Review Article

Application of Robotics in Dentistry – A Narrative Review

K Chandrasekharan Nair¹*, Hemalatha Konka², Viswanath Gurumurthy³, Pradeep C Dathan⁴ and Murukan PA⁵

¹*Professor Emeritus, Department of Prosthodontics, Sri Sankara Dental College, Akathumuri, Thiruvananthapuram, Kerala, India*

²*Registrar Prosthodontist, Al Harkan Dental Hospital, Al Qassim, Saudi Arabia*

³*Professor, Department of Dental Technology, College of Applied Medical Sciences, King Khalid University, KSA, Saudi Arabia*

⁴*Professor and Head of the Department of Prosthodontics, Sri Sankara Dental College, Akathumuri, Thiruvananthapuram, Kerala, India*

⁵*Former Professor, Department of Prosthodontics, Annoor Dental College, Muvattupuzha, Kerala, India*

*Corresponding Author: Chandrasekharan Nair K, Professor Emeritus, Department of Prosthodontics, Sri Sankara Dental College, Akathumuri, Thiruvananthapuram, Kerala, India.

Scopus Id: https://orcid.org/0000-0003-3114-3015

Abstract

Robotics has significantly influenced the diagnostic and therapeutic landscape of dentistry. Prolonged clinical working hours may contribute to operator fatigue, thereby reducing precision and compromising consistency in the quality of care. In this context, robotic systems offer distinct advantages by enabling repetitive, high-accuracy performance over extended periods while maintaining standardized outcomes. Early dental robotic applications largely depended on continuous human assistance; however, contemporary systems incorporate advanced sensing, navigation, and automation, with growing potential for remote operation and tele-assistance. Robotic technology is increasingly relevant across multiple dental specialties, including prosthodontics, implantology, oral and maxillofacial surgery, endodontics and orthodontics. The coming decades are expected to witness rapid advancements in robotic intelligence, miniaturization, and clinical integration, further expanding their role in routine dental practice. Although robots are unlikely to replace clinicians, they are expected to redefine clinical workflows by functioning as capable assistants, enhancing efficiency and accuracy, and allowing dental professionals to focus more on decision-making, creativity, and patient-centred care.

Keywords: Robotics; Brain; Endodontics

Introduction

Robot is an automatically operated machine that can replace human effort. In appearance it may not resemble human beings but it performs like a human being. Robotics has developed into an engineering discipline that deals with the design, fabrication and operation of robots. According to the International Organization for Standardisation (ISO), a robot is an automatic, position-controlled, programmable multi-functional manipulator with several axes. It can process various materials, parts, tools, and special devices through programmable automation to perform intended tasks.

History and evolution

The concept of robotics can be traced back to ancient civilizations related to Greece, China and Egypt. Ancient robots were named as automata and Greek mathematician 'Heron of Alexandria' (1st century AD) designed many self-operating machines and one of it was an automatic vending machine which received coins and served a limited quantity of holy water. Water powered clocks which worked on drips of water that filled or emptied a marked container which corresponded with time. Chinese have invented water based complex astronomical clocks which consisted of water reservoir, float and a pointer [1]. During the middle ages (5th-15th century AD) and the renaissance (14th – 16th century AD), advances in mechanical engineering brought in more sophistication to automata. Ismail al-Jazari, a scholar and mechanical engineer from the Islamic golden age is considered as the 'father of robotics' and he has designed more than fifty devices like water clocks, automated fountains, machines for lifting water from ponds and crankshafts. He wrote a book named 'The book of knowledge and ingenious mechanical devices' in the year 1206 AD [2].

The term 'robot' was introduced in the year 1920 by Czech playwright Karel Capek in his play 'Rossum's Universal Robots'. The Slavic word robota means forced labor. In the play, robots were manufactured and forced to work in a factory. The factory owners exploited them and finally the robots revolted and the humans were destroyed. The robots were also at the verge of extinction. One of the humans advises the robots: "If you desire to live, you must breed like animals". The insights present in the play had interestingly a futuristic vision and relevance [3].

The beginning of robotics in the modern era began during the middle of 20th century and during that time, mechanics, electronics and control theory had a mutual convergence. George Devol, an American inventor made the first programmable industrial robot, the 'unimate', patented in 1954 and deployed by the General Motors in 1961. It performed hazardous tasks like lifting hot metal pieces [4].

In the 1970s to 1980s, microprocessors, sensors, cameras and automation have arrived to the field of robotics. Concurrently academic research in robotics also flourished and which has emphasized kinematics, dynamics, machine vision and artificial intelligence. Robotic arms of various capabilities were subsequently developed. SCARA (selective compliance assembly robot arm) was introduced to be used for 'pick and place' assembly tasks. EO robots refers to end of arm tooling; a crucial attachment in a robotic arm which can perform gripping, welding etc. [5].

