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RESEARCH ARTICLE

FUTURE OF ROBOTICS AND TELE-DENTISTRY IN DENTISTRY

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Abstract: When one thinks of robotics and dentistry, one thinks about a day when a robot would be conducting surgery or taking X-rays. The dream has already come halfway through. So, if we snap out of our dreams and think about them practically, One would be surprised to see how robotics have taken over the healthcare industry like a storm. Robots can help surgeons or doctors by assisting and performing procedures. Therefore, if one thinks about the future of robotics, it will be streamlined through robotic surgeons and tele dentistry (Gurbuz, E., Gungor, M., & Hatipoglu, H. 2021). This paper is going to showcase how advanced robots are and their achievements. Also, it is going to showcase what the future might look like in the field of robotic dentistry and tele dentistry. Moreover, there will be a question of whether the benefit is worth it to patients or whether the advancement will create more problems in patients' lives.

Key words: Robotic Dentistry, Dental Robotics, Healthcare Automation, Robotic Surgery, Tele dentistry, Artificial Intelligence in Dentistry, Dental Technology, Medical Robotics, Future of Dentistry, Robot-Assisted Procedures, Dentistry Innovation, Healthcare Robotics, Digital Dentistry, Automated Dental Procedures

INTRODUCTION

The study and implementation of robots started years back. But in different forms. Coming to the dental world. Initially, there was an advancement in the process of taking x-rays. Not in a robotic form, but advanced machines were developed to ease the process of taking X-rays. Later, oral surgeons and dentists displayed the need for more detailed patient information, which led to panoramic and computed tomography being used in the picture. Hence, x-rays have advanced from film to digital sensors in diagnostic procedures. Further, the whole mouth advanced from a complete mouth series to a panoramic and from a panoramic to computed tomography.

In the treatment sector, it advanced from taking impressions to digital scanning of the tooth (Gurbuz, E., Gungor, M., & Hatipoglu, H. 2021). The implant surgeries advanced from placing the implant by the surgeon to surgeons using robots for guided implant surgeries. The future of robotics will level up in the next 10 years. Fortunately, the United States of America has developed the USA's first robot to provide guide surgeries. The haptic technology has left everyone amazed. The advancement will guide the surgeons and them in producing accurate and desired results for implant surgeries. The robots will reduce all human errors, and the doctor can perform complex surgeries. There will be utmost precision in their work which w, which will provide the best rest and enhance the quality of treatment (Gurbuz, E., Gungor, M., & Hatipoglu, H. 2021). In the past, robotics only helped to perform minimally invasive surgeries, but due to its advancement, it can now perform any complicated surgeries without minimal errors. In the field of robotics, innovation has led to trends like micro-robots and robotic arms, which have expanded the role of robots in the robot sector. The only drawback of robots is the cost of treatment, which has led to less adoption of its technology. Regardless of the drawbacks, healthcare still invests in robotics to stay at its edge (Gurbuz, E., Gungor, M., & Hatipoglu, H. 2021).

Coming to global markets, in 2018, the surgical robotic industry was valued at USD 3.9at billion and is estimated to reach USD 6.5 billion by the

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end of 2the 022. The United States of America and Europe are among the topmost countries in the robotics field. Fortunately, after seeing the advancement of many co, many countries are following the path of robotics in all healthcare fields. When Covid19 pandemic broke out, the field of telesurgery took center stage. However, compared to teledentistry, it is not as beneficial as telesurgeries. Telesurgery is known to be a surgical procedure that is carried out at a distance with the help of robots and computer technology. In the USA, it was first conducted by one of the surgeons of New York in 2001, who performed surgery on a 68-year-old woman in Strasbourg. France adopted telesurgeries in 2020. Moreover, due to the lockdown, surgeons could not perform surgeries, so the 5G technology has also contributed to the adaptation of telesurgeries. However, compared to tele telemedicine has not provided more benefit benefits in dentistry.

