

Robotics in Prosthodontics

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Abstract

Advancements in robotics have revolutionized various fields of health care, including prosthodontics. This review explores the integration of robotics into prosthodontic practice, focusing on its applications in designing, manufacturing, and fitting dental prostheses. Robotics offers precise and automated solutions that enhance the accuracy of prosthetic fabrication, leading to improved patient outcomes. Key technologies such as cloud-based robotic system robot and Yomi dental robot are pivotal in this transformation, enabling customized and patient-specific prosthetic solutions. Moreover, robotic systems aid in complex surgical procedures, providing dentists with enhanced dexterity and precision. Challenges such as cost, training requirements, and integration into existing clinical workflows are also discussed. Despite these challenges, the future of robotics in prosthodontics appears promising and can redefine the standard of care and patient satisfaction.

Keywords: Robotics, Prosthodontics, Dentistry.

INTRODUCTION

Robotics, as defined by the National Aeronautics and Space Administration, is a field of engineering and computer science that deals with the creation, manufacturing, and use of robots. It aims to build intelligent devices that can assist people in many ways. Advancements in robotics have allowed for more control over accurate execution, repeatability, and precision, making it more appropriate for use in the health sciences. Although widely employed in the medical field, robotics is still relatively new in dentistry. Commonly, robots are used to guide dentists throughout different treatment processes, such as implant insertion and tooth preparation, or to simulate patients for dental students. Numerous studies are continuously being conducted to improve the utilization of robotics in the field of dentistry.^[1] This article aims to provide an overview of the various applications of artificial intelligence (AI) and robots and their development to date in the complex field of prosthetic dentistry.

HISTORY

The first documented robot used in the medical field that is used for neurosurgery biopsy is a programmable universal machine for assembly 560.^[2] The first approved robot by the Food and Drug Administration (FDA) is an automated endoscopic system for optimal positioning used for endoscopic surgical procedures.^[3] Despite all the advances of robotic technology in the medical field, it is still in infancy in the dental

field.^[4] Dentistry employs a few manual robotic systems that are managed manually through the control interface of the computer. In 2002, Boesecke *et al.*^[5] presented the first robot-guided placement of dental implants. In 2017, YOMI™ (Neocis, Miami, FL, USA) became the world's first computerized navigation robotic system approved by the FDA to augment the clinical accuracy of dental implant surgery.^[6] The first fully automated dental procedure on a human was performed in August 2024 by a robot developed by Perceptive, a US-based company.^[7] Automatic tooth-crown-preparation robots, tooth-arrangement robots, drilling robots, and orthodontic arch wire-bending robots that meet clinical requirements have been developed.

ROBOTS IN COMPLETE DENTURES FABRICATION

Zhang *et al.* devised a robot system in 2001 that is used to fabricate removable full dentures.^[8]

Uses of robotic software were utilized for designing ideal and esthetic prostheses based on the factors such as (1) facial measurements, (2) shade matching (3) patient's desire,

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Received: 5 Oct, 2024; Accepted: 18 Oct, 2024; Published: 5 Nov, 2024

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How to cite this article: Raj DV, Kumar CR, Sujesh M, Lokanath AVR, Harilal G, Kavitha C. Robotics in Prosthodontics. J Res Adv Dent 2025;16(1):1-5.

Access this article online

Website:
www.jrad.co.in

DOI:
<https://doi.org/10.53064/jrad.2024.16.1.615>

(4) optimal function, (5) ideal occlusion, and (6) contacts. The main components of the complete denture robot system are (Figure 1):

1. Control and motion planning
2. 6° of freedom (6-DOF) cloud-based robotic system robot with an arm
3. Electromagnetic gripper
4. Computer with robot modulation software for arranging tooth
5. Denture base
6. Light source device
7. Light-sensitive glue.

ROBOTS AND FIXED PARTIAL DENTURE FABRICATION

The mechanical modification of a diseased, damaged, or faulty tooth to better accept a restorative material that will restore it to a healthy state is known as tooth preparation. These days, precise tooth preparation is achieved while minimizing harm to neighboring hard and soft tissues in the oral cavity by employing a high-speed dental handpiece. Under-reduction compromises restoration, whereas over-reduction damages pulp and soft tissues.

