

## Dental robotics: a groundbreaking technology with disruptive potential – review article

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### Abstract

Dental Robotics represent a groundbreaking technological frontier with the potential to disrupt traditional paradigms in oral healthcare. This abstract explores the transformative impact of robotic applications in dentistry, focussing on precision, reproducibility, and reliability. A comprehensive search was conducted on the PubMed database, Dental and Oral Science, and CINAHL to identify pertinent studies exploring the implications of robotics in dentistry. Studies incorporated in this analysis highlighted the significance of broadening the research scope beyond implantology. This review underscores the importance of integrating robotic dentistry into educational frameworks and advancing technological preparedness. As we navigate these challenges, the abstract underscores the pivotal role of robotic dentistry in shaping the future of oral healthcare. Robotic dentistry promises transformative advancements in oral healthcare with precision and reliability. Challenges like limited system availability and expertise highlight the need for increased dentist-engineer collaboration. Diversifying research, emphasizing non-invasive technologies, and integrating robotic dentistry into education are crucial for wider acceptance. Public awareness and regulatory clarity are pivotal for seamless integration, unlocking the vast potential of robotic technologies in the future of dental care.

**Keywords:** Dental Care, Health Care, Robotics, Dental technology.

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### Introduction

Machines known as robots, carry out programmed manual tasks automatically. Ongoing progress in robotics and artificial intelligence has increasingly automated numerous tasks, particularly those characterized by

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repetition and labour-intensive nature.<sup>1</sup> Robots consistently provide high performance and economic value, evolving into intelligent assistants and collaborators in various public settings.<sup>2</sup> Robotics has found applications in various sectors. Notably, the utilisation of robotics in the medical field has garnered increasing attention. Medical robots can be categorized into three types. Within the category of macrorobots, one finds rehabilitation robots such as home daily-care robots and smart wheelchairs, as well as surgical robots designed for procedures like brain and eye surgeries. This classification also includes minimally invasive surgical robots and medical endoscopic devices. On the other hand, bio-robots are designed to mimic human capabilities, including perception, cognition, and judgment.<sup>3</sup> There is a growing need to enhance efficiency and standardize existing approaches in healthcare. Dentistry presents numerous possibilities for the implementation of robotic and assistive technology to elevate the quality of dental care.<sup>4</sup> While dental robots have the potential to enhance treatment precision and outcomes, the process of robotic transformation is currently encountering various challenges.

The integration of digital technology in medicine and dentistry, along with compatibility with robotics, can play a crucial role in reducing errors and elevating both the quality and quantity of patient care by aiding in oral examinations, disease diagnosis, and treatment planning.<sup>5</sup> In the realm of education, robotic systems play a crucial role in training dental students. This training involves the utilization of full-body robotics, haptic interface technology, and advanced simulations. These tools contribute to providing fundamental learning experiences before students engage with real patients.<sup>6,7</sup> Beyond their role as dental assistants, they can be utilized for invasive dental procedures, including tasks such as tooth preparation and the autonomous placement of dental implants.<sup>8</sup>

### Objectives

This article offers a thorough examination of the current state of basic and applied research in the integration of robotics in dentistry. It explores the progress and

potential uses of robotics in key professional areas within different aspects of dentistry. This article identifies gaps in current research and proposes areas for future investigation in robotics and dentistry.

### Robots in dentistry

Dentistry currently utilizes a limited number of manually operated robotic systems controlled through computer interfaces. These manual robots have demonstrated the potential to offer safer and more precise drilling compared to traditional dental methods.<sup>9</sup>

While strides are made toward autonomous implant dentistry, promising robotic systems are not yet accessible to dentists. The widespread adoption of robots in dental practice faces challenges, including high acquisition costs and the inherent complexity of robotic hardware and methodologies, which must be addressed before becoming commonplace.<sup>9</sup>

### Materials and Methods

A comprehensive search was conducted on the PubMed database, Dental and Oral Science, and CINAHL to identify pertinent studies from 2009 to 2023 exploring the implications of robotics in dentistry. Studies were identified during the article search conducted from October 2023 till November 2023. The inclusion criteria encompassed only full-text articles that were published exclusively in the English language.

