Robots in Prosthodontics: A scientific fiction or reality?

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***Abstract:** Over the past few decades, as in all fields of the healing arts, there have been tremendous change in the various areas of dentistry. Robotics or artificial intelligence is a next generation technology that has opened new pathways to expand and explore the several areas of prosthetic dentistry. Robots are regarded as the most wonderful invention of human being and their application that aids to reduce the manual effort and increase the accuracy and precision of procedures are gaining momentum in several areas of prosthetic dentistry. Initially, robots in prosthetic dentistry were limited mostly for designing of complete dentures and for assisting dental implant surgeries but now with the advancements in the engineering and technologies their application in prosthetic dentistry have moved beyond that. This text aims at describing the assorted uses of robots and their progress so far within the elaborative field of prosthetic dentistry.*

***Keywords:** dental implants, prosthetic dentistry, robots, teeth arrangement*

***Introduction:** Prosthodontics has incessantly evolved and has shown itself capable of evolution in response to dynamic wants. Emergence of newer concepts, technologies, materials have an impact on the education, research, and practice of prosthetic dentistry. Introduction of robots in prosthetic dentistry was one such event.*

Since the 1990s, after the developments in industrial robot technology, the application of robot has been gradually extended to different fields including medical and dentistry. In 1994, the First International Symposium on Medical Robotics and Computer Assisted Surgery was held in Pittsburgh Pennsylvania, USA. [1,2,3]

The term "robot" was coined by Playright Karel Capek in 1921 in his play Rossom's Universal Robots. The word robot comes from the Czech word 'robota' which means forced labor. [7] Robotics is an interdisciplinary branch of engineering and science that was first introduced by writer Isaac Asimov in his science fiction

book named I robot which was published in 1950. According to the robot institute of America a robot is defined as "a reprogrammable, multifunctional manipulator designed to move materials, parts, tools or specialized devices through various programmed motions for the performance of a variety of tasks". [4]

The utilization of robots in the field of prosthetic dentistry might facilitate to extend the productivity of the staff, and may help to prevent the humans from doing some recurrent, boring, and dangerous work. Therefore, this robotic technology is paid abundant attention and its uses are progressively increasing on day-to-day basis. [2,3]

Types of robots in prosthetic dentistry: *The various types of robots in prosthetic dentistry are described below.*

Teeth arrangement robots for complete dentures and partial dentures*: These can be divided into 2 types:-*

- *Single manipulator tooth arrangement robot for complete dentures: Eg. CRS robotics with 6 DOF system*
- *Multimanipulator tooth arrangement robot for complete dentures: Eg. 50 DOF teeth arrangement robot, 84 DOF teeth arrangement robot*

The basic designing of teeth-arrangement robot, should allow qualitative description of teeth-arrangement principles to be quantitatively expressed. Accurate grasping and sequential location of artificial teeth should be accomplished with fewer degrees of freedom. [2]

Single manipulator robot system CRS robot was first produced in Canada. Single manipulator tooth arrangement robot system consists of: 6DOF CRS robot, a central control system with tooth-arrangement, an electromagnetic gripper, computer, robot control software for tooth-arrangement, motion planning and control, denture base, light source device, and light-sensitive glue. Three-dimensional virtual tooth-arrangement software is programmed based on VC++ and OpenGL. [2]

The 50DOF multi manipulator tooth arrangement robot system consists of 14 independent manipulators, a dental arch generator, and a slipway mechanism. The slipway mechanism is employed to achieve a 5-point [one fixed-point and four moving-points] control for the dental arch curve generator, which is used to form a dental arch curve that matches the one from a patient's mouth. Each of 14 manipulators can move on their own path to satisfy the need for every tooth's rotation. These manipulators support each tooth by a tooth-arrangement helper and provide the controls with 3 DOF [two rotations and one movement] to regulate every tooth for its position along Z, lingual, and near-far-medium directions. This robot system takes about 30 minutes to process the complete denture. [2]

84DOF multi manipulator tooth-arrangement robot system is driven by 84 motors and it consists of 14 independent manipulators on the dental arch curve. Each of them can move on their own path to satisfy the requirement for every tooth's position on the dental arch curve. The manipulators provide the control with 6 DOF (consisting of three rotations and three movements) that aids to align each tooth for its position along X, Y, Z, lingual, rotation, and near far-medium directions. Combining with the tooth-arrangement helper, this robot can notice any posture within the artificial teeth space. With this

tooth-arrangement robot, it is tough to comprehend the control and kinematic calculation of robot system because the quantity of driven motor is as several as 84. Aiming at this downside, the tooth arrangement strategy is planned based on the combination of dental arch curve generator and tooth-arrangement helper. [2]

Robots for dental implant surgery: *Robotic surgery is no longer a work of fiction it is a reality. Robotic systems should be used as the smart surgical tools that aids to increase the precision, quality and safety of surgical procedures but they are not intended to replace the human doctors. Robotic implant denture workbench, from preoperative surgical planning to the surgical arena, which is established by Ecole des Mines de Paris in France, and Umea University. Robot for Implantology should serve the following functions: pre-operation 3D reconstruction and path preplanning and real time navigation of intraoperative image. The structure of the robot should notice the versatile adjustment of insertion angle and position in the limited workspace with help of image guidance. [2,3,5,7]*