A micro-robot demonstrated a tooth preparation with the error of 0.089 ± 0.026 mm which works by modulating picosecond laser.^[9,10] Yuan and colleagues presented a robot for tooth preparation,^[11] that consists of (Figure 2):

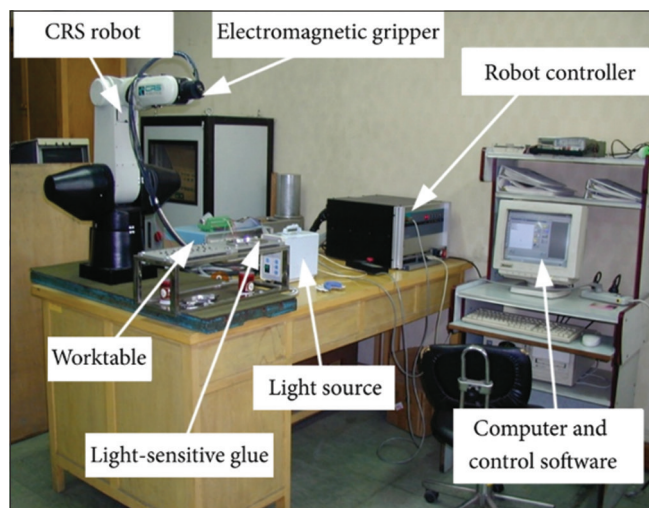


Figure 1: Overview of the components of complete denture Robot



Figure 2: Automatic crown preparation system

- a. Tooth fixture joins that target tooth with the robotic tool
- b. An arm of the robot with 6-DOF
- c. Low-heat laser is recommended for tooth preparation
- d. 3D motion path generated by computer-aided design/computer-aided manufacturing (CAD/CAM) software
- e. For the collection of 3D information, an intraoral scanner is used.

ROBOTS IN DENTAL IMPLANTOLOGY

Although dental implants have been around for decades, the real revolution began in 1980 when Dr. Per Ingvar Branemark discovered osseointegration. Human errors in implant surgery can lead to several complications, including damage to adjacent teeth crowns or roots, inferior alveolar nerve damage in the lower jaw, drilling into the sinus cavity jaw fractures due to insufficient bone or density, pressure or trauma to soft tissues from improper placement or sizing of abutments, and crowns, all exacerbating the implant complications.^[12] Since 1990s, many medical research teams started employing interactive computer programs for implant designing and planning, Sim/Plant, released in 1993, was the first software to allow clinicians to plan and coordinate with computed tomography (CT) scan data for pre-surgical implant placement and prosthodontic visualization. By the late 1990s, robotics extended these applications into mainstream surgery, using sensors for guiding surgical procedures. Chinese-based robot dentist placed implants in patient mouth precisely without human intervention in 2017.^[13]

Robotics applications in implantology may be roughly categorized into:

1. Robot-assisted implantology
2. Fully autonomous implant robots.

Robot-guided implantology

In 2009, the Yomi robot was designed by a USA-based company for guiding implant surgery which was approved by the FDA for use in patients at the chairside (Figure 3).^[14] The implant robot has three fundamental components;