In the 1990s, robotics entered into a new phase having intelligence, autonomy with human-robot interaction capabilities. In 1997, IBM developed Deep Blue computer which could defeat world chess champion Garry Kasparov and which show cased machine's ability to excel human being in a complex chess game. AI processing power was evident in this game. Evolving into a new sphere, advanced robots were made and which were designated as service robots, medical robots for surgery, autonomous vehicles and planetary rovers used in space exploration.

Dawn of the present century witnessed the rise of consumer robots (Roomba), warehouse logistics and automation (Kiva) and humanoid robots (Big dog). Big dog was a four-legged robot capable of doing complex movements, carry heavy loads for soldiers in rough terrains. Human-robot collaboration (Cobots) has successfully made automation accessible to different ranges of business. Today's robots are increasingly autonomous, capable of advanced sensing, AI driven decision making, refined movement capability and programmability. Robotics has extended its applicability by cutting inroads into medicine, surgery, dentistry and patient care and rehabilitation areas.

Components of a robot

There are seven key components for a robot: (Figure 1).

Controller/Processor

This is the "brain" of the robot that processes information received from sensors, runs the program, and sends commands to actuators. Without it, the robot can't function. It wouldn't know what to do or when to do it.
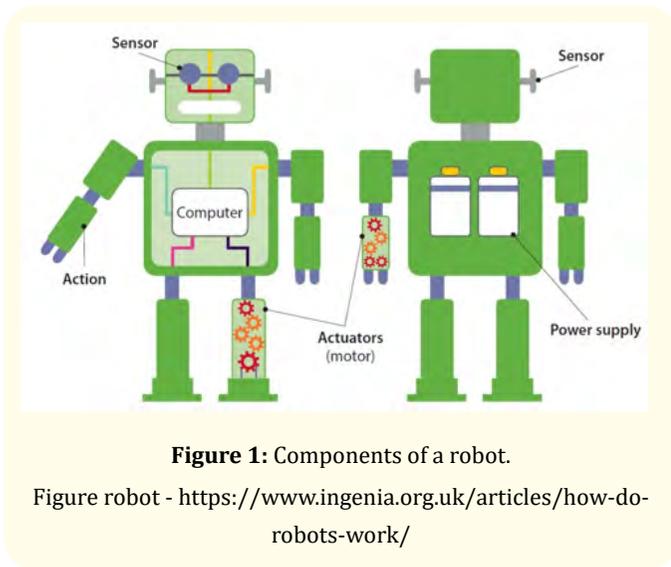
Figure 1: Components of a robot.
Figure robot - https://www.ingenia.org.uk/articles/how-do-robots-work/

Sensors

These are the input devices that let the robot perceive its environment. Robot detects the surroundings in terms of light, touch or distance and provides feedback and environmental awareness. Common types of sensors used in robotic systems are: 1. Vision systems for object detection quality inspection, and guidance, 2. Proximity sensors to detect objects nearby, 3. Encoders and Inertial measurement units (IMUs) for joint position, velocity, and balance, 4. Force and torque sensors for measuring contact pressure or resistance and 5. Temperature sensors for thermal monitoring.

Actuators

Actuators convert electrical energy into mechanical motion to make joints and parts to move. They convert the instructions received from the control system into physical action, like rotating a joint, driving a wheel, or moving an arm into position. Motors typically provide the raw rotational force. Most robots use electric motors like servo or stepper motors for precise motion control. Actuators include the motor and the mechanical parts that create movement, such as gears, belts, and linkages. These components are often called the "muscles" of a robot because they drive every physical action.

End-Effector

The tool attached to the robot (like a gripper, welder, or paint sprayer) which interacts directly with the objects.

Power supply

It is the energy source for all the components of the robot to operate. Electric power is the most common, especially in industrial and collaborative robots. These systems run on AC or DC electricity and may use internal or external battery packs. Pneumatic systems use compressed air to provide power to actuators. They're lightweight and fast but precision is limited. In robots that require higher force, hydraulic power is used.

Manipulator

It is the physical structure or body of the robot; very often an arm, made of links and joints that holds and positions the end-effector. It supports the movement and provides durability.

Software/Programming

The code and algorithms that instructs the robot what to do and how to perform its tasks. In collaborative robots, software includes intuitive no-code programming, which allows non-technical persons to teach tasks by demonstration or by drag-and-drop tools. Many platforms support standard programming environments like Python, Robot operating system (ROS), or proprietary Software developing kits (SDKs) [6,7].