Fig. 1: Yomi dental Implantology robotic system

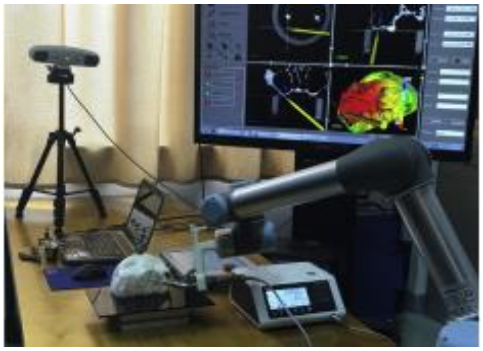

Fig. 2: The surgical robotic system consisting of robot arm, surgical navigation system, optical tracking device and pre-

The first documented case of a robot assisted surgical procedure was in 1985 when the (PUMA 560) Programmable Universal Manipulation Arm robotic system was used in a neurosurgical biopsy. This success offered greater insight for the use of such robotic systems for minimally invasive surgical procedures. The first commercially available robotic system for dental Implantology is the Yomi dental implantology robotic system [Fig. 1], developed by Neocis Inc., USA and approved by FDA in 2017. [3]

The robotically assisted dental surgical systems consists of two main components-the preoperative planning and surgical navigation [Fig. 2]. In the preoperative planning system, the surgeons have a different view based on CT data of the patient that are provided. The surgical navigation system makes use of an infrared light based navigation camera to find the proper position of the surgical device. These kind of robots may facilitate the surgeon in achieving good accuracy, designed to incessantly track the movements of the patient, while simultaneously provide a control over the drill when the dentist is advancing towards

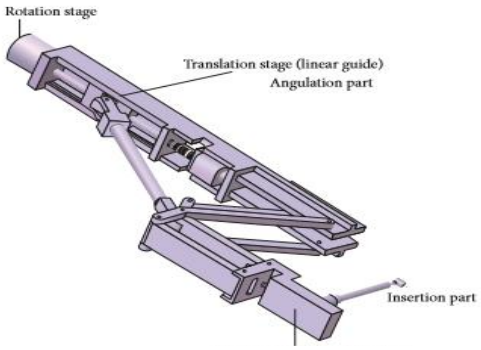

Fig3:Human Robot cooperative manipulator for dental Implantology

the tissue. The system continuously monitor the patient to avoid possible mistakes by the surgeon. With the help of monitoring and the real time 3D graphics, the procedure for the dental surgery can be planned immediately and executed in the dental clinic without any delay. The benefits of using these robots are generally a safer procedure for the dentists for more precise drilling, and faster healing times. [5,6,7] Figure 3 shows the Human-robot cooperative manipulator for dental Implantology surgery. The world's first fully automated dental implant surgery took place in south China [22/09 /2017] wherein a robot dentist installed two dental implants for a woman [Fig. 4]. Human doctors supervised the whole procedure but did not actively intervene. [8]

Fig. 4: World's first fully automated dental implant robotic surgery

Robot-assisted manufacture of surgical templates: *Robot-assisted manufacturing of surgical templates have shown better clinical results when compared to conventionally made surgical templates.*

Robot-assisted manufactured surgical templates can fully guide implant trajectory, are found to be less expensive, are minimally invasive and curtails the chances of human error in clinical practice. [5]

Dental masticatory robots: *A masticatory robot refers to a robot that can perform at least some defined human masticatory functions. [9] Multiple machines and devices are available for measuring human masticatory movements. But these machines and devices fail to simulate the whole suite of complex functions and movements involved during masticatory process. This led a way for the robotic reproductions of jaw movements in a holistic and controllable way, for various range of applications such as dental training, jaw simulation, and speech therapy.*

An example of dental masticatory robot is Dento Munch Robot Simulator. It is a 6 DOF robotic dental testing simulator. It consists of the artificial jaws and compliance module. The jaws represent a human-like mandible and maxilla with artificial teeth and have been reverse engineered. They can be used to test the efficacy of bridge, to simulate the wear of materials on dental components, such as individual teeth, crowns, bridges, or a full set of teeth etc. [10]

The mouth training robot: *The WY [Waseda–Yamanashi] series of robots have been developed for the training of patients with TMJ disorders. This robot is used for opening and closing a patient's mandible during a mouth opening training session. The most advanced version are WY-5 and WY-6. The WY-5 robot makes use of three*

translational components of the force to measure the biting force acting on it from the patient. The robot is operated remotely by a doctor robot that has two DOFs [for open/close and forward/backward movements] or three DOFs [for open/close, forward/backward, and right/left movements]. Muscular EMG measurements are incorporated into the WY robot to monitor any change in the patient's jaw muscle and to gauge robotic therapy. [9]