Figure 1. Image showing a growth rate of implant market (Gurbuz, E., Gungor, M., & Hatipoglu, H. 2021)

METHODOLOGY

1. Robotics in Digital Imaging :

a. Dental X-rays

Dental X-rays have brought advancements from developing films to using digital sensors. Further, advancements have been brought from wired digital sensors to wireless ones. Now, there are some advantages to using digital sensors over developing films. Some are

- 90 % less dose as compared to E-speed film
- Image quality can be manipulated after image acquisition.
- Contrast and intensity can be altered.
- Diagnosis is accurate
- Length can be measured on a digital image.
- Highly important in diagnosis and treatment planning
- A huge asset in planning surgeries for malformations, tumor investigation, and trauma.
- Through digital radiography, the same image can be used for different diagnostic purposes.
- For example, marginal bone loss measurement can be done with a lighter image view, and caries detection test can be done with darker images.
- The image can be seen immediately after post-exposure.
- However, there is a lag time between appearance and scanning due to the pressure-sensitive paint method.
- However, compared to the conventional method, it is the faster method.

The only disadvantage of using digital sensors is the price of the sensors compared to developing films. Due to their structure and making, the sensors are expensive compared to developing films. Also, the digital sensors took the course from PSP (Photostimulable Plate) to CCD (Charged-Couple Device) and CMOS (Complementary Metal Oxide Semiconductors) (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021).

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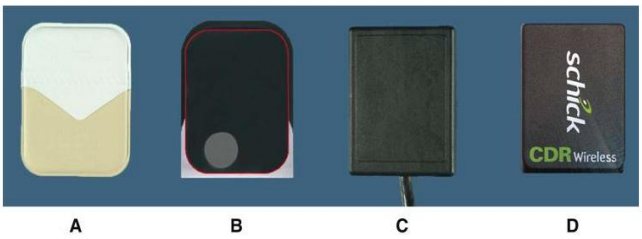

Figure 2. Image showing different types of digital censor

(Shah,N. 2014)

b. Panoramic

Panoramic imaging has been popular since the 1950s. It is considered one of the most important diagnostic tools used in specialized tomographic techniques that produce a flat representation of a curved surface. Its main principle is curved surface tomography, as it scans the entire maxilla, mandible, temporomandibular joints, and its related structures on a single film. In other words, it gives a panoramic or bird's eye view of the jaws. The main advantage of using panoramic is that no radiation is left in your body after the x-ray. It can provide valuable information that is important for diagnostic purposes. It is the best tool for dentists or oral surgeons to diagnose oral disease. It benefits young patients as no sensor or film must be placed inside the mouth. It can help to diagnose advanced periodontal disease, cysts, tumors, oral cancer, impacted teeth, jaw disorders, sinusitis, and many more oral pathological lesions. It is the most painless, fast, and easy way to conduct. Moreover, panoramic can act as an excellent diagnostic tool for patients with gag reflexes. However, every tool has some limitations.

The limitation of taking panoramic is that it does not provide detailed or precise information about each tooth or soft tissue. It can be used for initial evaluation purposes only. Also, due to the flat image of a curved structure, it can showcase some blurred vision; hence, measurements of teeth or bones would not be accurate. The relationship of the tooth to its surrounding structure cannot be monitored. Each tooth is analyzed in a mesial-distal direction, and the Bucco lingual direction is inaccessible. It can be used for routine dental practice and not expertise. A CT scan is an appropriate diagnostic tool for more precision, which will be discussed later. Below is the image of a panoramic film.

c. Computed Tomography (CT) scan

It was first developed in 1972 by Sir Godfrey H Hounsfield. It is known to be the most significant advancement So far in radiology. Now, CT has a narrow fan-shaped X-ray beam and uses various exposure sites to scan the internal structures. In other words, it provides a 3-dimensional view, which helps the provider to diagnose the case more efficiently.

