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Review Article

Robotics: A Next-Generation Technology in Prosthodontics

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Abstract

The use of robots is increasing in a number of medical specialties, including dentistry, to minimize manual labor and improve the accuracy of procedures. Artificial intelligence and robotics are next-generation technologies that are opening new avenues of growth and exploration for prosthetic dentistry. This article focuses on the applications and advances of robotics in prosthodontics to date. Robotic interventions in prosthodontics are primarily used for the design and fabrication of complete dentures and to support surgical procedures related to dental implantology. In both cases, significant advances have been made that allow procedures to be performed with high success rates and a higher degree of accuracy. The use of robots significantly reduces the time required for each procedure. However, the use of such sophisticated and uniquely designed robots for various prosthetic treatments must be strictly supervised by a qualified dentist. Clinical judgement and professional competence are essential.

Key words: Dental implants, Prosthetic dentistry, Robots, Teeth arrangement, Yomi system

INTRODUCTION

Prosthodontics has been constantly changing and proving that it can adapt to changing requirements. Education, research, and practice of prosthetic dentistry is influenced by the development of newer concepts, technologies, and materials. One of these developments has been the introduction of robots in prosthetic dentistry.[1]

As a result of advances in laboratory technology, biomaterial science, clinical procedures, and multidisciplinary research, prosthodontics has undergone continuous change. Probably, more than any other dental specialty, prosthodontics has demonstrated the ability to evolve in response to changing needs, and it will likely continue to do so.[2]

Playwright Karel Capek first used the word "robot" in his 1921 play Rossom's Universal Robot. The Czech word "robota," meaning forced labor is the origin of the word "robot." In his 1950 science fiction novel I robot, author Isaac Asimov first introduced the interdisciplinary field of engineering and science known as robotics. The Robot Institute of America describes a robot as "a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized equipment through various programmed motions to accomplish a variety of tasks." Robots can not only increase worker productivity by taking on repetitive, tedious, and dangerous tasks that humans cannot do, but they can also perform tasks that humans are incapable of doing.[1]

Robotic systems are not intended to replace human surgeons but are designed as intelligent surgical tools. They help improve the accuracy, standard, and safety of surgical procedures. Their ability to provide a communication link between preoperative surgical plans and the operating room is perhaps their most valuable capability. Even though all the necessary technologies have been developed and can be easily adapted, robotics in dentistry is still in its infancy. Robots are mainly used in dental implantology and partial and full dentures for tooth arrangement in prosthodontics.

With the advancement of robotics and artificial intelligence theory and the urgent needs of prosthodontics and

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orthodontics, a new type of medical robot has emerged, such as a robot in prosthodontics. Robots in prosthetics can perform the following tasks: Making full or partial dentures and performing dental implantation. The software of the expert system for prosthetics incorporates the extensive knowledge and skills that experienced dentists and dental technicians have acquired over the years.

The fabrication of full or partial dentures as well as dental implants is then made possible by robotics in prosthetics. Robotics in prosthodontics is a completely new application for this technology. Research on robots in prosthetics will also represent a theoretical and technological advance. In addition to realizing the quantification of full or partial dentures, dental implantology, and the development of prosthodontics, their successful application will also represent an advance in relative fundamental theory.[3]

ROBOTS IN THE DENTAL INDUSTRY

Dental Patient Robots

It was discovered that dental patient robots, also known as phantom heads because they only have a simple functional cephalic region and a tooth arrangement, are very different from real patients. Robotic dental patients were first proposed in Japan.[3]

Show Hanako

In order to create a lifelike robot that behaved exactly like a human in its gestures and responses, Showa University collaborated with the robotics company TMSK in the nation's capital. This helped the dental students learn more effectively.[4]

Geminoid DK

The first robot in a series based on characters from countries other than Japan is called Geminoid DK. These remote-controlled robots, known as geminoids, can copy different head motions and facial expressions by using cutting-edge motion capture technology.[4]

Simroid Robot

The Nippon Dental University Kokoro created the Simroid robot, which is used to instruct dentists. It is an improvement over the 2007 robot Simuloid, which was less effective. This robot was created to give dentists emotional feedback, particularly regarding pain and discomfort. It also responds to questions and commands and rates and evaluates the patient's treatment.[4]

DIFFERENT APPLICATIONS

A Tooth Arrangement Robot for Complete Denture

The most important step in the manual, traditional fabrication of complete dentures is to insert the artificial teeth into a dental cushion in the correct position and direction. This work can only be done effectively by specialized dentists and trained technicians. Robotic fabrication of denture systems has now replaced the traditional method. The size of the teeth, the positioning and alignment of the individual teeth in relation to each other, and the curvature of the dental arch differ significantly in complete dentures. The flexibility of a robot is an advantage as it can be configured to fabricate complete dentures.[3]

The Canadian company CRS Robotics Corporation manufactured a robotic system with a single manipulator (Figure 1) and 6 degrees of freedoms (DOFs). This system was then modified to fabricate full dentures (Zhang *et al.*, 2001; Song *et al.*, 2001).