Classification of robots

Classification by generations

Five different types of robots are identified according to the time frame it has passed through (Table 1).

Generation	Designation	Function
First	Robot manipulators	Pick up and move objects with restricted movements
Second	Learning robots	Gather information from the environment and make complex movements
Third	Reprogrammable robots	Equipped with sensors, use programming language, vary functions to suit the needs
Fourth	Mobile robots	Intelligent robots, capable of interpreting the environment in real time
Fifth	Robots with AI	Current development, intended to mimic human beings and autonomous

Table 1: Five generations of robots [8,9].

Classification of robots by their locomotion (Kinematics)

Robots can also be classified according to the movement capabilities; whether they can move or only remain as stationary. Stationary robots are further subdivided as follows:

- **Cartesian Robots:** These are the most common types of robots. These have three linear axes, mounted at right angles to each other and can move only in straight lines. Cartesian robots have a rigid structure and offer good levels of precision and repeatability. These are used in the industrial and the manufacturing sector [10] (Figure 2).

- **Cylindrical robots:** Body of this type of robot has a vertical arm on which a robotic arm moves up and down. The arm can rotate about the vertical axis and which can be extended or contracted. This construction makes the robot work in a cylindrical space. They are used for assembly operations, spot welding and for die casting machines [11] (Figure 3).

- **SCARA Robots:** This stands for Selective Compliance Arm for Robotic Assembly. This type of robot has two parallel revolute joints. They are used for assembly purposes and have wide acceptance [12]. (Figure 4).

- **Articulated Robots:** These robots can make a wide range of movements that include forward, backward, upward and downward motion. Because of their large working capabilities, articulated robots can be used for assembly, arc welding, material handling, machine tending and packaging [13] (Figure 5)

- **Parallel Robots:** When accuracy and dynamic response are required, parallel robots are used. These are closed-loop systems to support a single platform. An example of this kind of robot would be those used for drilling and milling [14] (Figure 6).

- **Wheeled Robots and legged Robots:** These are robots having wheels, and can be further classified as: single wheel robots, two-wheel robots, three and more wheel robots, bipedal robots (humanoid robots), tri-pedal robots, quadra-pedal robots and hexapod robots [15] (Figure 7).

- **Airborne Robots:** Drones are the finest examples of airborne robots. These can fly through the air [16] (Figure 8).
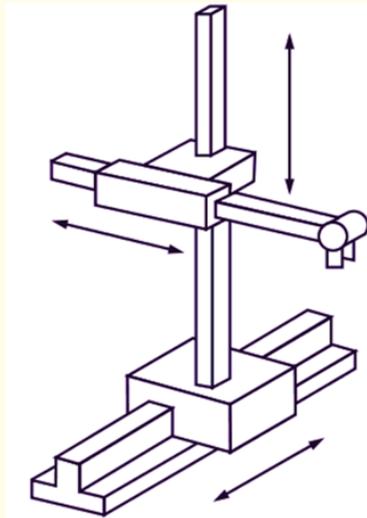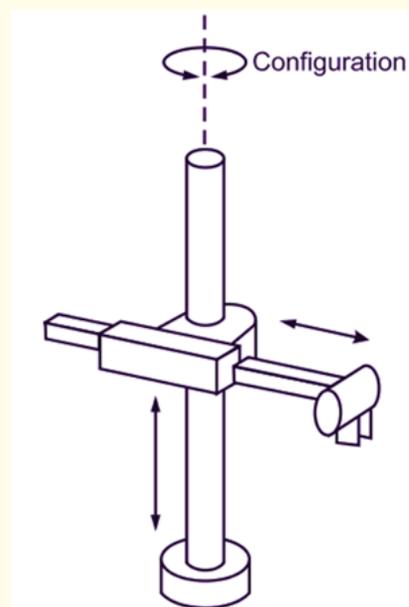

Figure 2: Cartesian-Robot.

https://electricalworkbook.com/cartesian-robot/

Figure 3: Cylindrical-Robot-Configuration.

https://electricalworkbook.com/cylindrical-robot/

Figure 4: SCARA robot.