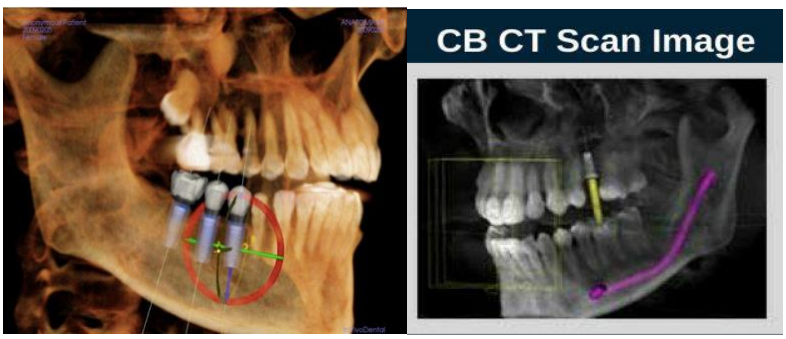

Figure3. Image showing pictures of CBCT scan of the maxillary and mandible (Cheng, K., Kan, T., Liu, Y., Zhu, W., Zhu, F., & Wang, W. et al. 2021)

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Digital Subtraction Radiography (DSR)

This is a technique that is used to analyze qualitative changes between 2 images that are taken at different points in time. This method was introduced by B.G Zeides Des Plantes in the 1920s. It is used for research purposes only.

d. Dental Implantology

Dental implants solely depend on the precision of their placement. The doctor uses a template guide and related navigation system to reduce the errors of implant positioning at the time of placement. There are some limitations to this procedure as well. There is often a minimal opening of the mouth, so it becomes tough for the provider to maintain his chair-side position for a longer time in that direction. The provider does experience fatigue, and the chances of errors during the procedure increase (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). Hence, the robot comes into the picture. Robot-assisted implant surgeries increase flexibility and stability and provide accuracy in implant placement. Further, computer assistance is formed to guide the implant placement procedure. In dental implantology, CT-scan analysis is the most important step in implant placement. Robotic-assisted implants do require surgical tracking for accurate placement in real-time. In 2002, the first robot-guided implant surgery was performed by Boesecke et al. It was a guided implant surgery where 48 implants were placed. Later, in 2012, there was an innovation of an autonomous robot that provided 6 degrees of freedom (DOF) for a root-shaped implant (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). Later, the 3-DOF robot was developed with a stereo camera that could identify dental handpieces and modulate them for the correct positioning of dental implants.

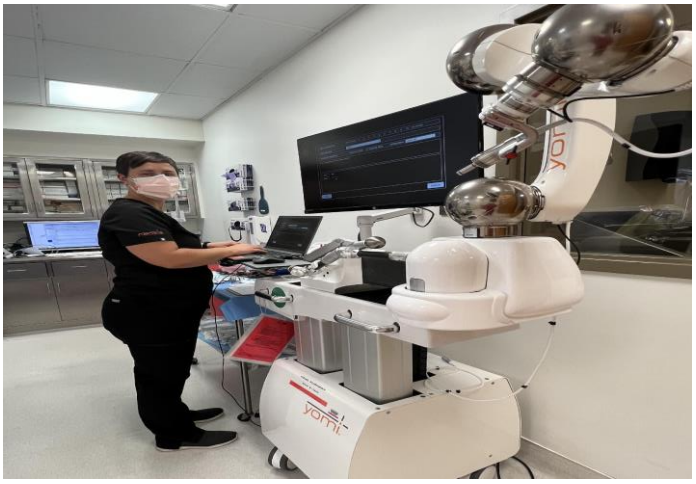

Figure 4. Image showing YOMI Implant robot (Hinali, 2022)

In 2017, came YOMI which was developed by Neocis, Miami, FL, USA. It is the world's first computerized navigation system that provides surgical guidance for implant placement. It is the first robot approved by the FDA that augments clinical precision for dental implant surgeries (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). The robot has haptic technology that can read providers' movements and help them plan the treatment. Further, Yomi guides the provider with detailed precision of measurements, and the technician assures that YOMI and the provider work together. The most important thing is that YOMI never overrides the provider's expertise (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). Various steps are followed for surgical guidance. First, the provider creates a virtual plan for a CT scan. Now, the provider places the splint and does the CT scan again. Third, the provider now merges the latest CT scan with neocis acquisition. This way, YOMI can scan the surrounding area around the splint. Below in the picture are the screws and yomilink bone that help to connect

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the robot with the jaw of the patients that is approved by the FDA.

