Review Article

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Robotics in Dentistry: A Review

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ABSTRACT

In recent years, robotics has emerged as a transformative force in the field of dentistry, revolutionizing many aspects of clinical practice and advancing patient care. This review provides an overview of the current state and future prospects of robotics in dentistry, focusing on applications such as robotic-assisted surgery, automated orthodontic procedures, and precision diagnostics. Highlighting technological advancements, we examine how robotics enhances precision, reduces procedural time, and increases safety in dental procedures. Additionally, the review addresses challenges such as high costs, the need for specialized training, and ethical considerations surrounding robotic integration into dental practices. By analyzing current research, this article aims to present a comprehensive understanding of the benefits, limitations, and impact of robotics in dental care. Future prospects and innovations are also discussed, paving the way for an increasingly automated and efficient dental industry.

Introduction:

The integration of robotics into dentistry marks a significant evolution in clinical practices, offering renewed approaches to traditional methods. As dental care demands precision and dexterity, the introduction of robotic assistance has introduced unparalleled advancements, significantly transforming the patient care landscape. Robotics, defined as the integration of mechanical devices operated via software algorithms to perform various tasks, has increasingly permeated multiple medical fields, including dentistry, due to its potential to enhance operational precision, safety, and outcomes.[1,2]

The rapid growth of robotics in dentistry can be attributed to several factors. Technological advancements in artificial intelligence (AI), machine learning, and sensor technologies have enabled the development of sophisticated robotic systems capable of performing complex dental procedures with enhanced accuracy and minimal human intervention. These innovations offer particular promise in areas such as surgical procedures, orthodontics, and diagnostics, where precision is critical.[1]

This review aims to explore the multifaceted impact of robotics in dentistry by examining the current applications, technological advancements, benefits, challenges, and future potential. Robotic systems in dentistry are increasingly

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utilized for tasks requiring high precision, such as implant surgery guidance, endodontic treatments, and intricate orthodontic adjustments. This not only aids in achieving more consistent and replicable outcomes but also mitigates the risks of human error.[2]

However, the transition to robotic-assisted dentistry is not without its challenges. Issues such as the cost of implementation, necessary infrastructural changes, and the need for specialized training are significant barriers to widespread adoption. Moreover, ethical considerations concerning patient safety and data privacy remain at the forefront of discussions regarding robotics in dental practices.[3,4]

By thoroughly reviewing current research and innovations, this paper seeks to delineate the transformative role of robotics in dentistry, laying the foundation for future advancements. Emphasizing both the challenges and the promising trajectory of robotics integration, the review aims to shed light on how dentistry is approaching a new era, marked by technological prowess and enhanced patient care. Through understanding these dynamics, dental practitioners, researchers, and policymakers can better navigate the expanding capabilities and implications of robotics in this essential field.

History of Robotics: Robot-assisted surgery began with groundbreaking research at the National Aeronautics and Space Administration (NASA). A remotely operated robotic device was created by NASA in the mid-1980s to perform surgical operations on both astronauts and troops in space. In the 20th century, the term "robot" was coined. The word "robot" was originally derived from the Czech word "Robota," which means "labor" or "drudgery," and was first used in the science fiction novel Rossum's Omnipotent Robots, written by Czech author Karel Capek and published in 1920. In 2000, the first robotic system for laparoscopic surgery in a doctor-robot arrangement was authorized by the FDA in the United States. A transcontinental live robotic cholecystectomy was used in 2001 to validate the doctor-robot idea. It was the first time a group of surgeons performed telepresence surgery on a patient in another location.[1-3]

Various Robots in Dentistry:[1,4,5]

1. Dental training robot: Dental therapy training is currently being conducted using patient robots. Clinical instruction uses the so-called "phantoms," which are composed of a tooth arrangement and a basic functional cephalic area.

2. Realistic humanlike robots: Dental students can experience what it's like to work with a real patient by using the realistic robot Showa Hanako, which is made to mimic a variety of common patient gestures and responses. Other robotic innovations, like the Geminoid, which has sophisticated motion capture technology, can be controlled remotely. The Geminoid F, another member of the Geminoid family, can even replicate human laughter and facial emotions. Other robots, such the HRP-4, have mastered the ability to sing and imitate human sounds and facial expressions.

3. SIMROID: SIMROID, a potential next-generation training model, is a perfect supplement to dental education. This incredibly lifelike dentistry training robot is actually an improvement over Simuloid, a less advanced model that was developed in 2007. With two cameras tracking the students' every move and data from its sensors being collected during the process, it can rate and assess the treatment.

