotic technology should not be regarded merely as another technological accessory, but as an attempt to introduce greater consistency and reproducibility into implant surgery. The current generation of dental implant robots can broadly be classified according to the degree of human–robot interaction into active, passive, and semi-active systems. Active systems can autonomously perform substantial components of implant site preparation and placement, whereas passive systems primarily provide positional guidance to the clinician. Semi-active systems occupy an intermediate position, combining automated functions with direct clinician involvement [1,2]. Examples described in the literature include YekeBot, Yomi, DentRobot, Remebot, Theta, HRC-DIS, Langyue, and HRS-DIS. The integration of preoperative digital planning with intraoperative positional control is one of the major advantages of robotic implantology. Robotic platforms

may incorporate optical tracking, patient monitoring, haptic feedback, and robotic-arm stabilization. Patient trackers can monitor movement during surgery and provide real-time feedback, while haptic guidance assists in maintaining the planned trajectory. Importantly, current systems continue to depend on human supervision, making contemporary robotic implantology predominantly a human–robot collaborative technology rather than completely autonomous surgery [1,4]. The most compelling evidence supporting robotic implantology concerns positional accuracy. Computer-assisted implant surgery has already demonstrated advantages over conventional free-hand placement, with both static and dynamic navigation improving the accuracy of implant positioning [3]. However, robotic systems may provide an additional level of mechanical stabilization by controlling the position and trajectory of the surgical handpiece.

A pilot randomized controlled trial reported substantially smaller deviations with robot-assisted implant placement than with free-hand surgery. Platform deviation was 1.17 ± 0.36 mm with robotic placement compared with 1.88 ± 1.12 mm with free-hand placement. Apex deviation was 1.41 ± 0.62 mm versus 2.89 ± 1.64 mm, while angular deviation was $3.46 \pm 3.11^\circ$ compared with $8.23 \pm 7.14^\circ$, respectively [4]. These findings suggest that robotic assistance can reduce positional variability associated with manual implant placement. Further evidence comes from studies examining haptic robotic guidance. Robotic systems have demonstrated promising accuracy in completely edentulous arches, indicating that haptic feedback and robotic positional control may be particularly useful where precise implant distribution is required [5]. The review also reports that different robotic systems demonstrated acceptable deviations in platform, apex, and angular measurements, supporting the potential of robotics for precise implant positioning [1].

The comparison between robotics and dynamic navigation is another important area of development. Tao, *et al.* reported that a robotic system demonstrated superior implant positioning accuracy compared with a dynamic navigation system, with lower entry, exit, and angular deviations [6]. Similarly, the Theta robotic system demonstrated lower angular deviation than a dynamic navigation system in an in-vitro investigation [7]. These findings suggest that robotic systems may provide mechanical stabilization beyond conventional dynamic navigation, where the clinician

remains responsible for manually maintaining the planned drilling trajectory.

However, this evidence requires cautious interpretation. Accuracy in a phantom or laboratory model is not synonymous with improved clinical outcomes. A considerable proportion of the existing literature consists of in-vitro investigations, translational studies, and small clinical series. Xu, *et al.* demonstrated that accuracy and efficiency varied according to the degree of human–robot interaction, with active and semi-active systems demonstrating favorable accuracy compared with passive systems [8]. Nevertheless, larger prospective clinical studies remain necessary to establish long-term safety, efficacy, implant survival, and patient-centered outcomes. Another important development is the comparison of different robotic architectures. Chen, *et al.* reported that the Theta robotic system demonstrated favorable accuracy compared with dynamic navigation, particularly with respect to angular deviation [7,9]. Qiao, *et al.* further demonstrated the accuracy and safety of a haptic-operated, machine-vision-controlled collaborative robot in a translational study [10]. Collectively, these investigations indicate that robotic systems are rapidly progressing from experimental prototypes toward clinically relevant technologies.

Surgical efficiency, however, remains more complex. Robotics may reduce intraoperative variability, but the technology can increase preoperative preparation because of registration, calibration, trajectory planning, and system setup. Available evidence suggests that operative times may be comparable with conventional surgery, whereas preparation time varies according to the robotic architecture [1,8]. Semi-active systems may offer advantages because certain registration and positioning procedures can be automated. Therefore, the relevant question is not simply whether robotic surgery is faster, but whether it provides a superior overall workflow when planning, setup, surgery, training, maintenance, and postoperative care are considered. Another important consideration is the scope of robotic capability. Current systems are particularly suited to planned osteotomy and implant positioning, especially in relatively straightforward flapless procedures. However, implant dentistry frequently requires biological judgment and delicate manipulation of hard and soft tissues. Guided bone regeneration, sinus augmentation, connective-tissue grafting, flap reflection, suturing,