Figure 5. Image showing accessory instruments and guidance tools used while placing the implant through YOMI implant Robot (Hinali,2022)

e. Oral & Maxillofacial Surgery

The oral and maxillofacial surgeons encounter malignant lesions very often. Lesions of the oropharynx are especially not easily accessible. The conventional treatment plan is through radiotherapy or chemotherapy (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). In addition, there is Salvage surgery that Is conducted through mandibulotomy by mandibular displacement. Hence, robotic surgery is the main attraction for cases of oropharyngeal carcinoma. Again, these surgeries cannot be done without computer assistance. Therefore, the use of CBCT I with 2-dimensional radiographs is the tool without which the provider cannot proceed or start the treatment (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021).

f. Prosthetic & Restorative Dentistry

As per the statistical data displayed by the American Dental Association (ADA), there are about 118 million adults in the USA who have a minimum of 1 tooth missing, and there are 19 million who do not have teeth at all (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). So, after losing the teeth, the patient's masticatory and vocal functions are compromised due to a change in the morphology. Robots in prosthetic surgery can produce partial or complete dentures. This will not only protect but will stabilize the tempo mandibular joint. The rich technique where the experience of skilled technicians and dentists are compelled into the software (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). Later, the robot analyzes that technique creates a partial or complete denture, and regains full occlusion. Robots in prosthetic dentistry are not only a theoretical but a technical innovation as well.

g. Tooth-Arrangement robot

Canadian scientists has developed a 6 DOF single manipulator robotic system for the tooth arrangement in partial or complete dentures. It is composed of light-sensitive glue, denture base, light source device, control and motion planning, and modulation software (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). This will override the problems of the provider or dental lab technician to manipulate the tooth position precisely.

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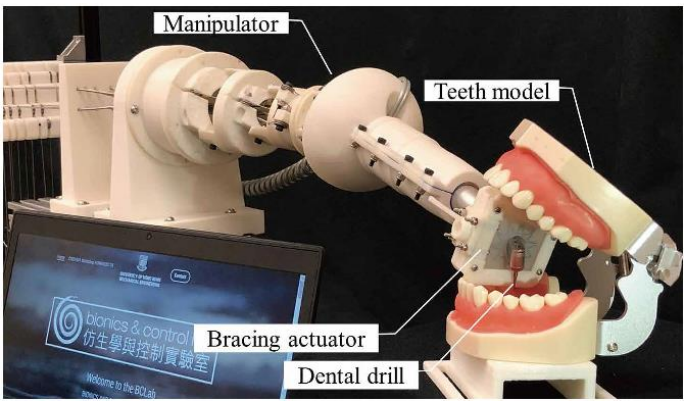

Figure 6. The image shows a robot arranging teeth in a manipulated position (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021)

h. Tooth Preparation

For dental clinicians prepping tooth for crown or bridge is very routine work. But still, clinicians face challenges even after their years of experience. Therefore, for clinicians, a robotic system that helps tooth preparation is very tempting and sensible. A 3D scanner is required to scan the required areas of the tooth for tooth preparation. The 3D scanner will be discussed later under cosmetic dentistry.

i. Orthodontics

For orthodontists, malocclusion is the key problem that influences appearance, oral function as well as health. Reduction in masticatory forces will give rise to many gastrointestinal disorders. The conventional method of any orthodontist is through manual operation technique. This has led to many limitations in clinical orthodontics (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021).

