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Dental Robotics: A Paradigm shift

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ABSTRACT: An emerging technology called robotics promises to transform healthcare practices. As science and technology progress, the use of robots in dentistry has aided in the creation of precise, intelligent, and minimally invasive dental procedures. Known as the "Father of Robotics," Joseph F. Engelberger created the first industrial robot in history. Many tasks have been computerized thanks to advancements in robotics and artificial intelligence. Nowadays, robots are employed in basic and applied dentistry research across different specializations. Clinically-required autonomous tooth-crown preparation, tooth-arrangement, drilling, and orthodontic archwire-bending robots have been developed. Robots, in our opinion, will soon alter the way dentistry is currently practiced and provide new avenues for advancement.

KEYWORDS: Robotics, artificial intelligence.

I. INTRODUCTION

[1] As we are witnessing a new world of automation affecting the way we live, learn, work, travel, and much more. Automation refers to technology that executes functions that humans would otherwise perform, from gathering information to acting. [2] Robots are devices that carry out computer-programmed, automated manual tasks. An increasing number of tasks, particularly tedious and hard jobs, have been automated thanks to advances in robotics and artificial intelligence. Robots are becoming more and more intelligent assistants and coworkers in many public spaces, delivering consistently high-performance, economically relevant work.

[3] One prominent application of automation within the healthcare industry is the use of robotics for dental work. Enhancing dental healthcare both quantitatively while standardizing existing practices is highly desired. [2] Robotic automation and technological assistance opened several doors in dentistry to improve the state of dental care. Robots could spare human resources for more crucial duties like patient interaction or other jobs requiring advanced cognitive abilities. Dentronics may enhance the accuracy and effectiveness of dental treatment.

[4] Automation and robots attempt to address some of the issues related to current dental procedures, including limited space and poor visibility for navigation, hand tremors due to fatigue and vibrations from instruments like drills, unstable postures that exacerbate the effects of fatigue and patient mobility. [5] Additionally, these robots reduce procedure time and increase accuracy, efficiency, quality and reliability of procedures, decrease the risk for complications such as bleeding, infection, swelling, and post-operative pain. Robotic systems have applications in education. Before working with actual patients, dental students can receive basic instruction through full-body robots, and advanced simulation.

II. HISTORY OF ROBOTICS

[6] The Programmable Universal Machine (PUMA 200, Westinghouse Electric, Pittsburg, PA, USA) was the first robot to be used in medicine over 25 years later. Its purpose was to align a needle during neurosurgical biopsies. In 2000, the USA Food and Drug Administration (FDA) approved the first robotic system for performing laparoscopic surgery in a doctor-robot setup. In 2001, the validation of the doctor-robot concept was performed via a transcontinental live robotic cholecystectomy. [7] Since then, experiments with robot technology in many fields of dentistry have been described, for example in implantology, restorative dentistry and education.

Some robotic solutions have become commercially available in recent years and are marketed for use in the general dentist practice, such as the implantology robot 'Yomi' (Neocis, Miami, Florida, USA).

III. APPLICATION OF ROBOTICS IN DENTISTRY

1. Dental implantology

[8] One of the greatest challenges with the implanting process is navigation, which can be remedied through computer-aided static or dynamic navigation and advances in automation can provide support for implant dentistry. However, location of missing tooth and limited mouth opening may affect the operator's working position resulting in fatigue and human error. Implant placement is now more flexible, stable, and accurate thanks to robot assistance.

[9] Boesecke et al introduced the first dental implant placement using robot guidance in 2002. With a working region scope of 70 cm, the robot system carried out the implant drilling guide to assist the surgeon in the procedure known as implant osteotomy, in which 48 dental implants were positioned 1-2 mm from the apical border. [10] A root-shaped dental implant was placed in 2012 by an autonomous robotic system with six degrees of freedom (DOF) using a volume-decomposition-based system. this was followed by the creation of a 3-DOF robotic system with a stereo camera that could recognize and adjust the dental handpiece in order to guarantee implant positioning and placement in accordance with the preoperative protocol. The computer automatically applied the planned surgical procedure to guarantee the right cutting site and force was applied correctly.

