International Journal of Dental Sciences
www.dentaljournal.in
E-ISSN: 2663-4708, P-ISSN: 2663-4694
Received: 25-12-2024; Accepted: 24-01-2025; Published: 08-02-2025
Volume 7, Issue 1, 2025, Page No. 40-42

Robotic dentistry, revolutionising the future of dentistry

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Abstract

Robots and artificial intelligence (AI) have revolutionised modern dentistry and are crucial in areas such as CAD-CAM technology, 3D printing, dental implants, dental imaging, and education. It uses a variety of human- robot communications such as Artificial Neural Network, resembling the human nervous system, haptics etc. for making an environment possible where robots can understand human emotions and responses. These advancements have significantly increased accuracy, efficiency, and improved patient care. There are certain disadvantages despite its many benefits, such as sudden communication breakdowns and technical malfunctioning, lack of an intuitive approach anda weak patient-physician bond. Both benefits and challenges of robotics in the field are analysed in this article.

Keywords: Robotics, dentistry, artificial intelligence, precision, CAD CAM,3-D printing, software, hardware, artificial neural network, robot assisted surgery

Introduction

Originally developed during the Industrial Revolution, Robotics has since developed into useful instruments in many different domains and have become an indispensable tool across multiple fields, including dentistry. The initial robotic systems in dentistry were basic machines built to assist with tasks such as drilling and cutting. While they contributed to specific procedures, they lacked the accuracy and adaptability, which is seen in modern dental robotics. These early devices primarily aimed to streamline workflow rather than substitute human involvement in treatments or surgeries [1].

These systems usually consist of software and hardware, which work together to guarantee precise treatment planning and implementation. The most basic hardware component is the robotic arm or surgical platform, which is outfitted with precision motors, actuators, and sensors to allow highlycontrolled movements. Software component includes Computer Aided Design (CAD) and Computer Aided manufacturing (CAM). Together with the imaging, this generate a 3D model of the patient's anatomy to guarantee that the robotic arm's actions are tailored to meet the needs of the patient [2]. This era also saw the rise of 3-D printing machines, which uses additive manufacturing methods using the same CAD software along with the help of advanced imaging like intra- oral scanners and CBCT [3].

Jenkins was the first to incorporate them into dental practice in 1967, opening the door for intelligent robots powered by artificial intelligence. A significant milestone came in 2017 with the development of the Yomi dental surgery robot by Neocis in Miami, marking the first FDA-approved robotic system for dental procedures [4]. Another ground-breaking achievement occurred in Barranquilla, Colombia, in 2024, where the US-based company Perceptive successfully performed the first fully automated dental procedure on a human using a robotic arm, artificial intelligence, and 3D imaging.

These technological advancements are designed to support rather than replace human expertise, improving both precision and efficiency. The goal of this study is to present a thorough examination of the available data in order to extract knowledge that will aid in choosing the course of future research.

Human-robot communication

Humans and robots can communicate in a variety of ways. Physical human-robot interaction (pHRI) is the physical interaction between humans and robots which has grown in importance in contemporary robotics and will be crucial for AI-DENTBOTS applications [5]. Here are some of the examples of pHRI -Patient tracker built into the robotic system tracks the patient's movement and gives real-time feedback, while haptic feedback permits physical direct ion. Furthermore, there are physical interactions or contact-based interactions, such as the usage of buttons and graphical interfaces and contact-free interactions, such as visual engagement based on RGB-D camera systems or comparable technologies such as infrared, which have been studied for years. AI deals with computerised models that can think and perform tasks rationally. The human nervous system serves as the inspiration for Artificial Neural Networks (ANNs), which are highly interconnected networks of computer processor systems. They solve complex problems that cannot be solved by algorithms [6].

Role of robotics in dentistry

Dentistry is undergoing a rapid transformation because of the integration of AI and robotics, which holds promise for improved accuracy, productivity, and patient-centred treatment in the future. AI-driven dental robots have a wide range of potential uses as technology develops, transforming everything from diagnosis to treatment delivery and post-operative care [7].

Use of robotics in surgery

Robot Assistant Surgeries (RAS) enhance precision for better outcomes and decreased invasiveness for improved patient safety. Theytackle issues that human operators encounter, like poor vision, operator exhaustion, and inexperience, all of which can result in mistakes. It's use in surgery covers a wide range, used in minimally invasive surgeries for tumor removal, reconstruction, trauma care, non- pathological conditions like obstructive sleep Apnea, implant placement and more, enabling better accuracy and faster recovery. Surgical procedures can be more predictable and less- invasive with the use of surgical guides, this directs the instruments to correct location [8, 9].

In the treatment of Head and neck tumors, especially those affecting the pharynx and larynx, can significantly impact a person's ability to speak and swallow. Traditional surgery often involves removing these vital structures, leading to potential speech and swallowing difficulties. However, robotic surgery offers a less invasive approach. By utilizing small incisions and robotic arms, surgeons can precisely target and remove tumors while minimizing damage to surrounding tissues. This technique has shown promising results in preserving speech and swallowing function in patients with head and neck tumors [10].

Precise implant placement, including accurate angulation, depth, and positioning, is crucial for successful dental implant outcomes, contributing to stability, durability, and aesthetics. Robotic assistance in implant surgery offers significant advantages, particularly in challenging cases. For example, patients with limited mouth opening, or those requiring complex angulations, present difficulties for traditional implant procedures. These situations can lead to poor ergonomics for the surgeon, increasing the risk of human error and operator fatigue. Robotic systems address these issues by providing enhanced precision and control, enabling surgeons to achieve optimal implant placement even in difficult anatomical situations [11]. This increased flexibility in implant placement is a major benefit of robot-assisted surgery. Several robotic systems are currently available or in development for dental implant procedures, including YekeBot, Yomi, and Dent Robot. These technologies promise to improve patient outcomes and expand the scope of treatable case [12].