### Review

#### Orthodontics

Fixed orthodontic therapy stands out as the most prevalent and efficient approach for addressing malocclusion, with the crucial step in this therapeutic technique being the bending of arch wire (AW).<sup>10</sup> SureSmile employs modern 3D technologies for diagnosis and treatment planning, utilizing a robotic system to customize fixed orthodontic appliances.<sup>11</sup> The SureSmile arch wire bending robot involves a robot affixed to a table.<sup>12</sup> Force sensors detect necessary over-bending for achieving the optimal morphology of the AW. These sensors may also include a heating system through which electric currents pass through the wire.<sup>13</sup>

Several systems, including "LAMDA (Lingual Archwire Manufacturing and Design Aid)," MOTOMAN UP6, and a Cartesian-type Orthodontic Arch-Wire bending robotic system, have been introduced for robotic arch wire bending.<sup>10</sup> Orthodontic arch wirebending robots offer the benefits of a straightforward structure, cost-effectiveness, and the capability to bend a variety of archwire types. This diminishes the labour intensity for the doctor, mitigates the risk of fatigue fractures in the

archwire resulting from repetitive bending, and enhances overall treatment efficiency.<sup>14</sup>

#### Endodontics

The practice of root canal therapy demands a high degree of precision and accuracy. Typically, an endodontic clinician employs magnification techniques to ensure optimal visibility of the root canal system. The examination involved employing micro-robots with catalytic capabilities to disrupt oral biofilms within the root canal.<sup>15</sup> "The Advanced Endodontic Development" initiative aspired to create an intelligent machine capable of autonomously conducting endodontic treatment.<sup>16</sup> Following the theoretical design, the robot will be attached to various teeth in the patient's mouth, creating a 3D tooth model from 2D radiographic images. Treatment procedures will be devised by a prescription system, with the microrobot executing automated processes for root canal drilling and filling.

#### Oral surgery

The constantly growing field of computer-assisted surgery has contributed to the perpetual advancement of preoperative design in maxillofacial surgery. Nevertheless, achieving stability and real-time precision in drilling and cutting processes continues to be a major challenge.

When malignant lesions of the oropharynx are inaccessible, radiotherapy and/or chemotherapy are frequently required as conventional treatments. Salvage surgery is conventionally performed via mandibular displacement and lip split, accompanied by mandibulotomy. With the exception of the treatment of oropharyngeal carcinoma, robotic oral and maxillofacial surgery has emerged as a viable alternative.<sup>8</sup> The da Vinci system was granted transoral approval by the US-FDA in 2009 for the treatment of specific malignant conditions and all non-cancerous lesions affecting the oropharynx, including those situated at the base of the larynx and the tongue. Clinicians employ computer-assisted dental implant surgery with increasing frequency. In addition to utilizing cone-beam computed tomography (CBCT) analysis, the system also implements bi-dimensional radiograph standardization.<sup>17</sup>

Additionally, oral cavity accessibility permits robotic surgery in the upper aerodigestive tract.<sup>18</sup> With its stereoscopic vision, multi-articulated instruments, and robotic limbs, transoral robotic surgery enables minimally invasive intervention of the oropharynx. When treating oral squamous cell carcinoma with minimal risk, robot-assisted surgery can also offer exceptional local control.<sup>19</sup>

For the treatment of obstructive sleep apnoea, transoral robotic surgery was initially proposed by Vicini et al.<sup>20</sup> in 2010. Ten human subjects participated in their investigation of the efficacy of tongue base reduction via transoral robotic surgery. They reported that patients tolerated robot-assisted surgery well and experienced minimal morbidity. Furthermore, all ten participants exhibited a substantial improvement in the apnoea-hypopnoea index. Reconstructing the mandible is a challenging and intricate undertaking. Typically, two groups of surgeons are required to collaborate for a minimum of seven hours during conventional reconstructive surgery. Robotic-assisted surgery has surfaced as a viable substitute due to the constraints imposed by manual accuracy and human resources. For fibula free-flap mandible reconstruction, pre-programmed osteotomy experiments utilizing a robot (KUKA, Augsburg, Germany) have been documented; this technique demonstrated a remarkable level of precision.<sup>21</sup> An additional investigation juxtaposed the practicability and precision of freehand technique guided by a computer-assisted navigation system with that of mandibular reconstruction utilizing an automated three-arm robot system.