[11] In 2017, FDA approved the first computerized navigation robotic system - YOMITM (Neocis, Miami, FL, USA) to improve the clinical accuracy of dental implant surgery by offering physical guidance for the drill's depth, orientation, and position. [12] Zhao unveiled the first autonomous implant placement system in 2017. Surgical tasks can be altered automatically with a high degree of autonomy, and procedures can be carried out without the need for dentist intervention.

[13] In 2017, an autonomous dental implant robot was also designed by Beijing University and the Fourth Military Medical University Hospital in Xi'an, China to address China's scarcity of highly skilled dentists as well as prevent surgical errors. [13] Fan S etal studied in vitro insertion of zygomatic implants in edentulous maxilla using autonomous surgical robotic system and observed a high degree of accuracy in the implant placement. Additionally, robotic implantology has proven effective in complex implant situations where alveolar bone has significantly decreased.

[14] The primary functions of intelligent robots in oral implantation include digital 3D scanning of the implant site prior to surgery, along with imaging data collection and diagnosis analysis, designing the plan for digital implant surgery plan and instantaneous directions and autonomous drilling during the procedure to enhance surgical precision, to lessen trauma to the patient, and expedite the healing process.

2. Oral & Maxillofacial Surgery

[15] Oral and maxillofacial robotic surgery has emerged as a promising treatment option particularly for oropharyngeal carcinoma. The da Vinci system was approved by the US Food and Drug Administration in 2009 for the transoral treatment of certain malignant as well as all non-malignant oropharyngeal lesions, including those that are situated at the base of the tongue and larynx. Clinicians are using computer-assisted dental implant surgery more and more frequently. The system makes use of both the bi-dimensional radiographs and cone-beam computed tomography (CBCT) analysis. [16] Additionally, robotic surgery is performed in the upper aerodigestive tract, which is accessible through the mouth. With its stereoscopic vision, multiarticulated instruments, and robotic arms, transoral robotic surgery minimally invade the oropharynx.

[17] Transoral robotic surgery has been widely used for the surgical treatment of obstructive sleep apnea in addition to the treatment of pathological conditions. For obstructive sleep apnea, continuous positive airway pressure is the accepted line of treatment. However, there are significant problems with continuous positive airway pressure treatment, including intolerance and poor patient compliance. [18] In 2010, Vicini et al first proposed transoral robotic surgery for treating obstructive sleep apnea. Obstructive sleep apnea can be treated surgically with a variety of techniques, such as bariatric surgery, weight loss in morbidly obese patients, maxillomandibular osteotomy, hyoid bone suspension, resection of the tongue base using CO2 laser or radiofrequency, uvulopalatopharyngoplasty etc.

[19] The process of mandibular reconstruction is difficult and complex. Two teams of surgeons must typically work together for at least seven hours to complete a conventional reconstructive surgery. Robot-assisted surgery has become popular as an alternative to manual surgery because of its limited accuracy and need for human resources. A high degree of accuracy was demonstrated by the pre-programmed osteotomies carried out by a robot (KUKA, Augsburg, Germany) in experiments on fibula free-flap mandible reconstruction.

[14] A robotic system has also been developed to aid in the repositioning of bone segments during orthognathic surgery. Robots for specialized procedures in oral and maxillofacial surgery, like velopharyngeal surgery, are also being developed.[20]

In a nutshell, robots are primarily used in oral and maxillofacial surgery for two tasks- acquiring and reconstructing preoperative 3D image data of the oral and maxillofacial region, analyzing lesion characteristics, and creating a targeted operation plan and precisely segmenting, reshaping, displacing, and fixing the craniofacial bone in accordance with the surgical plan.

