

A Review of Robotics in Dental Implantology

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Abstract

Technology has become a part of everyday life, whether at home, work or just pretty much anywhere. It is so prevalent that it is hard to imagine a practical life without it. This is true in the field of Dentistry as well where technology is becoming a part of everything that a Dentist or a patient interacts with. This review article aspires to give the reader a robust overview on one part of this technology called Robotics in Dental Implantology. There are many literature articles published on computer-aided or assisted Implantology but none with a focus on robotics exclusively for a specific dental application of Implantology. This paper will give a comprehensive overview of Robotics, its role in Implantology, types of Robotics in use in Implantology thus far and its impact on Implantology.

Key Words: Robotics, Dental Implants, Periodontitis.

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Introduction

According to National Aeronautics and Space Administration (NASA), Robotics is the study of robots which are machines that can be used to do tasks either by themselves or have a person telling them what to do¹. Current Robotic technology has increased its abilities such as precision, sensing, repeatability and controls which makes it more suitable in the field of medicine². In the past, robotics was used in cleaning floors, washing equipments and delivering hot meals to patient's bed but its use has been extended to assist surgeries and surgical planning³. In Dentistry, robotics has not seen a widespread application like other fields. Some of the known dental applications of robotics are; as teaching aids for dental students to simulate real patients, dental surgery and Implantology to include image-based simulation of implant surgery and drilling. While more research and trials are being carried out to fully exploit the benefits of robots from enabling and improving accuracy of dental procedure to may be fully replacing dentists in the future, the discussion in this paper will focus on how robotics are being applied in Implantology

Role of Robotics in Implantology

Although dental implants date back to thousands of years, it wasn't a major breakthrough until the 1980s. Many medical research teams in the 1990s used interactive computer applications including hardware and software as an aid for implant planning⁴. For instance, SIM/PLANT a computer guided implant treatment was the first commercially released software in 1993 which provided the clinicians with the ability to view and interact with the CT scan data to pre-surgically place the implant body and visualize the prosthodontic implications virtually at the same time⁵. In the late 1990s, it was robotics that extended the application from pre-surgical plans into mainstream surgery through automated monitoring of surgical procedures via sensors⁴. Fast forward to 2017, a

Chinese robot dentist successfully fit implants in patient's mouth without any human involvement.

Despite Implantology being considered one of the hottest fields in Dentistry, complications due to human errors are inevitable. Damage to adjacent nerves and improper placement are the most common complications of Implant dentistry⁶. A summary of human error caused in implant surgery are:

- Damage to crown or the roots of adjacent teeth. As a result a root canal or apicoectomy is needed to repair the injured tooth roots.
- When implant surgery is done on the lower jaw, inferior alveolar nerve may get damaged which causes pain, numbness or tingling in teeth, gums, lips, tongue or chin. The same symptoms can occur when the implant is placed right on top of the nerve which causes severe pain when chewing. If the nerve damage fails to heal by itself, then the implant may have to be taken out.
- Drilling through the jawbone into the sinus cavity is another complication during implant surgery.
- Sometimes, fracture of the jaw may occur if there is not enough bone or bone density.
- Pressure and trauma of the soft tissue around or under the implant due to improper placement or size of the abutment and crown restoration which may aggravate implant complications.

These complications arise due to the fact that the Dentist stray away from the correct location, depth and orientation of the plan while still controlling the actual drill delivery which requires extra-ordinary skills of the Dentists. Technology especially robotics or robot-assisted Implantology has been seen as a solution as it would eliminate the burden of Dentists and Patients. As mentioned earlier, while there are many technological advancements that aid Dentist in Implant surgery, this paper will focus specifically on Robotics and its application.

Robotic application in Implantology can be broadly classified into Robot-assisted Implantology and fully-autonomous Implant Robots. A Robot-guided Implantology increases accuracy and aesthetics in dental implant procedures through visual and physical guidance and a simple digital workflow⁷. A fully-autonomous implant robot on the other hand is independent under the supervision of a Dentist⁸.