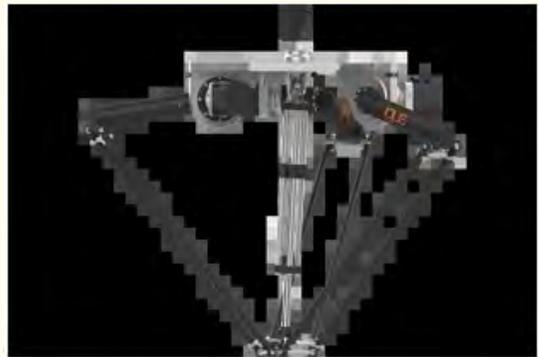https://www.ato.com/scara-robot-450-mm-arm-length?srsltid=AfmBOoqdbZ_xpL-qHvTna-MZM-s37EoTa1Gqu_s95s3VbanOFr0tt-jK

Figure 6: Parallel robot.

https://www.igus.in/product/22619?artNr=LCA-DR1000-04

Figure 5: Articulated robot.

https://www.aeroexpo.online/aeronautic-manufacturer/articulated-robot-3691.html

Figure 7: Wheeled and legged robot.

https://jetayugadgets.com/products/unitree-go2w-ent-u2-with-controller?srsltid=AfmBOoptp1

Figure 8: Airborne robot-Drone.

https://www.tourmyindia.com/blog/flying-drones-guidelines-india/

Figure 9: Fully automated robot dentist.

https://newatlas.com/health-wellbeing/robot-dentist-world-first/

Classification of robots by function

Robots are also classified according to their function or the environment in which they operate. There are five prominent areas in which robots are put into use; viz. industrial, domestic, educational, military and medical. This list might grow whenever newer application fields are found out.

- **Industrial robots:** These are developed to work in production units and assembly lines. SCARA robots, Parallel robots, Cartesian robots, articulated robots etc are the examples of industrial robots. Automation in industrial units happen through careful application of robotics. These have immense potential to automate all sorts of industrial processes [17].

- **Domestic robots:** Domestic robots are engineered to tackle house hold tasks like vacuum cleaning of floors, lawnmowing to trim grass, kitchen aid to cook and companionship to aged individuals [18].

- **Educational robots:** These are interactive tools that include programmable toys to AI powered assistants. Educational robots are used to teach science, technology, engineering, mathematics, coding, problem solving and critical thinking. These robots can promote active learning, adapts to individual pacing in learning, builds essential hard and soft skills and make complex subjects entertaining and engaging. Students are engaged to build robots and

teachers can facilitate students in active, project based learning [19].

- **Military robots:** These are autonomous or semi autonomous machines used by armed forces for transport, combat support, bomb disposal and reconnaissance. There is considerable reduction in risks to human soldiers when robots are integrated [20].

- **Medical robots:** Medical robots can provide surgical assistance using robotic arm technologies. Integrating technological advancements like AI, computer vision and data analytics has expanded the capabilities of medical robots. Robots can support patients and provide assistance in laboratories. Robots provide high level patient care, efficient processes in clinical settings and provide safer environment in the clinic and to patients and health care providers [21].

- **Robots in dentistry:** Robots are used in dentistry for precision, minimal invasion, consistent and improved outcomes and speed and efficiency. Robotics are widely used in clinical settings and laboratory procedures. The role of robotics is increasing in prosthodontics, implant surgery, restorative dentistry, endodontics, orthodontics and training of students using simulators [22].

Application of robotics in different dental specialities

Prosthodontics

Tooth preparation

Tooth preparation is the process of altering the contour of a defective, malformed, fractured (injured) or diseased tooth to create space for the placement of restorative material to re-establish normal contour, function and aesthetics of the tooth. Edentulism is a matter of concern amongst Indian population because of the increasing burden in relation to age, rural population and females. In 50+ population, total tooth loss is identified in 16%. In 65-74 population, tooth loss increases to 29%. Edentulism is prevalent amongst rural population and in females. Prosthodontic intervention is required in edentulous individuals to restore function predominantly mastication and speech. By the restoration, temporomandibular joints are also protected. The expertise of the clinician and the technician has to be utilised in large volume because of the increasing need. Human operations with high speed turbines have limitations and that necessitates

the use of robots. Laser ablation of hard tissues is considered to be safer and comfortable. In 2013, a microrobot device called LaserBot was launched and it was found that the robotic system could meet the requirements of crown preparation. However, the ablation time was too long but now it is modified and shortened to 17 minutes. On comparison, free hand tooth preparation and robotic preparations had similar accuracy but precision could not reach to that point. LaserBot had a miniature robotic end effector, laser generator, tooth fixture, laser transmission arm, laser scanner and computer console. Further evaluations are required to find out precisely the ablation efficiency on enamel, dentine and dental materials [23].

Tooth arrangement

Tooth arrangement for complete denture fabrication is carried out using 6-DOF CRS robot. This is an industrial manipulator with three cartesian axes and three rotational axes. Usually these are used for tasks like assembly, pick and place and welding. 6DoF allows for full 3D positioning (X Y Z translations) and orientation. Tooth arrangement robots usually consists of a light source, light sensitive glue, denture base, robot modulation software, electro magnetic gripper and computer. In more advanced 50-DOF, there is a dental arch generator and fourteen independent manipulators – each tooth has one manipulator. Within half an hour, tooth arrangement job will be completed. Repetitive positioning precision is calculated as +/- 0.1 mm [24,25].