j. Robotic System for Bending Orthodontic Arch Wire

Suresmile Orthodontic Arch Wire bending robot is installed on the side table of orthodontists. The wire is then integrated into the mobile arm with the help of the gripping tool. The arm has 6-DOF with 3 rotational and 3 translational axes (Cheng, K., Kan, T., Liu, Y., Zhu, W., Zhu, F., & Wang, W. et al. 2021). Suresmile, with the help of a 3D computer and the imaging technique, guides to diagnose and plan treatment and employs the robotic system to create a personalized fixed orthodontic appliance.

k. Endodontics

Root canal treatment is a technique that requires utmost precision and accuracy. Hence, an endodontist needs a proper vision to have sufficient vision. Nelson and his colleagues created a concept of a robotic system to get assistance for root canal therapy. these mini robots have the catalytic capability to create disruption in the oral films that are present inside the root canal (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). The researchers also suggested the use of a robotic system in preventing peri implantitis or dental caries.

l. Oral Radiology

Oral radiologists generally can penetrate any part of the oral cavity in a very minimal invasive manner (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). Then why need of robot? Well, the robot can be handled remotely by the oral radiologist without a single exposure. X-ray and sensor/film can be performed by a 6-DOF robotic arm with no side effects. The accuracy is too good, with no adverse effects.

m. Dental Hygiene applications

Plaque removal by manual or powered toothbrush is the most common method for preventing oral disease. Hence, a robotic system can be used to analyze the effectiveness of

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toothbrushes based on their abrasive ability based on their repeatability, and comparability (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021). Hence, the robotic system can measure and alter the efficacy of cleaning the tooth.

n. Dental Education

The concept of using a dental training robot was first introduced in 1969. Later, in 2017, experiments were conducted to use robots as humanoids so that dental students could get accustomed to real patients in the real world. "Hanako" is the most valuable contribution to the dental field that emulates a human through expression and action. It can also show movements of the elbow, wrist, tongue, and jaw and shake its head in case of pain, roll its eyes, and can also verbally express discomfort (Ahmad, P., Alam, M., Aldajani, A., Alahmari, A., Alanazi, A., Stoddart, M., & Sghaireen, M. 2021).

Figure 7. An image depicts a dental student gaining practical experience using a dental training robot (Cheng, K., Kan, T., Liu, Y., Zhu, W., Zhu, F., & Wang, W. et al. 2021)

2. Robotics in cosmetic treatment like Invisalign through iTero scanner:

The iTero scanner can scan a tooth and its surrounding structure in a 3-dimensional figure. it also provides the after-treatment preview before the d=start of the treatment. It has a time-lapse technology that can show the change before and after the treatment. It can guide proper occlusion (Invisalign and Fixing Overbites, 2022). It can change the dimension of the structure as desired. It is used for restorative, orthodontic, and lab services (Invisalign and Fixing Overbites, 2022). It provides excellent visuals for crowns, veneers, only, and bridges. It can be used for cosmetic orthodontic treatments like Invisalign and Smile Correct. The advantage of the scanner in Invisalign treatment is that it is more comfortable, allows for better oral hygiene and it's a noninvasive scanning (Invisalign and Fixing Overbites 2022).

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Figure 8. Image of a scanner used to fix smiles and occlusion (Invisalign and Fixing Overbites 2022)

3. Tele dentistry

Tele dentistry is very beneficial to oral and maxillofacial surgeons but not to general dentists. For general dentists, it helps conduct a pre-exam consult, where a patient just calls to develop a rapport and have a general discussion before their visit in person. It also helped in treatment planning to discuss the course of treatment with the patient without the need to be in person. Follow-up is greatly beneficial, especially after major procedures like root canal treatment and implant placement (North Carolina Oral Health Collaborative 2021). For medication guidance, teledentistry is a great tool where patients can have all the details on the medication's directions through the phone and save a lot of time (North Carolina Oral Health Collaborative 2021). After COVID-19, tele dentistry has become a huge market for oral surgeons where surgeons can remotely guide other surgeons to conduct the surgery with ease (North Carolina Oral Health Collaborative 2021). This will not only help to tackle emergency treatment but will also help to waive commute and treat COVID patients at the same time. Teledentistry is beneficial for surgeons to conduct surgeries remotely with another doctor under one's guidance. But have a limitation as well. Patient benefits are very limited.