1. Sensors: Which collects information from the environment
2. Effectors: It is the one that actually does the work

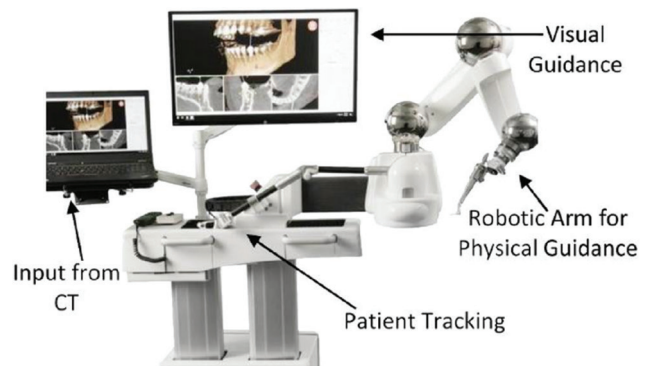


Figure 3: Components of Yomi robot-guided implantology system

3. Control system: It is the main component which understands the input and controls the performance of the robot.

CT is the main information source for the Yomi system. The planning will be done by dynamic software based on information collected from CT by accounting for the important anatomical structures such as nerves, adjacent teeth, sinuses, and blood vessels. The software provides surgical guidelines along with real-time 3-D graphics for navigation. While performing surgery, the robotic arm offers physical guidance, helping the surgeon position and drill to the appropriate depth while confirming progress.

Fully autonomous robotic implantology

For planning and supervision of the dentist's treatment, an autonomous robot was developed which is programmed to move in accordance to the planned position for the successful placement of implants in the correct angle, depth, and position, and also robot moves along the movement of the patient. The working process and software are similar to a guided robot except the autonomous robots perform independently without the involvement of dentist.^[15] In 2014, a Chinese-made robot successfully placed two implants in a woman in an hour with a marginal error of 0.2–0.3 mm in 2017 (Figure 4).^[16]

MICROBOTS FOR DENTAL IMPLANT SURFACES

Application of swarming magnetic micro-robots on dental implant surfaces offers several advantages over conventionally treated implant surfaces, leading to a higher degree of bone-to-implant contact and improved biomechanical fixation which includes biofilm eradication, enhanced surface



Figure 4: Robot placing two implants into a female patient. (Image courtesy: Robot dentist is first to fit implants without human touch; South China Morning Post September 22, 2017)

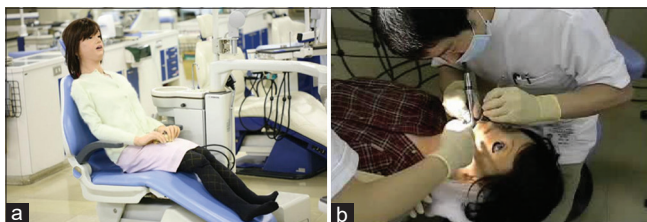


Figure 5: (a) Humanoid patient robot. (b) Training with humanoid patient

topography, increased surface area, controlled surface modification, improved osseointegration, reduced risk of infection, and biomechanical stability.^[17]

SPEECH ROBOTS

A university in Canada developed a speech robot in 2005 which is made of 3-DOF manipulators placed bilaterally and parallelly which drives the temporomandibular disorder (TMJs) simultaneously on both sides. It was created for the study of movements of the jaws for understanding of facial communication.^[18]

HUMANOID PRACTICE ROBOT

One significant challenge in dental education is the approval from the ethical community for using human subjects for training clinically. To address this, humanoid practice robots, such as Simroid, were introduced. These full-body models can be placed on dental chairs and mimic real patients' movements and conversations through computer control. They react and alert students, simulating various accidents during treatment, such as reactions to pain, emesis reflex, cough reflex, and irregular pulse, helping students practice and learn without using human subjects.^[19]

WASEDA JAW (WJ) SERIES ROBOTS

The WJ robot is used to study patients' mastication movements and forces resisting jaw opening and closing training. It is also utilized to evaluate and treat TMJ dysfunctions. The robot features two artificial TMJs, and three DOFs, and can simulate clenching and grinding trajectories. It is powered by 11 artificial muscle actuators, each comprising a DC motor, encoder, wire, and force sensor, designed to replicate muscle contraction forces.^[20]

MOUTH TRAINING ROBOTS

The Waseda-Yamanashi (WY) series of robots were also used to train patients with TMJ disorders by assisting in mouth-opening exercises. The latest versions, WY-5 and WY-6, measure biting force with three translational force components. The device is monitored by a doctor and has two or three DOFs for various movements. Electromyography values of muscles are integrated into the WY robot to track alterations in the patient's masticatory muscles and assess the robotic therapy outcome.^[20]