3. Prosthodontics

a. Tooth arrangement

[21] The development of robots that prepare and arrange teeth has been the main focus of recent research. These machines exhibit high levels of cognition and accuracy. In prosthetic dentistry, robots could fabricate full or partial dentures. using a computer program that incorporates the skill of technician and experience of dentist. Both technically and theoretically, the study of robots in prosthetic dentistry would be revolutionary. Its successful completion would advance prosthetic dentistry in addition to achieving the quantification of the partial or complete denture.

[22] Canadian researchers created a single-manipulator robotic system that uses a 6-DOF CRS robot to fabricate a full denture. A 3D virtual tooth arrangement program is written in VC++ and OpenGL. This virtual three-dimensional tooth arrangement program generates or choose a file pertaining to the patient's medical history, use an expert's experience to create a jaw arch and dental arch curves based on the patient's measurements and displays 3D virtual teeth on a screen and adjust each tooth's position.

[23] Zhang et al. were able to create an optimal dental arch for the patient by creating a robotic manufacturing system to arrange teeth for complete dentures. Initially, the patient's jaw arch parameters were acquired, and tooth-arrangement software was used to create control data. Then the robot picked up the artificial teeth, the tooth-arrangement tool, and the intermediate blocks and put them together. Ultimately, the entire denture was changed when wax was poured into the tooth-arrangement aid to create a fixed tooth arch. The same group made great strides toward creating robots that arrange teeth. A 50-degree-of-freedom multi-manipulator robotic tooth arrangement system allows the fabrication of a complete denture in just 30 minutes.

b. Tooth preparation

Currently, dental handpieces with high speeds are used to prepare teeth. There are, however, a lot of related risks. Dentists must simultaneously strive to meet precise tooth preparation standards and prevent harm to the delicate tissues within the small oral cavity. Over- or under-preparation can lead to issues like pulp inflammation and heat sensitivity, which can damage soft tissues and lower the quality of the restoration.

[24] LaserBot is a microrobot device that was introduced in 2013 in order to accomplish clinical tooth-crown preparation. This robotic device precisely controlled a femtosecond laser beam in three dimensions. Furthermore, because of its small size, the device could be installed on any tooth.

[25] Otani et al evaluated the precision and accuracy of traditional freehand tooth preparation versus an automated robotic system for porcelain-laminated veneers and found that the robotic tooth-preparation system's accuracy was comparable to that of the traditional freehand method.

[26] Yuan et al presented a tooth preparation robotic system that included the following hardware components: (a) a tooth fixture that serves as a link between the target tooth and the robotic tool, protecting the neighboring tooth from laser-cutting; (b) a 6-DOF robotic arm; (c) an effective low-heat laser suitable for hard tissue preparation; (d) CAD/CAM software to create a 3D laser motion path and design the target shape for tooth preparation; and (e) an intraoral 3D scanning device to gather 3D information about the subject's teeth fixture, opposing teeth, neighboring teeth, and the target tooth.

c. Articulation

[27] Following the arrangement of the artificial teeth in the CAD software, the occlusal relationship can be modified by using the virtual articulator to simulate jaw opening and closing, forward/backward, and lateral movements. Apart from virtual articulators, robotic articulators are also under investigation. A novel kind of robotic articulator replicates the patient's functional mandibular movement with six degrees of freedom using an accurate six-axis micropositioning stage. A full veneer crown restoration can be created with this articulator system without requiring intraoral occlusal setup modifications. The system shows promise for increasing denture occlusion accuracy because the articulator can replicate dynamic jaw movements during functional jaw movements with high accuracy. But since only one patient has been looked at, more investigation is required to assess this.

4. Orthodontics

[29] Malocclusion is a common oral condition that affects oral function and health in addition to appearance. Furthermore, a number of gastrointestinal conditions, including dyspepsia, are brought on by diminished masticatory function. The most popular and successful orthodontic treatment for malocclusion is fixed orthodontic therapy, and the most important part of this therapeutic approach is the bending of the orthodontic arch-wire (OAW). The two main pillars of conventional orthodontics are manual treatment and visual inspection. Because of the hyper-elasticity of OAW, the ambiguity of manual operation, and the intricate morphology of the formed OAW, it is difficult to realize the bending of OAW.