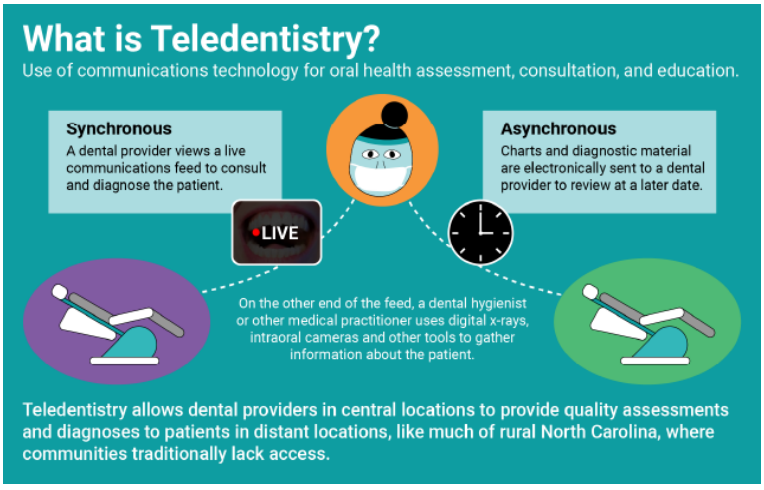

Figure 9. This image illustrates how tele dentistry has benefited patients in North Carolina (North Carolina Oral Health Collaborative 2021)

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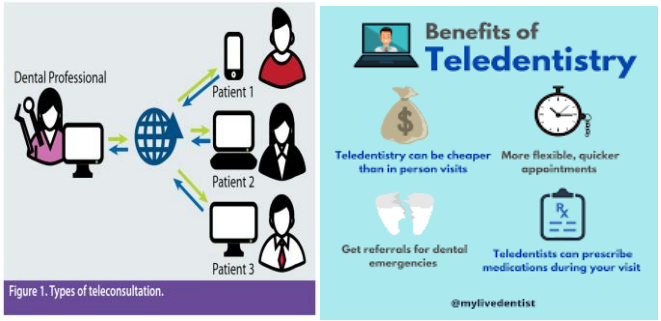

Figure 10. Image showing benefits of tele dentistry (North Carolina Oral Health Collaborative 2021)

MARKET RESEARCH AND ANALYSIS

Robotic Dentistry Market is expected to reach a 21.6% CAGR(Compound Annual Growth Rate) during the forecast period of 2022-2029. The dental surgery segment accounted for the largest share of the market in 2020 (Data Intelligence,2022). The segment is increasingly benefiting due to technological and computer science advancements (Data Intelligence,2022). This has led to an increase in the use of robotics, especially in the field of Oral Surgery. Robotics in dentistry provides an advantage over free-hand techniques to place instruments. This technology not only serves precision but also accuracy in the treatment. Overall, accuracy and precision will provide excellent quality of care (Data Intelligence,2022). Below is the list of key players in robotic dentistry in the market.

Covid -19 Analysis

COVID-19 has not completely but moderately affected the market of robotic dentistry. The unprecedented demand so f hospitals has given rise to robotic demand. The vision of robots has relieved the minds of patients of preventing pathogen spread. Lockdown did result in disruption of the entire supply chain of the healthcare industry, but robots have helped to overcome the insufficiency of the supply (Data Intelligence,2022). Also, according to the American Dental Association, 76% of dental offices were open only for emergency cases, and about 17% were closed entirely. 5% of offices were facing an extremely low volume of patients. Thus, there was a decline in procedure volume for a short period that limited the market expansion in early 2022 (Data Intelligence,2022).