Oral implantology

The outcome of dental implant treatment is dependent on the precision of implant placement. Usually, dentists make use of surgical template guidance. Human errors are quite common with difficult situations of the edentulous site and restrictions experienced in mouth opening. Robots are expected to provide reliable and successful results because of accuracy and stability. Robotic applications are of two types:1. Robotic assisted 2. Fully automated. Air force medical university in China developed a fully automatic optical navigation system that could do surgical placement of implant according to a predetermined operative plan. Robot system can complete anterior implant placement within 20 minutes. Researchers have tried to introduce robotics in the placement of zygomatic implants and exclusive systems for that are also designed. Robots have acquired comparable or better surgical results than surgeons. However more preclinical trials are required to confirm the results [26,27].

Oral and maxillofacial surgery

Recently transoral robotic surgery has been developed for the surgical interventions of head and neck region. Precisely it is robot assisted surgery performed in the upper aerodigestive tract. The tract refers to respiratory and upper digestive system encompassing mouth, nose, pharynx, larynx and oesophagus. Robotic surgical system so far developed is mainly intended for soft tissue resection in the field of oral and maxillofacial surgery. The beneficiaries belong to head and neck cancer, gland resection, gland stone resection, tongue base resection in sleep apnoea and cleft lip and cleft palate surgery. Surgeons usually supervise and control the robotic arm [26,28-30].

Robot assisted surgery can provide excellent local control in the treatment. In 2009 US-FDA approved the da Vinci system for treating select malignant and non malignant lesions of the oropharynx. This is a robotic assisted platform designed for minimally invasive procedures. Small incisions are made using 3DHD vision (this is an advanced, high definition, 3D imaging technology which gives depth perception). It allows surgeons to see tissue planes, structures and anatomy, clearly in 3D, improving precision and spacial orientation. Surgeon operates through a console and gets good access. Patients get fast recovery. Another advantage is that robot can successfully complete the surgery irrespective of the position of the jaw [31]. Robotic assistance enables the surgeon in the acquisition and reconstruction of 3D image data of the oral and maxillofacial region before the execution of the surgery and can design a targeted operation plan.

Orthodontics

In the earlier times, robotics was specifically integrated to orthodontics, in order to obtain clinical diagnosis and treatment plans. Robotics enhances treatment precision and efficiency in arch wire bending and fabrication of aligners. Arch wires are critical components in orthodontic treatment and orthodontists usually fabricate it manually. It is not an easy job because of the toughness and super elasticity of the wires used. Manual methods of wire bending may allow errors to creep in and robotics can possibly avoid this. Sure smile is a popular robotic system used for wire bending. 3D printing of aligners is carried out with the aid of robotics. Robot guided orthodontic surgeries help in placing mini-implants and in maxilla/mandible repositioning [32].

LAMDA (Lingual Archwire Manufacturing and Design Aid) is a system used for arch wire bending. Here the nickel titanium arch wire is heated up to 600^0F and within six minutes the bending is carried out. Research workers have observed higher quality with LAMDA bent arch wires compared to manually fabricated ones. Arch wire bending robots are simple in structure, has low cost and can fabricate different designs of arch wires. It is a great help for the clinicians and can prevent fatigue fracture caused due to repeated bending that happens during manual fabrication [33].

The robotic system used in orthodontics usually consists of exclusive arch wire bending system of cartesian type, bending die, supporting structure, rotary and the base. Robotic applications provide improved, predictable and safer orthodontic care with higher, efficiency. While high costs and limited accessibility are current drawbacks, the technology is advancing to include, potential future uses with nanorobotics. The integration of robotics is shifting the focus of orthodontists from manual labour to complex diagnosis and treatment planning [34].

Endodontics

Success of conventional endodontic treatment greatly depends on the expertise of the clinician and possibility of incidental failure cannot be ruled out. In the recent past sophisticated technologies like artificial intelligence and robotics have been integrated to obtain accuracy, efficiency and high scale of success in the treatment viz. root canal preparation, disinfection, obturation, and microsurgery. Robotic-assisted instrumentation effectively controls procedural errors, improves ergonomic advantages for the operator and reduces the chances of post-surgical complications. Traditional root canal treatment need highly refined manual skills and it frequently is accompanied by procedural flaws like ledge formation, canal transportation, apical perforation and inefficient debris removal. Robotics tries to overcome such drawbacks by offering computerized, image-based, and AI-enabled solutions that ensure precise canal shaping, adequate irrigation and accurate obturation [35].