NANO-ROBOTS IN PROSTHODONTICS

Nanorobotics involves creating robots at the nanometres scale (1 nm = one-millionth of 1 mm). In prosthetic dentistry, nano-impression materials with nano-fillers enhance flow and reduce voids, improving precision in recorded impressions and model pouring. They are utilized also in esthetic dentistry for re-naturalization, replacing previous restorations with biological materials indistinguishable from natural teeth.^[21]

ROBOT-ASSISTED MANUFACTURE OF SURGICAL TEMPLATES

Robot-assisted manufacturing of surgical templates has demonstrated superior clinical results compared to conventional methods. By completely guiding implant trajectory, these templates lower the possibility of human error in clinical practice.^[21]

ADVANTAGES OF ROBOTICS IN PROSTHODONTICS^[22]

- Robots deliver incredibly accurate and reliable outcomes, particularly for placing dental implants
- The variability associated with human performance may be minimized using robots to conduct tasks at a constant quality level
- Digital technology such as CAD/CAM systems may be used with robots to create highly customized and intricate prosthetic designs
- During procedures such as implant placements, robotic technologies allow for more accurate cutting and drilling, resulting in less injury to surrounding tissues
- More accuracy may be achieved in the creation of prostheses by robotic milling and manufacturing techniques, which will enhance the patient's fit and functioning
- Haptic technology-equipped robots can minimize human touch, assisting dentists in more precisely and securely controlling operations
- Robots are revolutionizing prosthodontics using these benefits, resulting in improved patient outcomes and more effective dental treatment.

Limitations

Although there have been great developments in robotics in dentistry, particularly in terms of efficiency and precision, there are still a number of drawbacks. The cost of purchasing and maintaining robotically assisted surgical equipment is high. Dental professionals and personnel frequently need specialized training to operate robotic devices, and integrating them with current systems can be challenging. The limited practical applicability of robotic systems in dentistry arises from their inability to function independently; human supervision is still necessary. Making decisions and managing unforeseen circumstances need human interaction. Insufficient input data constantly increases the possibility of errors. The long-term dependability of dental robots is yet unknown as this technology is still in its infancy. Addressing these challenges is essential for greater acceptance and success.

Future scope of robotics in prosthodontics

- As more prosthodontic procedures get automated in the future, fully autonomous implant insertion and crown fabrication may become possible
- Robotic systems integrating AI can help with decision-making and treatment planning
- The combination of robotics and 3D printing technology will improve the production of highly personalized

prostheses that are suited to the individual demands of every patient

- Prosthetic materials, such as scaffolds for dental restorations or biocompatible tissues, may be bioengineered with the help of robotic systems in the future, opening the door to more robust and natural-looking prostheses
- Robotics and tele-dentistry developments might make it feasible for dentists to do prosthodontic operations remotely.

CONCLUSION

The utilization of robots in the field of prosthodontics can improve the precision and accuracy in all treatment procedures. With the potential to improve precision, efficiency, and personalization in dental treatment, robots in prosthodontics hold great promise for the future. Sustained progress in AI, automation, and digital integration will augment the functionalities of robots, possibly revolutionizing prosthodontic treatments and resulting in enhanced patient outcomes and worldwide accessibility to excellent dental services. However, they are designed to assist prosthodontists during treatment procedures but not to replace them.