4. Endo Micro Robot: By avoiding issues with traditional methods including insufficient opening and excessive tooth extraction, micro endodontic robots can provide patients safe, precise, and dependable root canal therapy. This machine will carry out the autonomous root canal drilling, cleaning, filling, and probing with intelligent management and online monitoring. Reducing the need for the dentist's expertise, eliminating human error, and providing a means of accurate diagnosis and treatment are some of the specific goals for microrobot design.

5. Dental Nanorobots: Nanorobots are tiny machines made of nanoscale or molecular components that are measured in nanometers. The application of nanotechnology to local anesthesia, dentition renaturalization, permanent hypersensitivity treatment, full orthodontic realignment in a single visit, covalently bonded diamondized enamel, and ongoing oral health maintenance with mechanical dentifrobots are some potential treatment options. Dental nanorobots, which are controlled by computers, could be used to eliminate bacteria that cause cavities or to fix tooth imperfections where decay has already begun.

6. Surgical Robots: For maxillofacial surgery, a surgical robot system has been designed that allows the surgeon to interactively train the robot during the procedure, after which the robot carries out the preprogrammed duties. Orthognathic surgery planning, bending, intraoperative positioning in predetermined positions, deep saw osteotomy cuts, milling bone surfaces, and drilling holes are all done with robotic techniques.

7. Dental implant robots: Depending on how much human-robot contact there is, it can be divided into active, passive, and semiactive systems. A. Active Robots: YekeBot (YekeBot Technology Co., Ltd., Beijing, China) is one example. These autonomous robots are able to prepare the implant site, put the implant, and enter and exit the mouth. The operator's main responsibilities include changing the drill, giving directions, and keeping an eye on the robot's progress. B. Passive robots: During the process, the operator must control the robotic arms of robots like Yomi (Neosis Inc., Miami, United States) and DentRobot (Dcarer Medical Technology Co., Ltd, Suzhou, China). The operator is in charge of the robot's mouth entry and exit, implant site preparation, and implant placement. C. Semi-active robots: Implant site preparation and insertion can be done autonomously by semi-active implant robots, such as the Remebot implant robot (Baihui Weikang Technology Co., Ltd, Beijing, China). However, in order to manipulate the robotic arm during mouth entry and departure, these robots need the operator's help.

Application of Robots in Dentistry[1,3,5-12]

Prosthodontics: The creation of tooth-preparation and tooth-arrangement robots has been the primary focus of recent research; their high standards, high intelligence, precision, and other benefits have made them the development direction for intelligent prosthodontic therapy.

1. Tooth-crown preparation robots: LaserBot, a microrobot device, was introduced in 2013. In order to accomplish clinical tooth-crown preparation, this robotic apparatus precisely controlled the motion of a femtosecond laser beam in three dimensions (3D). Moreover, the device may be put on any tooth because to its modest size. However, this robotic system's ablation time was far longer than anticipated. Using 3D motion planning software, the same team created an automated tooth-preparation robot that is precisely controlled by an ultra-short pulse laser. The average preparation time for freshly extracted human entire first molars has been reduced to 17 minutes, while also guaranteeing the precision and viability of tooth preparation.

2. Tooth–arrangement robots: To successfully create a perfect dental arch for the patient, Zhang et al. created a robotic manufacturing technique to position teeth for complete dentures. First, tooth-arrangement software was used to create control data and gather the patient's jaw arch parameters. The fake teeth, tooth-arrangement aid, and intermediate blocks were then retrieved and put together by the robot. Ultimately, a fixed tooth arch was achieved by pouring wax into the tooth-arrangement helper, transforming the entire denture. The development of tooth-arrangement robots saw notable advancements thanks to the same team. A tooth-arrangement robot with five-DOF mechanisms in parallel and series architectures was presented in 2008, and kinematic equations were established. In 2009, the use of a multi-manipulator for tooth arrangement was suggested. In 2010, a tooth-arrangement robot arch generator's high-precision coordinated motion control was examined employing high-resolution timing control pulses.

3. Robotic articulator: A novel kind of robotic articulator replicates the patient's functional mandibular movement with six DOF using an exact six-axis micropositioning stage. This articulator technology eliminates the requirement for intraoral occlusal setup changes when fabricating a complete veneer crown repair. The device may increase the precision of denture occlusion since the articulator can faithfully replicate dynamic jaw motions during functional jaw movements. However, more research is required to evaluate this approach because just one case has been investigated.