extraction, and management of unexpected intraoperative findings remain predominantly dependent on human expertise [1]. Cost and accessibility also represent important barriers. Robotic systems require considerable investment in hardware, software, training, maintenance, and infrastructure. Physical access may also be problematic in patients with restricted mouth opening and in difficult-to-reach areas such as the second molar region [1]. These limitations raise an important question for clinical practice: does the incremental clinical benefit of robotic surgery justify its economic and logistical burden? The next frontier may be the integration of artificial intelligence with robotic implantology. Artificial intelligence can potentially assist in CBCT interpretation, anatomical assessment, implant planning, and comparison of preoperative and postoperative datasets. A systematic review has identified expanding applications of AI in implant dentistry [11], while deep-learning approaches have demonstrated potential for automated dental implant planning using CBCT images [12]. Nevertheless, increasing automation should not be equated with elimination of the clinician. The ideal future model may instead involve artificial intelligence providing information, robotics providing mechanical precision, and the dentist providing biological judgment and clinical responsibility. Such a human–technology partnership is more realistic and clinically appropriate than the concept of completely autonomous dental surgery.

The future of robot-assisted implantology should therefore be approached as a partnership rather than a replacement paradigm. Robotics can reduce tremor, improve trajectory control, enhance reproducibility, and potentially decrease operator-dependent variability. Yet successful implant treatment involves considerably more than accurate drilling. It requires diagnosis, patient selection, biological understanding, prosthetically driven planning, management of complications, and individualized clinical judgment.

In conclusion, robot-assisted dental implant surgery has progressed from technological novelty toward a clinically relevant component of digital implantology. Current evidence demonstrates encouraging improvements in implant positioning accuracy, particularly when compared with free-hand surgery, while early comparisons with dynamic navigation are also promising [4,6,7]. However, the available evidence remains insufficient to justify unrestricted adoption. Larger prospective clinical trials, standardized accuracy outcomes, long-term implant survival data,

cost-effectiveness analyses, and patient-reported outcomes are required before the full clinical value of robotic implantology can be established. Ultimately, the success of dental robotics should not be measured by how autonomously a robot can operate, but by how effectively technology can augment the clinician's capabilities while preserving human judgment at the center of patient care.

Bibliography

1. Bahrami R., *et al.* "Robot-assisted dental implant surgery procedure: A literature review". *Journal of Dental Science* 19 (2024): 1359-1368.
2. Aydemir CA and Arisan V. "Accuracy of dental implant placement via dynamic navigation or the freehand method: a split-mouth randomized controlled clinical trial". *Clinical and Oral Implants Research* 31 (2020): 255-263.
3. Bolding SL and Reebye UN. "Accuracy of haptic robotic guidance of dental implant surgery for completely edentulous arches". *Journal of Prosthetic Dentistry* 128 (2022): 639-647.
4. Shi JY., *et al.* "Improved positional accuracy of dental implant placement using a haptic and machine-vision-controlled collaborative surgery robot: a pilot randomized controlled trial". *Journal of Clinical Periodontology* 5 (2024): 24-32.
5. Revilla-León M., *et al.* "Artificial intelligence applications in implant dentistry: a systematic review". *Journal of Prosthetic Dentistry* 129 (2023): 293-300.
6. Bayrakdar SK., *et al.* "A deep learning approach for dental implant planning in cone-beam computed tomography images". *BMC Medical Imaging* 21 (2021): 86.
7. Tao B., *et al.* "Accuracy of dental implant surgery using dynamic navigation and robotic systems: an in vitro study". *Journal of Dentistry* 123 (2022): 104170.
8. Xu Z., *et al.* "Accuracy and efficiency of robotic dental implant surgery with different human-robot interactions: an in vitro study". *Journal of Dentistry* 137 (2023): 104642.
9. Chen J., *et al.* "Comparison the accuracy of a novel implant robot surgery and dynamic navigation system in dental implant surgery: an in vitro pilot study". *BMC Oral Health* 23 (2023): 1-9.

10. Qiao SC., *et al.* "Accuracy and safety of a haptic operated and machine vision controlled collaborative robot for dental implant placement: a translational study". *Clinical and Oral Implants Research* 34 (2023): 839-849.
11. Liu L., *et al.* "Robotics in dentistry: a narrative review". *Dental Journal* 11 (2023): 62.
12. Wu Y., *et al.* "Robotics in dental implantology". *Oral and Maxillofacial Surgery Clinics of North America* 31 (2019): 513-518.