WJ (Waseda Jaw) series robots: *The WJ robot is employed as a patient robot to understand patient's mastication movement and resistance forces during jaw opening and closing training. This robot can also be used to evaluate and treat TMJ dysfunctions. These robots consists of two artificial TMJs and have three DOFs and implements artificially produced trajectories for clenching and grinding. The robot is driven by eleven artificial muscle actuators [AMA]; and each AMA is made up of a set of DC motor, encoder, wire and force sensor. The AMA was designed to simulate the forces of muscle contraction. One end of the tendon is attached on the robotic mandible and the motor pulls the opposite end. [9]*

Robots for treating TMJ disorders*: WAO-1 is an oral-rehabilitation robot [Waseda Asahi Oral-rehabilitation robot No. 1] developed at Waseda University, Japan. It consists of two 6 DOF arms with plungers, a body with headrest, a control box, a computer and an automatic massage trajectory generation system with virtual compliance control. This robot system massages the patient's face by pressing or rubbing with a plunger whose motion is automatically computer-controlled. WAO-1 is the first robot that provides massage to the facial tissues of a patient with oral disorders, to the muscles of mastication [masseter and temporalis] and saliva producing oral structures such as to the parotid gland and duct and hence may be used in the treatment of TMJ disorder and dry mouth. [11]*

Humanoid practice robot*: One big obstacle for dental education is that the employment of human subjects in clinical training is ethically tough. To overcome this issue, humanoid practice robots were introduced. Such robots are full-body model which can be positioned on a dental chair. They act like real patients and can mimic the movements and conversation of an actual patient through computer control. They react and make alerts, and may produce different reactions that simulate accidents that can occur during treatment like reaction to pain, emesis reflex, cough reflex and irregular pulse, when the students may end up doing faulty operational steps while getting dental training. An example of humanoid practice robot is Simroid. [6,12]*

Speech robots: *This was developed at the University of Canadian province in 2005. It consists of two 3-DOF parallel manipulators that drives the two TMJs, one at each end of the jaw. It has been developed to review the role of the jaw movements in perceiving and understanding face-to-face communication. However, no details have been published yet for this research. [9]*

Microrobotised dental implant surfaces: *Microrobotised dental implant surfaces can be used to obtain a higher degree of bone-to-implant ratio and an enhanced biomechanical fixation between the bone and implant compared to the conventionally treated implant surfaces. [13, 14]*

Nanorobots: *Nanorobotics is the technology of producing robots at or close*

to the microscopic scale of a nanometer [1 nm equals one millionth of 1 mm]. For the application in prosthetic dentistry, nano impression material containing nano-filler is available. Nano fillers are integrated to polyvinylsiloxane material to enhance its properties such as flow, decrease the number of voids and thus provide more precision in the recorded impression and hence better model pouring. Nano robots can also be used for dentition re-naturalization procedures in esthetic dentistry. They excavate old amalgam restorations and remanufacture teeth with biological materials, indistinguishable from original teeth. [15]

Advantages of Robots:

1. *More accuracy and precision.*
2. *Stable and untiring, and hence can be used repeatedly without rest.*
3. *Able to accurately process and judge quantitative information fed into the system.*
4. *Decreased surgical errors (Eg. While filtering any surgical tremors, the system may provide scaled movements of the hands in millimetres).*

Disadvantages of robots:

1. *No judgment of the situation and hence unable to use any qualitative information.*
2. *Robotic surgeries are more resource demanding and have steep learning curves.*
3. *Dexterity requirement is high.*

Future needs: *Progress has been made in the research regarding the application of robot in prosthetic dentistry but it is not yet complete. Viewing from the state of the art of application of robot in prosthodontics more quality research and improvisation is needed to optimize the robotic systems with accuracy within the limited workspace of the oral cavity. Improvements in the Sensor and Control Technique, and a highly efficient and coordinated control algorithm for tooth-arrangement robot is also required to grasp and accurately arrange the artificial teeth. For dental implantology robot, the research in the future has to focus on the registration between intraoperative navigation image and preoperative reconstruction image, real-time acquisition, and feedback of drilling depth and the implant force. Human-computer interaction technology is also one of the key technologies of motion control of the robot in prosthodontics. For facilitating the operation, a sort of human-friendly computer interaction software ought to be designed to provide humanization input and feedback for the operators. [2]*

Conclusion: *The intervention of robotics in the field of prosthetic dentistry is no longer fictional but it is still at the stage of infancy. In this era of expeditiously growing ideas and technologies, quality research is required to maximise the use of this magnificent innovation. The use of robotic systems for providing the prosthetic treatment can improve the accuracy as well as the precision of the treatment provided under the supervision of expert clinicians. However, these artificial intelligence cannot obviate the veteran dentist for their expert skills and judgements. Also the patients will be needed to indoctrinate toward the acceptance of this technology along with clinicians for the betterment of mankind. The use of this artificial intelligence in the assorted field of prosthetic dentistry will be a topic of intense discussion in the near future and will be a common reality in a matter of time.*

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