The main components of the system include a CRS robot, an electromagnetic gripper, a computer, a central control system with robot control software for planning and executing movements, a prosthetic base, a light source, and a photosensitive adhesive (Wang and Li, 2001).[3] Robotic arm of the typical CRS robot system is shown in Figure 2.

The robotic system's three-dimensional virtual tooth-arrangement software helps create the patient's medical history data, expert-drawn jaw, and dental arch curves according to the patient's mandibular arch parameters, and dental arch curve adjustments. Once the designed dentitions are displayed in three dimensions, a virtual observation environment is provided and each tooth position can be changed interactively. The robot control software handles the calibration of the tooth arrangement, the initial positioning of the robot, the generation of control data for the tooth arrangement, and the general control of the robot. The maximum load capacity of this robot system is 3 kg; the maximum speed is 4.35 m/s; and the positioning repeatability is 0.05 mm. In the production of a complete prosthetic system for patients, this system was used after its modification. The system is based on the use of a unique photosensitive substance that hardens when illuminated. In this system, standard teeth are selected and implanted in fixed positions by a robot. However, it was found that the system had difficulty accurately gripping and manipulating the artificial teeth.

As a result, better robotic systems with more DOF were developed. An advanced system with 84 DOF and 14

independent tooth manipulators on the dental arch curve was developed as a result of further research (Zhang *et al.*, 2008). The manipulators could move along the tooth tail in either direction to change the position of the tooth on the dental arch. The tooth could be adjusted in position along the X, Y, Z, lingual, rotational, and near-far-mid axes using a tooth arrangement helper with 6 DOF (three rotations and three movements).[5]

This robot can assume any position in the area of the artificial teeth, which solved a number of problems with the previous robot. The fact that this system is driven by 84 independent motors complicates its control, which reduces its efficiency.[3]

Subsequently, 14 independent manipulators, a tooth arc generator, and a sliding path mechanism were used to create a significantly improved robotic system for the 50 DOF tooth arrangement as shown in Figure 3 (Zhang *et al.*, 2011; Zhang *et al.*, 2010). The dental arch curve generated by the dental arch generator corresponds to that in the patient's oral cavity.

The dental arch generator is controlled by the glide path mechanism. The 14 independent manipulators can move along their own tails to compensate for the rotation of each tooth, just like the 84 DOF robotic system. These manipulators each have 3 DOFs, two rotations and one movement, so they can position each tooth in the Z, lingual and near-far-mid directions. Two parallel, rotating vertical rods are located under each manipulator to provide the additional 3 DOFs needed to adjust the tooth in the X, Y and rotational directions. This type of adjustment has helped reduce the system's motor requirements to 50, improving system efficiency. This 50 DOF robotic system for tooth adjustment is simpler and easier to control than previous generation systems and produces a complete denture in as little as 30 min. The system's repeatable positioning accuracy is 0.07 mm for a single manipulator and 0.1 mm for the entire robotic system.[3] The robotic system for total denture fabrication has made great strides in efficiency, but the process still relies heavily on manual labor. The main obstacles to widespread use of the system are its high cost and lack of knowledge about its operation.[3] Virtual prototype for tooth-arrangement robot of Cartesian type is shown in Figure 4.