Oral Implantology:

In order to help with dental implant treatments, dental implant robots provide a variety of features and technologies that increase accuracy and efficiency (such as operation and preparation time) in implant placement. On the other hand, a study by Qiao et al. shed some light on how robots affect surgical time. They discovered that the surgical procedures required about 20 to 25 minutes for the implantation of a single tooth implant, and 47 to 70 minutes for the placement of two edentulous arches. Numerous dental implant robots, such as the following, have been developed and put into use:

1. YekeBot dental surgery robot: YekeBot is a sophisticated robotic system created by Yekebot Technology Co., Ltd. (Beijing, China) for the express purpose of helping dental surgeons place dental implants precisely. This robot has a robotic arm that can drill holes and install implants in addition to entering and leaving the patient's mouth on its own.

2. Autonomous robotic computer-assisted implant surgery (r-CAIS): The Remebot robot serves as the foundation for the sophisticated dental surgery robot known as r-CAIS, which has been modified to become an active robot. It is intended to carry out implant placement and osteotomy under the guidance of the physician during surgery. The two systems that make up r-CAIS's technology are task autonomy and robot assistance. A semi-active robot, such as the Remebot robot, which has an operating arm and a coordinate measurement machine arm, is used in the r-CAIS robot assistance system. During the implant osteotomy procedure, the surgeon receives visual assistance and haptic feedback from this technology. The operating arm is still continuously under the surgeon's supervision, though, which might lead to mistakes and be difficult to control. Conversely, the surgeon has discrete control over the r-CAIS system thanks to the task autonomous robotic system. With this technology, the robotic system performs the implant osteotomy duty on its own after the surgeon designates the implant placement site. The surgeon's job is to keep an eye on the process and step in if needed. All things considered, r-CAIS is an active dental surgery robot that improves the accuracy and productivity of implant osteotomy and placement procedures by fusing task autonomy with robot support.

3. Yomi dental surgery robot: The passive implant robot Yomi was created in the US by Neocis. It is made especially for dental surgery and helps with the accurate placement of a

dental implant by using a coordinate measurement machine (CMM) arm. A CMM arm that automatically places the implant and an operational arm that surgeons physically control make up the Yomi system. The U.S. Food and Drug Administration (FDA) approved Yomi in 2017, stating that it satisfies safety and efficacy requirements.

4. DentRobot dental surgery robot: A passive implant robot called DentRobot was unveiled by Dcarer Medical Technology Co., Ltd. in 2022 with the purpose of helping with dental implant surgeries. The surgeon controls the robot with a foot controller, which makes use of optical tracking technologies. To prepare the implant site and insert the implant, the surgeon physically maneuvers the robotic arm into the patient's mouth. The robotic arm gives the surgeon three-dimensional physical direction during drilling.

5. Remebot dental surgery robot: In 2023, the semi-active implant robot Remebot was unveiled by Baihui Weikang Technology Co., Ltd. (Beijing, China). Remebot was created especially to help in dental implant preparation and implantation. The surgeon guides and pulls the robotic arm into the patient's mouth using a foot controller to control Remebot.

6. Theta dental surgery robot: In 2023, Hangzhou Jianjia Robot Co. LTD created the Theta robotic dental implant system, a semi-active robot made especially for dental implant operations. Dental implants may be positioned, drilled, and placed precisely thanks to the combination of control buttons and an optical navigation system.

7. Humanerobot collaborative implant system (HRCDIS): A semi-passive robot called HRCDIS was created for human-machine cooperation. It combines an operational job management system with a zero-force hand-guiding technique. The robot makes use of a modified Universal Robots UR5 Cobot and a visual position tracking system that includes an optical camera and positioning marker.

8. Langyue dental surgery robot: Shecheng Co. Ltd. created the semiactive collaborative Langyue dental surgery robot with the express purpose of supporting dental surgeons during surgeries. In order to maximize the surgical procedure, it combines both autonomous and passively induced actions. The robot can do duties including sensing patient mobility, guiding drilling, and positioning the robotic arm and infrared tracking probe on its own. However, the actual drilling process necessitates human cooperation. The surgeon uses a haptic controller to fully control the drill's pressure and speed, and they start the drilling process by lightly pressing the handpiece.