[30] The SureSmile OAW bending robot, which is part of the robotic system for bending orthodontic arches, is mounted on a table or other surface that provides support. SureSmile uses a robotic system to customize fixed orthodontic appliances and uses state-of-the-art 3D computer and imaging techniques for diagnosis and treatment planning. Anticipating the treatment can help with detailed planning of the course of treatment. The main objective of using CAD/CAM is to raise the standard, effectiveness, and consistency of orthodontic treatment.

[31] For quick and precise OAW bending, Gilbert created LAMDA (lingual arch-wire manufacturing and design aid). This system can only realize motion in the XY plane; as a result, it cannot bend the OAW with closed-loop. An additional robotic system for bending the OAW is MOTOMAN UP6.

Robots that bend orthodontic archwires are inexpensive, have a straightforward design, and are capable of bending a variety of archwire kinds. This lessens the doctor's labor intensity, avoids the fatigue fracture of the archwire brought on by frequent bending, and enhances the effectiveness of the treatment.

5. Endodontics

[32] The technique of root canal therapy requires a high degree of accuracy and precision. To ensure adequate vision of the root canal system, an endodontist typically uses magnification in their work. A robot system to help with root canal therapy was proposed by Nelson and associates. The authors hypothesized that the "vending machines" main purpose was to supply the dentist with the tools needed for root canal therapy as it was being performed. [33] A recently published report examined the robotic system in the lab and proposed using micro-robots with catalytic capability to segmentoral biofilms inside the root canal. Additionally, the researchers described the use of these robotic systems for other purposes, such as implant infection prevention or dental caries.

[34] A K-shaped file or rotary file breaking in the root canal during root canal therapy carries a risk of creating a root perforation. "Omni Phantom" has been created to assist users in effectively training in endodontic procedures. The process of cleaning the inner surface of the root canal and burring the enamel and dentin can be experienced by the user through the use of a simulated K-file.

[35] At Columbia University, Hong Seok put forth the idea for "The Advanced Endodontic Development." The goal of this project was to create an intelligent microrobot that is capable of autonomous endodontic treatment. Dong et al. talked about the mechanical layout, production, and innovations of this robot. The conceptual design calls for mounting the robot on a number of the patient's teeth while two-dimensional radiographic pictures are used to create a three-dimensional model of the tooth. The treatment protocols will be designed by a prescription system, and the microrobot will carry out automated root canal drilling and filling.

Apart from the robotics employed in endodontic therapy, the advancement of micro-endodontic robots can surmount the constraints of conventional treatment, like inadequate oral

opening, and offer patients a more dependable, accurate, and secure root canal experience. Nonetheless, more investigation is still needed to design and produce microsensors and actuators.

IV. LIMITATIONS

It is an acclaimed and acknowledged truth that innovations come with new challenges. Likewise, Robotics has limitations like high cost and skilled learning of robotic technology. Another limitation of Robotics is acceptance by patient and Dentist both. According to a research, female patients do not prefer robotic treatment. Not only sexual orientation but also, if procedures have incurred invasiveness, acceptance decreases.

V. CONCLUSION

Entire generation is moving towards a novel age of Robotics. Dentistry too, is metamorphosing into Robotic Dentistry. Robotics with Artificial Intelligence has changed the face of Dentistry. Last few decade scientists are working on Robotic system with improved instructional efforts, hence working in direction of better health care system. Few technical and cost related issues are acting as obstacles. Since research has been going on, scientists are trying to overcome these limitations of cost and limited sensory capability of robots. Soon Dentists well acquainted with Robots will work wonders in their field. Its beautifully quoted

Hope is a belief in a better tomorrow

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