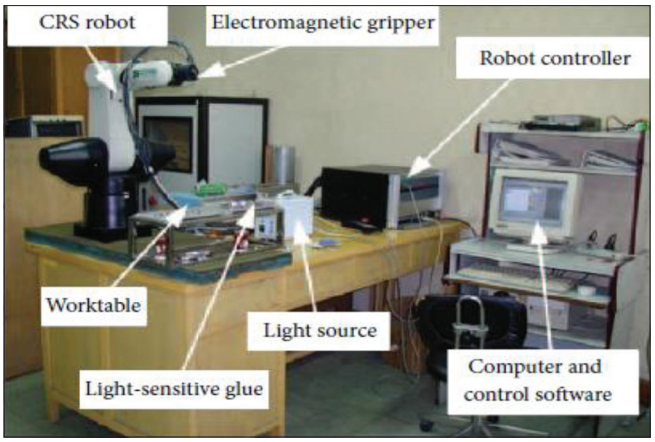

Figure 1: Single manipulator tooth-arrangement robot system for complete denture

Figure 2: Robotic arm of the typical CRS robot system

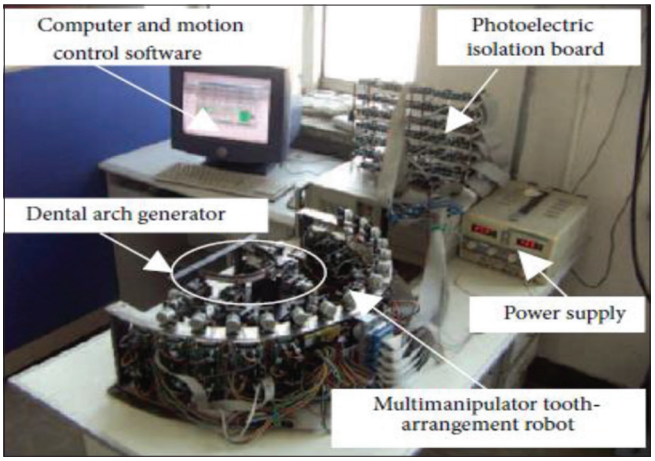

Figure 3: 50 degrees of freedom multimanipulator tooth-arrangement robot system

ROBOTS FOR DENTAL IMPLANT SURGERY

Robotic surgery for dental implants, once found only in science fiction, is now a reality. Robotic systems are not intended to replace human surgeons, but to be used as intelligent surgical tools that help improve the accuracy, quality and safety of surgical procedures. Ecole des Mines de Paris in France and Umea University have developed a robotic workbench for dental implants that covers the entire surgical spectrum from preoperative planning to

Figure 4: Virtual prototype for tooth-arrangement robot of Cartesian type

the operating room. The robot is expected to perform the following tasks in implantology: preoperative 3D reconstruction, path pre-planning and intraoperative image navigation in real time. The structure of the robot should accommodate flexible, image-guided insertion angle and position adjustment in the limited working space.[1]

Developed by Neocis Inc. in the USA and approved by the FDA in 2017, the Yomi robotic system for dental implantology is the first robotic system for dental implantology available on the market.

Preoperative planning and surgical navigation are the two main components of robotic dental surgical systems (Figure 5). Based on the data provided by the patient computed tomography, surgeons have a different perspective in the preoperative planning system. An infrared light-based navigation camera is used by the surgical navigation system to determine where to place the surgical tool. These robots, which continuously track the patient's movements and take control of the drill as the dentist approaches the tissue, can help the surgeon achieve good accuracy. To help the surgeon avoid potential errors, the system continuously monitors the patient.

With the help of monitoring and real-time 3D graphics, the dental procedure can be planned immediately and performed without delay in the dental clinic. Benefits of using these robots include faster healing times and generally safer procedures for dentists as they drill with greater precision. On September 22, 2017, a robotic dentist placed two dental implants in a woman in Southern China, performing the first ever fully automated dental

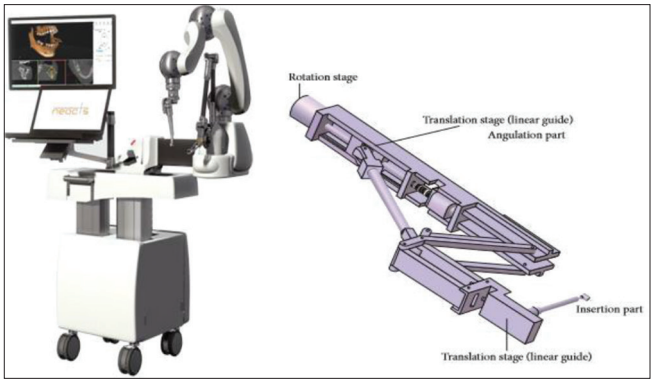

Figure 5: Yomi dental implantology robotic system

Figure 6: World's first fully automated dental implant robotic surgery

implant surgery shown in Figure 6. The entire procedure was supervised by human doctors who did not directly intervene.[1]