9. Hybrid robotic system for dental implant surgery (HRSDIS): A semi-active robot called HRS-DIS was created in Shanghai, China. It is made up of a 6-DOF Stewart manipulator and a 5-DOF serial manipulator. The Stewart manipulator guarantees exact placement and rigidity, while the serial manipulator increases the robot's work area. Using a force transducer, the surgeon can physically control the robot's motions through a handpiece that is connected to the Stewart manipulator.

Operative Dentistry:

1. Detection of dental caries: Numerous studies on the identification of dental caries, vertical root fractures, apical lesions, pulp space volumetric assessment, and tooth wear evaluation have been conducted in the field of operative dentistry. Each grayscale pixel in a two-dimensional (2D) radiograph has an intensity, or brightness, that indicates the object's density. An artificial intelligence algorithm may identify patterns and make predictions based on these features. In a study by Lee et al., they used a deep learning-based convolutional neural network (CNN) algorithm to diagnose and detect dental caries. They found that the deep CNN algorithm performed very well in identifying dental caries in periapical radiographs.

2. Nanorobots: Dental robotics, endodontic and conservative dentistry, cavity preparation and restoration, local anesthetic, dentin hypersensitivity, single-visit orthodontic realignment, tooth repair, and local drug delivery are all applications for nanotechnology-based dental nanorobots. The nanoscopic dental robots provide precise and timely care.

Endodontics: The development of micro-endodontic robots, a type of robotics used in endodontic treatment, can help patients receive more dependable, accurate, and safe root canal therapy by overcoming the drawbacks of conventional treatment, such as inadequate mouth opening. The "Omni Phantom," a robot equipped with a haptic virtual reality simulator, has been created to facilitate effective endodontic treatment training. The user can experience the process of cleaning the inner surface of the root canal and burring the enamel and dentin by using a simulated K-file. "The Advanced Endodontic Development" is the name of the proposal that Hong Seok of Columbia University proposed. The goal of this project was to create an intelligent microrobot that could treat endodontics on its own. Dong et al. talked about this robot's inventions, manufacturing process, and mechanical design. The conceptual design calls for mounting the robot on a number of the patient's teeth while using two-dimensional radiography images to create a three-dimensional tooth model. The treatment processes will be designed by a prescription system, and the microrobot will drill and fill the root canal automatically. The design and production of microsensors and actuators, however, still need more investigation.

Oral & Maxillofacial Surgery: In oral and maxillofacial surgery, robots are primarily used for the following tasks: accurately segmenting, reshaping, displacing, and fixing the craniofacial bone in accordance with the surgical plan; analyzing the characteristics of the lesion; and acquiring and reconstructing 3D image data of the oral and maxillofacial prior to the procedure. Oral and maxillofacial surgery has effectively employed robotics, and robots for specialized procedures like velopharyngeal surgery are also being developed.

1. Detection and diagnosis of oral cancer: Most often, surgical resection is necessary for malignant lesions. Early diagnosis and detection of mucosal lesions are crucial for preventing surgery. Sometimes lesions with similar appearances need to be definitively diagnosed by biopsy or radiography.

2. Robotic dental drill: In order to locate the alveolar bone in a patient with a restricted jaw, a very tiny needle is utilized to puncture the gum. A great degree of accuracy was demonstrated by a robot (KUKA, Augsburg, Germany) that was pre-programmed for fibula free-flap mandible restoration.

Periodontics:

1. Tooth cleaning robots: The robotic system's ability to provide repeatable, noteworthy variations in the cleaning effectiveness of powered toothbrushes was demonstrated by a number of in vitro tests. Artificial teeth covered with a material that simulates plaque were brushed by a six-axis robot that was programmed with specific clinical toothbrushing protocols.

Orthodontics arch wire bending robots: Orthodontic archwires can also be bent with this robotic technology. Arch wires can be bent by the SureSmileArchWire bending robot. Likewise, a heater in "LAMDA (Lingual Archwire Manufacturing and Design Aid)" can heat a nickel-titanium archwire to 600°F and bend it in six minutes.

Oral Radiology: Oral radiologists are generally thought to be able to minimally invasively enter the oral cavity and reach practically every part of the tooth. The use of robots has several advantages: (a) the oral radiologist can be located far from the site of the radiography procedure, preventing radiation exposure; (b) robotic systems have been developed with multiple degrees of freedom for navigation, which improves their dexterity compared to humans. As a result, radiography instruments would be safer, easier, and simpler to navigate in teeth with complicated morphology and anatomy. A 6-DOF robot arm was recommended for positioning the X-ray source and sensor/film, and no adverse effects were noted.