Robot-guided Implantology

Robot-guided Implantology is spearheaded by Neocis, a company based in the United States of America (Miami, Florida, USA). Founded in 2009, this organization has been approved by Food and Drug Administration (FDA) to use its flagship product "Yomi" with real-world patients in a clinical setting⁹.

According to the consortium on cognitive science instruction, a robot has three basic components; sensors, effectors and control systems¹⁰. Sensors help robots gather information about the environment to guide its actions. Some of the commonly used sensors are microphones, buttons, cameras etc. An effector of the robot is the one that actually does the work. An example of effectors is robotic arms helping a surgeon pick a surgical knife. Control system also known as the brains of the robot determines the behaviour of the robot. Yomi in its simplest form consists of these three basic components.

The primary input to the robot-guided Yomi comes from a CT scan. The CT information is then fed into dynamic planning software that allows the surgeon plan the surgery accounting for key anatomical features like the nerves, sinus and adjacent teeth¹¹. This step sets the parameters of the implant surgery and establishes limits for visual and physical guidance. As shown in Figure 1, visual guidance is a real time three-dimensional graphics that provide navigation during surgery and confirms progress. Physical guidance is provided by the robotic arm (Figure 1) which guides the surgeon to position and drill till appropriate depth.

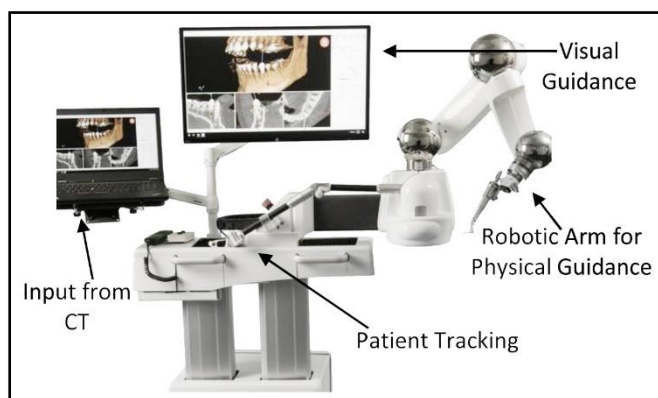


Figure 1: Yomi: Robot-Guided Implants

This collaborative robotic arm enables minimally invasive surgery which leads to faster surgery, faster recovery and less pain for the patients. The robotic arm physically constraints the surgeon's drill movement to match the plan through Haptic guidance technology. Yomi prevents any deviation from the plan with full view of the surgical site. The surgeon precisely drills into the osteotomy and is stopped when reaching the planned depth. Patient tracking throughout the surgery is done through intra-operative tracking that maintains accuracy throughout the surgery and follows the patient if they move.

Robot-guided implants like Yomi comes with its own merits and limitations. Advantages include extremely high accuracy and precision, stable and untiring repeated performance and ability to accurately process quantitative information fed into the system¹². Limitations include the fact that the judgment of the situation is limited to the data fed into the software and/or tracked by patient tracking system, supervision by an experienced Dentist is still required and the cost of the system is prohibitive¹².

Fully-Autonomous Robotic Implantology

Chinese Robot dentist made headlines in 2017, when it successfully fitted two new teeth into a woman's mouth (Figure 2)¹³. The one hour procedure resulted in implant fitted within a margin of error of 0.2-0.3mm. The artificial teeth the robot implanted were created by 3D printing which is another breakthrough technology gaining popularity among Dentists since early 2000s¹⁴.

This fully-autonomous surgery by a Robot being the first of its kind, it involved a lot of planning and multiple Dentists supervision. The dental staff fitted position orientation equipment to the patient and the robot was programmed to move into the correct position to carry out the surgery in a pre-determined movements, angle and depth needed to fit the new teeth. The robot adjusted its positions in-line with patient's own movement. The functioning, process and set up is very similar to Robot-guided Implantology discussed above with the exception that in an ideal implementation a fully-autonomous robot will require minimal to zero Dentist involvement.