In root canal treatment there are risks of K-file or rotary file breaking inside the canal, causing root perforation. A robot Omni Phantom, is recently developed with haptic virtual reality simulator for training purposes in endodontics. The haptic component gives good simulator effects like burring the enamel, dentin and cleaning the inner surface of the root canal. A recent innovation is the use of micro robots which have catalytic capability to disrupt oral biofilms present inside the root canal. These robots can be used in other applications like prevention of peri-implant infection and dental caries [36]. Robots can be used to assist the clinician while performing root canal therapy by serving as a vending machine to provide the required root canal instruments to the operator in a particular pre-determined order [37].

Oral radiology and robotics

Presently used radiographic techniques are highly sophisticated which can access every aspect of the tooth with accuracy and hence a doubt may be raised on the utility of a robot in radiography. If a robot is used, the radiologist can be remotely placed from the site of operation and hence the risk of radiation exposure can be avoided. Robotic systems have been developed to work with radiography and that have better dexterity than human beings. A 6-DOF robotic arm can position the x-ray source and the sensor/film with superior accuracy. In subtraction radiography, robots can position the X-ray source and the sensor repeatedly in the same-position. This is useful in periodontal diagnosis, caries detection and implant assessment. Cephalometric film based tracings for comparisons in orthodontics will get better quality and accuracy with robotic integration [38,39].

Robotic jaw movement analyser

Mandibular movements are recorded and reproduced by fully adjustable articulators and pantographs. These are fairly accurate but heavily dependent on operator skills and selection of clinical reference points which vary according to individual preferences. The mechanical components of articulators have limitations to copy the movements of the temporo -mandibular joint. Digital simulation of mandibular movements has been made possible but only in a virtual environment. Optoelectronic motion capturing system is used to record mandibular positions. Bionic jaw motion (BJM) system is composed of a jaw movement analyser, robotic articulator and computer with necessary software. Facial scanner or optoelectronic motion tracking systems are recently introduced. BJM has an advantage of recording functional movements besides the border movements [40].

Robotics in medicine and health care

Robotics has strengthened the practice of modern medicine by transforming the way clinicians diagnose, treat and rehabilitate

patients with precision, efficiency and predictability. Surgeons use robotic systems to perform minimally invasive procedures, resulting in smaller incisions, reduced blood loss, less tissue damage and faster patient recovery. Therapeutic robots like PARO assist individuals who suffer from dementia or depression. Rehabilitation robotics—including robotic exoskeletons and therapy devices—supports functional recovery after stroke or spinal cord injury by enabling repetitive, guided movements and objective progress monitoring. Autonomous mobile robots manage tasks like transporting medicine, linen and food, as well as sanitizing hospital rooms using UV light. Robots like Giraff enable remote monitoring of patients in rural areas and in elderly care. Robotic dispensing systems like ScriptPro manage counting of medicines, labelling and storage thereby reducing human error considerably. Presently long-distance surgeries are performed using 5G connections opening up a new vista in remote expert care. These developments highlight the potential of robotics in medicine and proves that robots are not merely an automation tool but a powerful extension of clinical capability [41].

Limitations of robots

The cost of acquisition and maintenance of a robotic system is comparatively very high and has a deterrent effect on the prospective users. Robotic application area in dentistry is very restricted and requires significant training. Robotic arms and tools cannot have flexibility and most of them are rigid. The registration and calibration of a robotic system requires considerable time which adds to the operative times. The technology has a steep learning curve and the operators need to undergo specialised training. Success of robotic treatment mainly depends on meticulous preoperative planning and that is so with all high-tech interventions. Research related to robotics is still in its infancy and hence adequate evidence could not be explored. Patient acceptance and compliance amongst dentists with automated procedures is limited especially amongst female gender. Involving robotics in healthcare can possibly raise ethical concerns related to decision-making, patient privacy, autonomy, and appropriate use. Establishing clear guidelines and ethical frameworks is of paramount importance while integrating robotic solutions in healthcare scenarios [39,42,43].

Discussion and Conclusions

Dental treatment demands a high degree of precision to ensure predictable clinical outcomes. Many dental procedures are technically demanding, time-consuming, and may cause significant patient discomfort, while the restricted operating field and need for sustained fine motor control increase the likelihood of human error. In this context, integrating robotics into dental practice offers significant advantages. Robotic systems facilitate meticulous preoperative planning through comprehensive data acquisition, digital modelling, and analytical processing, leading to improved treatment accuracy and enhanced procedural success, especially in implantology where precision is critical. For example, robot-assisted implant placement has demonstrated significantly lower deviations in platform, apical, and angular measurements compared with freehand surgery, suggesting enhanced accuracy and clinical safety [22,25]. Narrative and scoping reviews also underscore that robotic systems can improve procedural efficiency and accuracy across multiple dental applications, including implant surgeries and guided interventions [44,45].