Beyond addressing pathological conditions, transoral robotic surgery has been widely employed for surgically treating obstructive sleep apnoea. A 6-degree-of-freedom (6-DOF) robotic arm was suggested to assist surgeons during orthognathic surgery. Utilizing 3D data derived from a CT scan, the surgeon is responsible for positioning before the actual surgery.<sup>22</sup>

In the realm of oral maxillofacial surgery, robotics play a crucial role in acquiring and reconstructing 3D image data of the oral and maxillofacial regions before the operation. This involves analyzing lesion characteristics and devising a targeted operation plan. Additionally, robotics contribute significantly by precisely segmenting, reshaping, displacing, and securing the craniofacial bone according to the surgical plan. The evident effectiveness of robotics in oral and maxillofacial surgery is showcased through these essential procedures.

### **Prosthodontics**

Exploring the use of robots in prosthetic dentistry represents a groundbreaking endeavor involving both technical and theoretical innovations. For the protection of the temporomandibular joint and the restoration of the craniofacial morphology and normal function in edentulous patients, efficient prosthodontic care is essential.<sup>23</sup> The domain of prosthodontic robotics is perpetually advancing. Ongoing investigations strive to address obstacles including financial implications, ease of

use, and adherence to regulatory standards, thereby facilitating the development of advanced and convenient robotic systems.<sup>4</sup> Robotic implementations in the field of prosthodontics can be categorized into three distinct domains.

### **Tooth preparation**

Although tooth preparation for crown and bridge is routine for clinicians, it remains difficult despite plenty of professional knowledge and experience. The main challenge lies in reducing the tooth to an adequate extent to create space while minimizing damage to the sound tooth structure. The notion of a robotic system being employed for tooth preparation is perceived as rational and enticing by clinicians. As a clinical aid for tooth drilling, a mechatronic system has been subjected to in vitro testing. While the report presented favorable results, its validation in a clinical setting has yet to take place.<sup>24</sup> Researchers in China devised an automated micro robotic system to fabricate three-dimensional crowns for teeth employing a picosecond laser and investigated the optimal parameters for this system.<sup>25</sup> This microrobot device was introduced in 2013 known as LaserBot. In order to perform clinical tooth-crown preparation, this robotic apparatus provided precise three-dimensional (3D) motion control of a femtosecond laser beam.<sup>26</sup> However, the duration of ablation using this robotic system was considerably longer than anticipated.<sup>27</sup> Using 3D motion planning software, the same crew created an ultra-short pulse-laser automatic tooth preparation robot that was precisely controlled. The average time required to prepare newly extracted human intact first molars has been reduced to seventeen minutes, in addition to assuring the feasibility and precision of the process.<sup>28</sup> Despite the fact that the robotic system successfully produced adequate tooth preparation, additional experiments are necessary to ascertain the ablation efficiencies for various tooth layers, including dentin, enamel, and other dental materials. Laser Bot was awarded a contract to Robotoo Robotics (Isreal) in 2018 and is undergoing an enhancement at this time.<sup>29</sup>

### **Tooth arrangement**

Conventional complete dentures are produced through manual means, with the critical stage consisting of positioning and aligning the synthetic teeth in a dental pad in the correct position and orientation. In general, senior technicians and dentists require outstanding proficiency to complete this procedure. The progressive advancement of computer-aided design/computer-aided manufacturing (CAD/CAM) technology has facilitated the incremental development of virtual artificial tooth-

arrangement systems. In recent times, the utilization of 3D digital technology has enabled the attainment of more intricate mandible position recordings and balanced molar arrangements. The software permits unrestricted movement of the entire dentition, local dentition, and individual teeth in the sagittal, coronal, and horizontal planes. Additionally, it allows for localized adjustments to the dentition radians in order to accommodate the contours of the dental arch. The data contained in the CAD process is further processed by CAM into instructions for operating and controlling production machinery. At the laboratory design level, CAD/CAM programmes effectively mitigate the influence of dental technician expertise disparities. Nevertheless, in the manufacturing phase, the implementation of robotic systems equipped with advanced operational functionalities is necessary to streamline operations, standardise design processes, prevent human error, and enhance production velocity and effectiveness. Currently, robotic research is being conducted to determine how dental arrangements function.