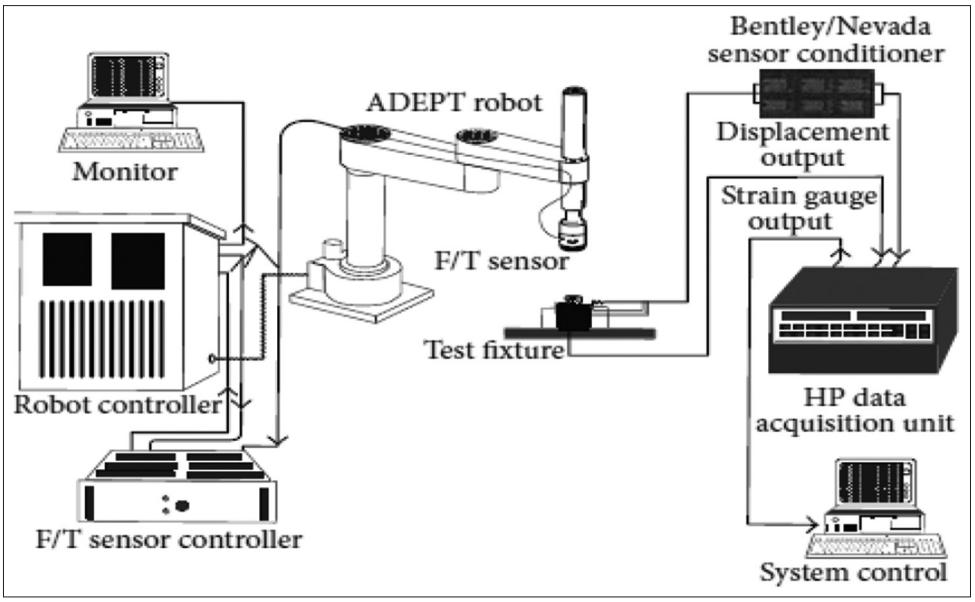

Figure 7: Measurement system for mastication force after dental implantology

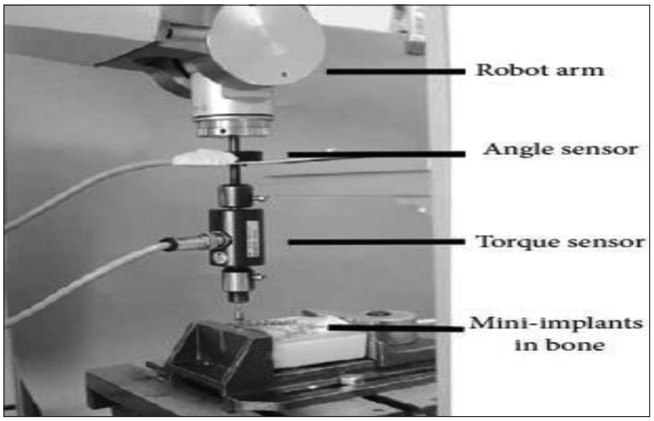

Figure 8: Implant surgery system constructed by the University of Duesseldorf

Robot-assisted Surgical Template Fabrication

Compared to traditionally manufactured surgical guides, robotic-assisted surgical guide manufacturing has led to better clinical outcomes. Robotically fabricated surgical guides can fully control the trajectory of the implant, are less expensive, minimally invasive, and reduce the likelihood of human error in clinical practice.[1]

Dental Masticatory Robots

A robot that can perform at least some specific human masticatory functions is called a "masticatory robot" There are numerous instruments and devices for measuring human masticatory movements. These devices and machines are not sufficient to simulate the full range of complicated movements and functions that occur during mastication. This paved the way for realistic and controllable robotic replication of jaw movements for a variety of applications, including dental education, jaw simulation, and speech therapy. The Dento Munch robotic simulator is an example of a dental masticatory robot. It is a 6 DOF robot for dental test simulations. It consists of the compliance module and artificial jaws. The jaws have been recreated to resemble a human lower and upper jaw with artificial teeth. They can be applied to dental components such as individual teeth, crowns, bridges or an entire denture to simulate the wear of materials and test the effectiveness of the bridge.[1] Measurement system for mastication force after dental Implantology is shown in Figure 7.

The Mouth Training Robot

Robots from the Waseda-Yamanashi (WY) series have been created for the training of temporomandibular joint (TMJ) disorder patients. During a training session for opening the mouth, this robot is used to open and close the patient's mandible. The WY-5 and WY-6 versions are the most sophisticated. The WY-5 robot measures the biting force coming from the patient by using three translational components of the force. A doctor robot with two DOFs (for open/close and forward/backward movements) or three DOFs (for open/close, forward/backward, and right/left movements) remotely controls the robot. The WY robot incorporates muscular EMG measurements to track any changes in the patient's jaw muscle and evaluate robotic therapy.[1]

Waseda Jaw (WJ) Series Robots

In order to comprehend the patient's mastication movement and resistance forces during jaw opening and closing training, the WJ robot is used as a patient robot. TMJ dysfunctions may also be assessed for and treated with the aid of this robot. These robots implement artificially produced clenching and grinding trajectories and have

three DOFs, two artificial TMJs, and two TMJs. Eleven artificial muscle actuators (AMA) that each consist of a set of DC motor, encoder, wire, and force sensor power the robot. The AMA was created to mimic the forces generated during muscle contraction. The motor pulls the opposite end of the tendon, which is attached to one end of the robotic mandible.[1]