In addition to precision, robotic arms can be stabilized with high fidelity, reducing operator variability and mitigating risks associated with clinician fatigue. Remote guidance and instruction via networked robotic systems further expand the potential for expert collaboration and telementoring in complex cases. When combined with artificial intelligence (AI), these technologies support enhanced diagnostics and automate certain treatment planning tasks, which may improve patient experience and clinical outcomes [46].

The adoption of robotics and AI in dentistry also has educational implications. As robotic platforms and AI-driven tools become integral to clinical practice, dental training curricula will need to evolve, incorporating competencies in digital technology, robotics, and computer-assisted clinical skills to prepare future practitioners for technologically advanced care [47].

Despite these advantages, the wider integration of robotics and AI must be accompanied by careful consideration of legal, ethical, and security concerns. Patient protection remains paramount, and clinicians must ensure that data acquired and interpreted by robotic systems are reliable and clinically validated. Large volumes of patient data required for AI systems raise concerns related to privacy, consent, accountability, and regulatory compliance, as current legal frameworks remain underdeveloped in many regions [48]. Ethical considerations, including transparency, bias detection, and accountability, should be embedded into implementation

strategies to safeguard patient rights and maintain professional integrity [22].

Therefore, comprehensive, standardized legal and regulatory frameworks are urgently required to guide the safe and ethical application of robotics in dentistry. In this regard, it is worthwhile to recall foundational ethical principles such as Isaac Asimov's Three Laws of Robotics, which highlight the necessity of prioritizing human safety, obedience, and responsible technological design in human–robot interactions:

- A robot may not injure a human being or, through inaction, allow a human being to come to harm.

- A robot must obey the orders given to it by human beings except where such orders would conflict with the First Law.

- A robot must protect its own existence as long as such protection does not conflict with the First or Second Law [49].

Conflict of Interest

The authors declare that they do not have any conflict of interest.

CRediT Authorship Contribution Statement

K.Chandrasekharan Nair: Conceptualization, Initial draft preparation, Formal analysis, Supervision, Hemalatha Konka: Selection of articles, review of articles, Viswanath: Conceptualization, Initial draft preparation, Pradeep Dathan: Selection of articles, Initial draft preparation, review of articles, Murukan P A: review of articles.

All authors have read and agreed to the published version of the manuscript.

Bibliography

1. https://www.historyofinformation.com/detail.php?id=10

2. https://www.britannica.com/biography/al-Jazari

3. Ágoston E Eiben., *et al.* "Robot evolution: ethical concerns". *Frontier in Robotics AI* 8 (2021): 744590.

4. https://www.historyofinformation.com/detail.php?entryid=4071

5. https://www.emergentmind.com/topics/eo-robotics

6. https://standardbots.com/blog/what-are-the-main-components-of-a-robot

7. https://en.wikipedia.org/wiki/Software_development_kit

8. https://www.designtechproducts.com/articles/classification-of-robots

9. https://www.telefonica.com/en/communication-room/blog/types-of-robots-classification-applications-and-examples/

10. https://electricalworkbook.com/cartesian-robot/

11. https://electricalworkbook.com/cylindrical-robot/

12. https://www.ato.com/scara-robot-450-mm-arm-length?srsltid=AfmBOoqdbZ_xpL-qHvTna-MZM-s37EoTa1Gqu_s95s3VbanOFr0tt-jK

13. https://www.aeroexpo.online/aeronautic-manufacturer/articulated-robot-3691.html

14. https://www.igus.in/product/22619?artNr=LCA-DR1000-04

15. https://jetayugadgets.com/products/unitree-go2w-ent-u2-with-controller?srsltid=AfmBOoptp1

16. https://www.tourmyindia.com/blog/flying-drones-guidelines-india/

17. https://www.sciencedirect.com/topics/engineering/industrial-robot

18. https://www.balluff.com/en-us/blog/the-5-most-common-types-of-fixed-industrial-robots

19. https://www.iberdrola.com/about-us/our-innovation-model/educational-robots#

20. https://standardbots.com/blog/military-robots

21. https://www.intel.com/content/www/us/en/learn/robotics-in-healthcare.html

22. Hamza Younis Boya Xu., *et al.* "Accuracy of robot-assisted implant surgery versus freehand placement: a retrospective clinical study". *International Journal of Clinical Implant Dentistry* 11 (2025): 1.