This fully autonomous Robot took four years to develop jointly by the Stomatological Hospital, based in Xian, and the robot institute at Beihang University in Beijing¹³. The technology is still in its infancy in a demonstration stage when compared to Robot-guided technology which Neocis (maker of Yomi) claims that the units are being sold to Dentists in the USA. Nevertheless the achievement is significant and has set a high bar for Implant technologies being developed.



Figure 1: Robot Dentist fitting two teeth into a women's mouth in China

Impact of Robotics in Implantology

While technology is catching up in Dentistry in comparison to other medical field, Robotics is fairly a very new term in dentistry. Hence, mainstream deployment of Robotics is very limited and so are its evidences in a clinical setting. However, a literature scan for the evidences for success of robotics returned limited scholarly review, so the search was expanded to include robotics and computer-assisted studies which hopefully establishes the building blocks in the evaluation of Robotics in Implantology.

A phantom experiment of image-guided robotics for dental implantation concluded that the system accuracy is comparable to other similar systems for dental implantation with a Fiducial Registration Error (FRE) and Target Registration Error (TRE) values recorded as less than 0.30 mm and 1.42 ± 0.7 mm¹⁵. FRE is a common measure which is the root-mean square error in fiducial alignment between image space and physical space. The estimate of FRE error is an indication of the accuracy of the system's ability to provide guidance to surgical targets for a given case¹⁶. TRE is the measure of displacement of actual probe from the target in a guidance system¹⁷.

In another study of analysis of all of the major data sources including unpublished data in the internet, computer-assisted/-guided/-aided Implantology has been found to overcome the errors encountered during implant osteotomies and positioning precisely¹⁸. In a meta-regression analysis of 2,827 studies to summarize the accuracy and clinical performance of computer assisted implant systems, the mean error was estimated at 0.74 mm (max value of 4.5 mm) at the entry point in the bone and 0.85 mm (max of 7.1 mm) at the apex.

In a clinical study of 102 patients involving 250 implants in armed forces dental clinic in Germany, the patients were treated with a system that allows transfer of virtual planning of implant positions using

cone beam CT data to surgical guide template. The results concluded that in all cases critical anatomical structures were protected and no complications were detected in postoperative panoramic radiographs¹⁹. A flapless surgery plan was realized in 58.1% of the 250 implants¹⁹.

These literatures conclude promising evidences in robotics and many building blocks of robotics such as the computer-assisted Implantology. But, a more mainstream implementation and wider population study should lead to more robotics dominance in Implantology.

Conclusion

In general Robotics and technology lags in Dentistry compared to the pace of technological adoption curve in other major job markets such as industrial and information technology. Dental Implantology however has seen a remarkable adoption of technology evolving from computer-aided surgical planning to fully autonomous. This could be attributed in part to the complexity and human induced errors involved in Implant surgery especially damages caused to adjacent nerves and improper placement of implants. Robotics has seen its application in the automation of either a portion or all of the implant surgical process in a Dental office. Robotics-guided Implantology, that is partial automation of implant procedure, is more advanced from a technology maturity stand-point. The Dentist is still in control of the process and it minimizes patients' burden. Fully-autonomous robotic Implantology has sure gained interest but the technology is still in its infancy and it is expected to stay that way for the foreseeable future. Irrespective of the type of robotics, the benefits seen in error reduction and in minimizing patient burden will outweigh the cost associated with this technology for some of the developed economies such as US and Europe. According to the Oxford university study, the job of a Dentist is one of the top 10 jobs that a robot will never replace with only a 0.4% of a chance of automation²⁰. This paper did find evidences that could push the limits of the validity of this study by a tiny bit. Whether the risk is seen to the profession or not, the entire dental community can agree to the fact that Robotics will surely have a positive impact on Patients.

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