Limitation:[1,3]

1. Possible patient risk: Inadequate data storage, circuit disruption, or data errors can interfere with patient care. However, robots cannot perform some complex tasks by themselves, such as retrieving a broken file from a tooth during a root canal or performing bone transplants for implant patients. In these situations, dentists' effectiveness over dental robots is still crucial.

2. Absence of research data and recommendations: They are not very important because there are no standards or criteria for machine learning investigations. Therefore, it is advised that reporting standards and procedures be established for machine learning research pertaining to dentistry.

3. Problems with trust: Robots are machines, not people. It is incorrect, in the opinion of the patient, to place entire trust and confidence in a computer that will perform tasks more accurately and effectively than a physician.

4. Expensive: Both the patient and the physician must pay a high price for mechanical advancements in clinical and dental applications. Robotic technology is not used in the majority of routine and repeated treatments, including as scaling, curettage, restoration, and bonding orthodontic wires in the oral cavity. Using robots for tiny and repetitive chores might be quite expensive for the patient.

5. Concerns about security or privacy and the moral conundrums: There is also discussion over the moral conundrums raised by using robots to diagnose and treat patients in place of people.

Conclusion:

The use of robotics in dentistry compensates for the shortcomings and limitations of manual procedures by offering more precise and sophisticated movements than the human hand can provide. It is an extension of the functions of the human hand and eye. Robodentistry affects dentistry in both positive and negative ways. By helping dentists with oral examinations, diagnosis, and treatment planning, as well as by performing minor procedures on patients to reduce errors and improve the overall caliber and volume of patient care, it can, on the one hand, improve patient outcomes. However, there are a number of privacy, safety, and health issues that limit their usage in dentistry on their own. Despite being discussed and used in many fields, the robotic world of accuracy and precision still has a number of drawbacks. Human replacement by robots is viewed as science fiction in poorer nations. The pursuit of progress never stops. Therefore, robotic dentistry is a science fantasy concept that may soon become a reality.

References

Liu L, Watanabe M, Ichikawa T. Robotics in Dentistry: A Narrative Review. Dent J (Basel). 2023 Feb 24;11(3):62.

Grischke J, Johannsmeier L, Eich L, Griga L, Haddadin S. Dentronics: Towards robotics and artificial intelligence in dentistry. Dent Mater. 2020 Jun;36(6):765-778.

Mayta-Tovalino F, Munive-Degregori A, Luza S, Cárdenas-Mariño FC, Guerrero ME, Barja-Ore J. Applications and Perspectives of Artificial Intelligence, Machine Learning and "Dentronics" in Dentistry: A Literature Review. J Int Soc Prev Community Dent. 2023 Feb 27;13(1):1-8.

Lumbini P, Agarwal P, Kalra M, Krishna KM. Nanorobotics in dentistry. Ann Dent Spec 2014;2:956.

Adel S, Zaher A, El Harouni N, Venugopal A, Premjani P, Vaid N. Robotic Applications in Orthodontics: Changing the Face of Contemporary Clinical Care. Biomed Res Int. 2021 Jun 16;2021:9954615.

Shetty NJ, Swati P, David K. Nanorobots: Future in dentistry. Saudi Dent J 2013;25:4952.

Bansal A, Bansal V, Popli G, Keshri N, Khare G, Goel S. Robots in head and neck surgery. J Appl Dent Med Sci 2016;2:16875.

Ahmad P, Alam MK, Aldajani A, Alahmari A, Alanazi A, Stoddart M, Sghaireen MG. Dental Robotics: A Disruptive Technology. Sensors (Basel). 2021 May 11;21(10):3308.

Rawal, S.; Tillery, D.E., Jr.; Brewer, P. Robotic-Assisted Prosthetically Driven Planning and Immediate Placement of a Dental Implant. Compend. Contin. Educ. Dent. 2020, 41, 26–30.

Sun, X.; Yoon, Y.; Li, J.; McKenzie, F.D. Automated image-guided surgery for common and complex dental implants. J. Med. Eng. Technol. 2014, 38, 251–259.

Adel S, Zaher A, El Harouni N, Venugopal A, Premjani P, Vaid N. Robotic Applications in Orthodontics: Changing the Face of Contemporary Clinical Care. Biomed Res Int. 202

Cheng C, Yinan X, Zongxin X, Lei S, Yanan X, Yanli Y. Robotic and Microrobotic Tools for Dental Therapy. J Healthc Eng. 2022 Feb 18;2022:3265462.1