23. Yuan F and Lyu P. "A preliminary study on a tooth preparation robot". *Advances in Applied Ceramics* 119 (2020): 332-337.

24. Jiang JG., *et al*. "A review on robot in prosthodontics and orthodontics". *Advances in Mechanical Engineering* 7 (2015): 198748.

25. Liu L., *et al*. "Robotics in Dentistry: A Narrative Review". *Dentistry Journal* 11 (2023): 62.

26. Y Li., *et al*. "Clinical application of robots in dentistry: A scoping review". *Journal of Prosthodontics Research* 68.2 (2024): 193-205.

27. Haidar Z. "Autonomous Robotics: A fresh Era of Implant Dentistry . . . is a reality!". *Journal of Oral Research* 6 (2017): 230-231.

28. Walvekar RR., *et al*. "Robotic-assisted transoral removal of a submandibular megalith". *Laryngoscope* 121 (2011): 534-537.

29. Capaccio P., *et al*. "Transoral robotic surgery for hilo-parenchymal submandibular stones: step-by-step description and reasoned approach". *International Journal of Oral and Maxillofacial Surgery* 48 (2019): 1520-1524.

30. Viswanath Gurumurthy., *et al*. "Obstructive Sleep Apnea-A Review". *Acta Scientific Dental Sciences* 9.4 (2025): 15-25.

31. Ma Q., *et al*. "Development and preliminary evaluation of an autonomous surgical system for oral and maxillofacial surgery". *International Journal of Medical Robotics and Computer Assisted Surgery* 15 (2019): e1997.

32. Gilbert A. "An in-office wire-bending robot for lingual orthodontics". *Journal of Clinical Orthodontics* 45 (2011): 230.

33. Zhang YD and Jiang JX. "Analysis and experimentation of the robotic system for arch wire bending". *Applied Mechanics and Materials* 121 (2012): 3805-3809.

34. Zhang Y and Jiang J. "Study on precise acceleration/deceleration planning of arch wire bending robot". *ICIC Express Letter* 7 (2013): 73-78.

35. Ahmed Yaseen Alqutaibi., *et al*. "Contemporary Applications and Future Perspectives of Robots in Endodontics: A Scoping Review". *The International Journal of Medical Robotics and Computer Assisted Surgery* 20 (2024): e70001 1 of 11.

36. Hwang G., *et al*. "Catalytic antimicrobial robots for biofilm eradication". *Science Robotics* 4 (2019): eaaw2388.

37. Nelson CA., *et al*. "A novel vending machine for supplying root canal tools during surgery". *Journal of Medical Engineering and Technology* 36 (2012): 102-116.

38. Burdea GC., *et al*. "Robotic system for dental subtraction radiography". In Proceedings of the 1991 IEEE International Conference on Robotics and Automation, Sacramento, CA, USA, 9-11 April (1991): 2056-2062.

39. Ahmad P., *et al*. "Dental Robotics: A Disruptive Technology". *Sensors* 21 (2021): 3308.

40. Carossa., *et al*. "Individual mandibular movement registration and reproduction using an optoeletronic jaw movement analyzer and a dedicated robot: a dental technique". *BMC Oral Health* 20 (2020): 271.

41. https://ep.jhu.edu/news/robots-making-a-difference-in-healthcare/

42. Milner MN., *et al*. "Patient perceptions of new robotic technologies in clinical restorative dentistry". *Journal of Medical Systems* 44 (2020): 1-10.

43. https://www.intel.com/content/www/us/en/learn/robotics-in-healthcare.html#:~:text

44. Jain S., *et al*. "Accuracy Comparison between Robot-Assisted Dental Implant Placement and Static/Dynamic Computer-Assisted Implant Surgery: A Systematic Review and Meta-Analysis". *Medicina* 60.1 (2024): 11.

45. Alquitaibi Hamadalla., *et al*. "Applications of robots in implant dentistry: A scoping review". *Journal of Prosthetic Dentistry* 134.4 (2025): 1052-1061.

46. Saeed A., *et al*. "Future of Using Robotic and Artificial Intelligence in Implant Dentistry". *Cureus* 15 (2023): e43209.

47. Siang Lin GS., *et al*. "Exploring the Ethical Dimensions of Artificial Intelligence and Robotics in Dental Education". *Bangladesh Journal of Medical Science* 23 (2024): 999-1007.

48. Kurian N and Cherian JM. "Humanoid Robotics in Dentistry". *British Dental Journal* 237 (2024): 821-822.

49. https://en.wikipedia.org/wiki/Three_Laws_of_Robotics