REFERENCES

1. Wu Y, Wang F, Fan S, Chow JK. Robotics in dental implantology. *Oral Maxillofac Surg Clin North Am* 2019;31:513-8.
2. Zamorano L, Li Q, Rhiew R. Robotic applications in neurosurgery. In: *Robotics in Surgery: History, Current and Future Applications*. New York: Nova Science Publishers Inc.; 2006.
3. Chadebecq F, Lovat LB, Stoyanov D. Artificial intelligence and automation in endoscopy and surgery. *Nat Rev Gastroenterol Hepatol* 2023;20:171-82.
4. Jiang JG, Zhang YD. Motion planning and synchronized control of the dental arch generator of the tooth-arrangement robot. *Int J Med Robot* 2013;9:94-102.
5. Boesecke R, Brief J, Raczkowsky J, Schorr O, Daueber S, Krempien R, *et al.* Robot Assistant for Dental Implantology. In: *Medical Image Computing and Computer-Assisted Intervention-MICCAI 2001: 4th International Conference Utrecht. The Netherlands: Springer Berlin Heidelberg*; 2001. p. 1302-3.
6. Yeshwante B, Baig N, Tambake SS, Tambake R, Patil V, Rathod R. Mastering dental implant placement: A review. *J Appl Dent Med Sci* 2017;3:220-7.
7. Elgarba BM, Fontenele RC, Mangano F, Jacobs R. Novel AI-based automated virtual implant placement: Artificial versus human intelligence. *J Dent* 2024;147:105146.
8. Zhang YD, Zhao ZF, Lu PJ, Wang Y, Song RJ, Lu JL. Robotic system approach for complete denture manufacturing. *IEEE ASME Trans Mechatron* 2002;7:392-6.
9. Wang D, Wang L, Zhang Y, Lv P, Sun Y, Xiao J. Preliminary study on a miniature laser manipulation robotic device for tooth crown preparation. *Int J Med Robot* 2014;10:482-94.
10. Wang L, Wang D, Zhang Y, Ma L, Sun Y, Lv P. An automatic robotic system for three-dimensional tooth crown preparation using a picosecond laser. *Lasers Surg Med* 2014;46:573-81.
11. Yuan F, Wang Y, Zhang Y, Sun Y, Wang D, Lyu P. An automatic tooth preparation technique: A preliminary study. *Sci Rep* 2016;6:25281.
12. Troisi RI, Patriti A, Montalti R, Casciola L. Robot assistance in liver surgery: A real advantage over a fully laparoscopic approach? Results of a comparative bi-institutional analysis. *Int J Med Robot* 2013;9:160-6.
13. Sreelekshmi S, Varghese K, Abraham JP, Jaysa JJ. Applications of

- robotics in prosthodontics-a review. *Int J Innovat Res Adv Stud* 2017;4:38-41.
14. Natarajan M. A review of robotics in dental implantology. *J Indian Dent Assoc* 2018;5:14-7.
15. Yuan FS, Wang Y, Zhang YP, Sun YC, Wang DX, Lyu PJ. Study on the appropriate parameters of automatic full crown tooth preparation for dental tooth preparation robot. *Zhonghua Kou Qiang Yi Xue Za Zhi* 2017;52:270-3.
16. Liu L, Watanabe M, Ichikawa T. Robotics in dentistry: A narrative review. *Dent J (Basel)* 2023;11:62. Robot Dentist is First to fit Implants Without a Human Touch. *South China Morning Post*; 2017. Available from: ??? [Last accessed on 2018 Jan 07]. Ventola CL. Medical applications for 3D printing: Current and projected uses. *P T* 2014;39:704-11.
17. Mayorga-Martinez CC, Zelenka J, Klima K, Mayorga-Burrezo P, Hoang L, Ruml T, *et al.* Swarming magnetic photoactive microrobots for dental implant biofilm eradication. *ACS Nano* 2022;16:8694-703.
18. Mahule A, Shaikh A, Avinash S, Jaykumar G, Vandana G. Robots in prosthodontics: A scientific fiction or reality? *Int J Res Technol* 2021;9:16-22.
19. Takanobu H, Okino A, Takanishi A, Madokoro M, Miyazaki Y, Maki K. Dental Patient Robot. In: 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems. Beijing: IEEE; 2006. p. 1273-1278.
20. Li Y, Inamochi Y, Wang Z, Fueki K. Clinical application of robots in dentistry: A scoping review. *J Prosthodont Res* 2023;68:193-205.
21. Chandu GS, Mathew NT, Sarathe J, Ramteke A, Gir M. Robotics: A next-generation technology in prosthodontics. *Int J Sci Study* 2023;11:7-13.
22. Karnik AP, Chhajer H, Venkatesh SB. Transforming prosthodontics and oral implantology using robotics and artificial intelligence. *Front Oral Health* 2024;5:1442100.