Zhang et al.<sup>30</sup> achieved an optimal dental arch for the patient by arranging teeth for complete prostheses using a robotic manufacturing system they devised. To begin, the parameters of the patient's mandible arch were acquired, and control data were generated utilizing software designed for dental arrangement. The artificial teeth, tooth-arrangement assistant, and intermediate blocks were subsequently grasped and assembled by the robot. In order to achieve a fixed tooth arch, wax was subsequently injected into the tooth-arrangement assistant, resulting in the transformation of the entire denture. Significant advancements were made by the same group in the development of robotics for dental arrangement. They established kinematic equations<sup>31</sup> and proposed a tooth-arrangement robot in 2008 comprised of five-degree of freedom (DOF) mechanisms arranged in parallel and series. In 2009, a method for organizing teeth utilizing a multi-manipulator was proposed.<sup>32</sup> A study conducted in 2010 examined the utilization of high-resolution timing control pulses to accomplish precise coordinated motion control of an arch generator for a tooth arrangement robot.<sup>25</sup> Zhang et al. provided contributions to the theoretical phase. In order to address the laborious and imprecise challenges associated with conventional tooth-arrangement approaches, the authors put forth the notion of a miniature, expert-level robot that operates on Cartesian coordinates.<sup>33</sup> They optimized the control points of the dental arch generator in accordance with the objective function, multivariate design, and constraint function that were determined through an analysis of the generator's

motion.<sup>34</sup> They investigated the automatic acquisition of dental arches and implemented motion planning and synchronized control of the dental arch generator using a mathematical model.

### Articulation

Once the occlusal relationship has been optimized in the CAD software through the arrangement of artificial teeth, it is possible to modify it by employing the virtual articulator to simulate mandible opening and closing, as well as forward, backward and lateral movements. The investigation also includes robotic articulators alongside virtual articulators. By utilizing a precision six-axis micro positioning stage, a novel variety of robotic articulators recreate the patient's functional mandibular movement with six degrees of freedom. By employing this articulator system, a complete veneer crown restoration can be manufactured without requiring any intraoral occlusal modifications to the configuration. The ability of the articulator to faithfully replicate dynamic jaw movements that occur during functional jaw movements holds promise for enhancing the precision of denture occlusion. In light of the fact that only one patient was examined, additional research is required to assess this method.<sup>35</sup>

### Discussion

The literature suggests that integrating robots into dentistry can improve precision, reproducibility, and reliability. Enhanced interdisciplinary collaboration is required to increase collaboration between dental professionals and engineers to ensure a comprehensive understanding of the unique challenges and opportunities in robotic dentistry.

To propel the future of robotic dentistry, several strategic recommendations are crucial. Firstly, prioritize research and development efforts to enhance the technological readiness, focussing on improving system availability, programming capabilities, and affordability. Diversify interdisciplinary studies to explore non-invasive applications, moving beyond the predominant focus on dental implantology, to ensure wider acceptance among dentists and patients. Integrate robotic dentistry into dental education programmes, fostering familiarity and comfort among future practitioners. Accelerate collaborative efforts between dentists and engineers to address existing challenges and promote seamless integration. Invest in public awareness campaigns to dispel misconceptions and build trust in robotic dental technologies. Furthermore, work collaboratively with regulatory bodies to establish clear guidelines, fostering a supportive environment for innovation. These recommendations, if implemented, will pave the way for

a more inclusive, technologically advanced, and widely accepted future for robotic dentistry.

### Limitations

Despite the promising advancements, applications of robotic dentistry face notable limitations. The current scarcity of robotic systems and a deficiency in programming expertise restrict the breadth of research and hinder widespread adoption. The predominant focus on dental implantology in interdisciplinary studies raises concerns about the broader acceptance of invasive robotic procedures among both dentists and patients. Additionally, the technological readiness of robotic dentistry requires improvement in terms of reliability, efficiency, and affordability. Longitudinal clinical studies are essential to assess the long-term efficacy and safety, yet such data is currently limited. Public awareness and trust-building efforts are crucial, and regulatory frameworks must evolve to address the complexities and ensure patient safety. As we acknowledge these limitations, strategic efforts and advancements are necessary to overcome these challenges and unlock the full potential of robotic dentistry in the future of oral healthcare.

### Conclusion

In conclusion, robotic dentistry stands at the forefront of transformative advancements in oral healthcare. The demonstrated benefits in precision, reproducibility, and reliability offer promising prospects for the field. However, challenges such as limited system availability and a shortage of expertise underscore the need for increased collaboration between dentists and engineers. Diversifying research beyond implantology, focussing on non-invasive technologies, and integrating robotic dentistry into education are pivotal steps for broader acceptance. Technological refinement, backed by longitudinal clinical studies, is essential for overcoming existing hurdles. Public awareness and regulatory clarity will play pivotal roles in ensuring a seamless integration of robotic dentistry into mainstream practices. As we navigate these challenges, the future of dental care holds tremendous potential through the innovative and strategic incorporation of robotic technologies.

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