Market Research and Analysis in Teledentistry

The global market of teledentistry is expected to reach USD 4.80 billion by 2030, based on the report presented by Grand View Research, Inc. The market of tele dentistry is expected to expand at a CAGR of 16.13% between 2022 to 2030 (Tele dentistry Market,2022). There is an increased use of smartphones and the internet in dental applications, which facilitates augmenting the industry market. Also, one of the other reasons for the rise of the market is the geriatric population (Tele dentistry Market,2022). which has led to the adoption of tele dentistry. Based on the benefit of being cost-effective and more convenient. The main players in the market are going for strategic initiatives, which include acquisitions, mergers, and software launches to maintain the edge of competition in the market. Below is the Tele dentistry market Segmentation (Tele dentistry Market,2022).

DISCUSSION

After all the analysis and knowing the methodology of robotic dentistry, here comes whether Robotic Dentistry will be a disruptive or destructive approach. Based on the details entailed in the methodology, the use of robotics in dentistry ranges from treatment to drug delivery. Robotics is gaining tremendous attention in the market. The change in dentistry is accelerating and will certainly continue to accelerate. Dental restorations and dental materials have

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transformed drastically over time. Dentistry has thrived and survived through the ages, regardless of the transformation. The care of orofacial and longevity of teeth is improving every year. Robotic Dentistry has altered the minds of dentists in performing their procedures and thinking (Ahmad P, 2021). The experience of patients is also improving. If about YOMI, though the outcome is precise and accurate, the patient's comfort zone is a little compromised. But scientists are working on it. A better version with patient-centric benefits will be seen in the market in the coming years. Uncourtly, Robotic Dentistry has been more disruptive than destructive (Ahmad P, 2021). However, there are some limitations to it. The most or biggest disadvantage of Robotic dentistry is its cost. It is expensive and requires expert guidance to proceed with the procedures. Moreover, patient acceptance and compliance are much of a question. Without that, dentists cannot move forward with the robotic approach. Also. Studies have stated that patients are more likely to opt for robotic dentistry if handled by a male than a female. Further, regardless of the sex approach, the acceptance to receive the treatment is decreased due to its invasiveness (Ahmad P, 2021).

Teledentistry is another technology that is bringing change to the dental profession. But it completely relies on dental professionals. The dental professional uses teledentistry through phone, text, or video to conduct surgery or consult. Teledentistry is used for emergencies,s and patients do not have to travel to visit the dentist. Many studies have shown that the access to dental care has increased due to tele dentistry. As far as the patient has any hardware to connect, it becomes easy for patients to talk to the dentist and get some information about the procedures and treatment plan. There is so much to discuss from the patient's and partitioner's point of view. Based on the facts and research, the American Tele Dentistry Association has stated that tele Dentistry has led to proper hygiene, more affordable care, improved communications between the doctor and patient, and saved time. According to a study conducted by DentaQuest Partnership about 75% of dental providers will rely on teledentistry.

CONCLUSION

Through this paper, it is claimed that the use of robotics in dentistry improves accuracy, precision, reliability, and reproducibility. However the quantity of research performed in robotic dentistry is limited due to the lack of accessible systems. There is still no expert to guide the programs and regulate the robots. Collaboration between engineers and dentists is needed for effective research and experiments to be carried out. It goes without saying that technology has been reshaping the dental profession hundreds of years ago. Today, virtual and robotic dentistry are known to be the leading practitioners in this 21st century characterized by strong finance and high quality. The future of dental robots depends on whether the consumer accepts or rejects the advancement. But this is not going the hinder the advancement in the field. Based on all the facts, cases, limitations, and advantages, one can say that robotics has created an impact and has caused an advancement in dentistry. But we must use robotics only when its benefit is centric to patients and not providers. Teledentistry can be useful, but its benefits are limited to consultation only. Robotics and teledentist dentistry can create a bigger impact on the world.

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