Robots for Treating TMJ Disorders

Waseda University in Japan created the oral-rehabilitation robot known as Waseda Asahi Oral-rehabilitation robot No. 1 (WAO1). It is made up of a body with a headrest, two 6 DOF arms with plungers, a control box, a computer, and an automatic massage trajectory generation system with virtual compliance control. By pressing or rubbing a plunger whose motion is automatically computer-controlled, this robot system massages the patient's face. The WAO1 is the first robot that massages a patient's facial tissues, mastication muscles (masseter and temporalis), and saliva-producing oral structures, such as the parotid gland and duct. As a result, it may be used to treat TMJ disorder and dry mouth.[1]

Speech Robots

This was created in 2005 at the Canadian province's university. The two TMJs: one at each end of the jaw are driven by two 3-DOF parallel manipulators. It has been designed to examine how jaw movements affect how we perceive and comprehend face-to-face communication.[1]

Humanoid Practice Robot

The ethical difficulty of using human subjects for clinical training in dental education is a major barrier. Humanoid practice robots were introduced to address this problem. These robots can be mounted on a dental chair and are full-body models. Through computer control, they behave like actual patients and can mimic the gestures and speech of a real patient. When the students receive dental training, they may end up performing ineffective operational procedures, and these reactions, such as pain response, emesis reflex, cough reflex, and irregular pulse, simulate accidents that may happen during treatment. Simroid is a type of humanoid training robot.[1]

Microrobotized Dental Implant Surfaces

In comparison to conventionally treated implant surfaces, microrobotized dental implant surfaces can be used to achieve a higher bone-to-implant ratio and improved biomechanical fixation between the bone and implant.[1]

Nanorobots

Producing robots at or close to the microscopic scale of a nanometer, 1 nm is equal to one millionth of a millimeter, is known as nanorobotics. Nanoimpression material with nano-filler is available for use in prosthetic dentistry. To improve polyvinylsiloxane's flow, reduce the number of voids, and thus provide more precision in the recorded impression and better model pouring, nanofillers are incorporated into the material. Nano robots can also be used in cosmetic dentistry for dentition re-naturalization procedures. They remove outdated amalgam fillings and recreate teeth using biological materials that are identical to the original teeth.[1] Implant surgery system constructed by the University of Duesseldorf is shown in Figure 8.

ROBOTIC ADVANTAGES

1. Greater accuracy and precision.
2. Stable and durable, allowing for continuous use without rest.
3. Capable of correctly processing and evaluating quantitative data introduced into the system.
4. A reduction in surgical errors.

ROBOTIC DISADVANTAGES

1. Lack of situational judgement renders them unable to use any qualitative data.
2. Robotic operations require more resources and have challenging learning curves.
3. There is a high demand for dexterity.

FUTURE REQUIREMENTS

Research into the use of robots in prosthetic dentistry has advanced, but it is not yet finished. In order to optimize the robotic systems with accuracy within the constrained space of the oral cavity, more high-quality research and improvisation are required, according to the state of the art of robot application in prosthodontics. To grasp and precisely position the artificial teeth, a tooth-arrangement robot also needs improvements in sensor and control techniques as well as a highly effective and coordinated control algorithm. Future research for dental implantology robots must concentrate on real-time acquisition, feedback of drilling depth and implant force, and registration between intraoperative navigation image and preoperative reconstruction image. One of the key technologies for controlling the robot's motion in prosthodontics is human-computer interaction. A type of software for human-computer interaction should be created to provide operators with humanization input and feedback to streamline the operation.

CONCLUSION

Although still in its infancy, the use of robots in prosthetic dentistry is no longer speculative. To maximize the

benefits of this great innovation, high-quality research is needed in this era of rapidly evolving ideas and technologies. In the coming years, robotic assistance in prosthetic dentistry will continue to be a hotly debated topic. Under the guidance of an experienced dentist, the use of sophisticated and customized robots helps to improve the accuracy and precision of various prosthetic treatments. However, it is impossible to completely eliminate human intervention. Clinical judgement and professional expertise are essential. Based on their experience and skill, artificial intelligence cannot replace an experienced dentist. In addition to doctors, patients must also be convinced to accept this technology for the benefit of humanity. Within a short time, the use of this artificial intelligence in the diverse field of prosthetic dentistry will be an everyday reality and the subject of intense discussion.

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