Role in restorative and endodontic procedures

In restorative dentistry, innovations have led to better-fitting crowns, bridges, and veneers, improving both aesthetics and functionality. Similarly, endodontics has seen remarkable progress, allowing for more accurate root canal procedures that minimize risks and enhance patient outcomes. These developments are transforming dental care, ensuring longer-lasting restorations and more predictable treatment results [13].

Combining robotic systems with state-of-the-art laser technology, such as picosecond lasers, represents a significant shift. With the use of these devices, full-crown preparations can be done automatically and with extreme precision, reaching cutting depths of about 60 μm for resin teeth and 45 μm for genuine teeth. It takes less than twenty minutes to complete these preparations. The advancement of robotic arms for mechatronic systems helps dentists address issues like weariness and shaky movements that can lower the standard of dental practice [14].

The Endo micro robot are tiny robots used in endodontic treatments. It uses online monitoring and an intelligent system to perform autonomous drilling, cleaning, shaping, and three-dimensional filling of the root canal system giving error- free outcomes, it consists of micro position and orientation adjustment equipment, a journey distance controller, microsensors, an automatic feed rate, and apex sensors with flexible hoover and drill attachments [15].

Role in orthodontic corrections

Orthodontics gains efficiency in bracket placement and aligner creation, leading to shorter treatments and increased comfort. In 2004, Butscher and colleagues created SureSmile, the first wire-bending robot. The LAMDA system, another modern machinery, makes wire bending quick and accurate, also capable of bending archwire in two planes. Furthermore, painless tooth movements made possible by Nanorobotics to improve patient comfort. Additionally, robots are essential to the production of aligne rs since they guarantee prompt treatment modifications and i ncreased orthodontic care efficiency [16].

Role in imaging

AI driven robots and advanced imaging techniques work in conjunction with each other. It's integration with CBCT enhances diagnostic accuracy and visualization of complex structures.X-ray imaging using robotic system gave excellent accuracy than the mechanical adjustments [17]. It plays important role in virtual treatment planning, intra-oral scans and the CBCT scans provide with detailed characteristics of complex antomical structures, which is later used to make study models, surgical guides, prosthesis etc.

Impact on educational purposes

Dental education is revolutionized through real-time simulation and feedback, fostering better skill development in a safe learning environment. The SIMROID, with its 86 motions and expressions, mimics a human being, making it an intriguing addition to dental treatment. It can make jaw, tongue, elbow, and wrist motions, roll its eyes, blink, shake its head in distress, and vocalise pain and discomfort therefore giving emotional feedbacks. Additionally, using a uvula sensor, it may mimic the vomiting reflex as well as functions that cause bleeding and salivation [18]. Tanzawa, *et al*. unveiled a medical emergency robot to aid dental students in becoming accustomed to emergency circumstances [19]. As early as the year 2000, 3D printers were used for medical modelling and create intricate models of the patient's jaws. This makes it possible to thoroughly examine anatomy—especially intricate, uncommon, or unfamiliar anatomical structures—and prepare or practise a surgical strategy prior to surgery. As a result of which new surgical techniques and procedures have been developed [20].

Challenges and limitations

Robotic dentistry, while offering potential advancements in precision and efficiency, faces several significant challenges. Technical vulnerabilities, such as system malfunctions, power outages, and connectivity issues, can disrupt robotic operations, potentially jeopardizing patient safety and treatment outcomes. Moreover, the inherent limitations of artificial intelligence become evident in the inability of robots to adapt to unforeseen circumstances or

interpret subtle patient cues, unlike human clinicians who possess critical thinking and adaptability. Ethical and legal problems such as determining liability for errors and safeguarding the privacy and security of patient data gathered and used by robotic systems are critical. The high cost of robotic systems poses a significant barrier to widespread adoption, potentially increasing treatment costs for patients and exacerbating disparities in access to advanced dental care. Furthermore, effective utilization of robotic systems necessitates specialized training for dentists, which can be time-consuming and expensive. Over-reliance on technology may lead to a decline in manual skills and increase the risk of operator errors [21].
The psychological impact on patients cannot be ignored. The presence of robots may induce anxiety and discomfort, potentially diminishing the patient-dentist relationship and hindering effective communication and trust-building. The focus on precision in robotic procedures may inadvertently lead to overtreatment, subjecting patients to unnecessary procedures. Finally, the scope of application for robotic dentistry is currently limited. While excelling in specific procedures, robots may not be suitable for all dental interventions, particularly those requiring significant adaptability, creative problem-solving, and nuanced clinical judgment [22, 23].

Conclusion

The application of artificial intelligence and robotics in dentistry has reshaped perspectives on dental treatments. The general public anticipates a greater use of robots in operative procedures, while practitioners appreciate their potential for enhanced job satisfaction and educational benefits, while robotics are expected to play a crucial role in the future of dental care, there is still a lack of extensive outcome-based research in this field. Furthermore, concerns regarding the accuracy and dependability of dental robots persist, as potential software or hardware failures could lead to complications. Therefore, further studies are essential to ensure their safe and effective integration into dental practice, maintaining a balance between automation and human judgment for the best patient outcomes.

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