Dentoronics: The Future of Dentistry Towards Robotics

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KEYWORDS
Dentoronics, robots, machine learning, artificial intelligence, technology

ABSTRACT
Dentistry has seen massive improvements and advancements from the traditional techniques to the digital world that has widened the scope of dental treatment and procedures. Bio-robots application in oral diagnosis and treatment models can promote new avenue of technological innovation. This abstract explores the domain of dentoronics, where robotics and AI converge to reshape the future of dental care. While the Dentoronics revolution holds immense promise, challenges such as cost, regulatory approvals, and ethical considerations need to be addressed. Currently robots are used in basic and applied research in various specialized fields where tooth-crown preparation robots, drilling robots, implant surgery robots, teeth arrangement robots, arch wire bending robots are being developed. Stimulation-based training can benefit and bring the revolution in dentistry. Nevertheless, Dentoronics is poised to redefine the future of dentistry by providing safer, more efficient, and inclusive oral healthcare solutions, ultimately improving the well-being of countless individuals worldwide. As the field continues to evolve, embracing the robots are used in basic and applied research.

1. Introduction

A field of dentistry has seen significant advancements in recent years, integration of Robot and AI is one among those significant technological advancements that has now extended to this field to enhance new avenues for clinical excellence. A robot is a programmable mechanical device capable of performing tasks and mobile operations automatically [1]. AI is a technology in a field computer science which are capable of performing tasks typically carried out by human intelligence [2]. While the two fields complement each other they serve distinct purpose. Advancements in AI and robotics have brought greater efficiency in labor-intensive tasks, extending even to operating rooms. Through Machine Learning, a subset of AI, robots continuously adapt to human processes, revolutionizing surgical and dental procedures [2, 3]. This review article aims to explore the current advancements in dentoronics to evaluate their impact on dentistry and visualize the future being driven by the robotic system and artificial intelligence.

Methods

To obtain up-to-date information, a search was conducted on the PubMed database using the terms such as "Robotics", “Artificial Intelligence,” “Machine Learning” to explore well documented content. Full-text articles were thoroughly examined, and relevant related articles were analyzed as well.

History of Dental robotics

The history of robots in date back more than 3000 years [4]. The introduction of the da Vinci Robotic system in 1999 marked a significant milestone, demonstrating the potential for robotic assistance in field of gynecology and is presently used in head and neck surgery [5, 6]. In 2001 suresmile orthodontic robotic system was developed which helped in arch wire bending [5]. The first human like robot named Showa Hanako was created in the year 2010 which was able to show gestures like humans. This established a foundation on creation of many other robots namely, Geminoid-F, HRP-4 [7]. In late 2010s, Neocis Yomi introduced Yomi robot for guidance in dental implant surgeries, allowing dentists to achieve greater precision and control [5]. In recent years, advancements in artificial intelligence (AI) and robotic engineering have led to the development of more capable dental robots like SIMROID which can evaluate the treatment procedures and helps in performing surgeries [7].

Artificial Intelligence and Robotics

AI is a modern technology that has already contributed to advancements in the medical field, pushing the boundaries of innovation. AI is concerned with designing an algorithm that enable computers to exhibit traits of human intelligence, such as learning, problem-solving, reasoning, and language comprehension [8]. The data collected are processed using machine learning and instilled into the robotic system. The procedures from collecting data to generating the responses and predictions are termed as data mining. The AI methodologies like ANN can perform specific tasks like image identification and classifications (eg: root canals while performing RCT, periodontal diseases, and oral cancers by analyzing radiographs and other imaging modalities), while Fuzzy logic algorithm helps in decision making process of humans and produces acceptable solutions [7].

Classification of Machine Learning [9]

1. Supervised Learning

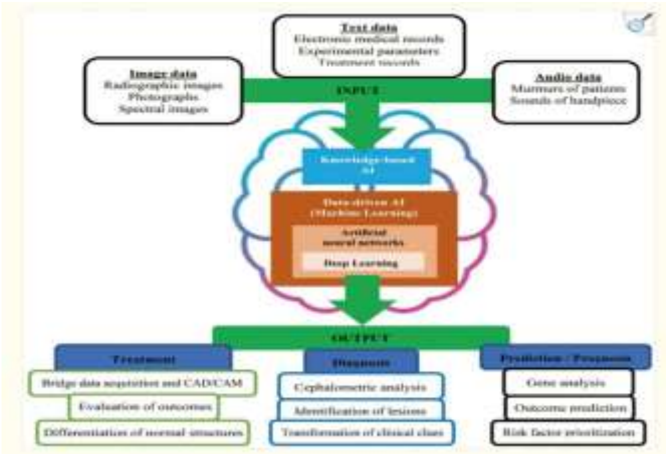
Learns from labeled data.
Used for classification (categorizing data) and regression (predicting continuous values).
Example: In medical imaging, expert radiologists label diagnostic images for AI training.

2. Unsupervised Learning

Works with unlabeled data, identifying patterns without predefined categories.
Used for clustering (grouping similar data) and distribution estimation.
Example: AI models grouping medical images based on similarities without prior labels.

3. Reinforcement Learning

Learns by interacting with an environment, receiving rewards or penalties based on actions.
Applied in robotics, video games, and computer vision.
Example: AI-controlled robotic arms optimizing movements through trial and error.



Artificial Intelligence Hierarchy and its key applications in dentistry [10]

Applications of Robotics and AI in Dentistry

The use of robotics in dentistry is progressing with the development of advanced technologies are increasingly being utilized to improve diagnostic accuracy, treatment outcomes. Robotics in dentistry enhances surgical precision, automated procedures, and increased accessibility, AI on the other hand, aids in diagnosing dental conditions, planning treatments, and predicting patient outcomes with greater accuracy. Robotics and AI together can not only transform the clinical practices but also continue to evolve, their potential to reshape the future of dentistry

Oral medicine and Radiology

AI algorithms can analyze diagnostic images to plan treatment, which robotic systems then carry out with high precision. This integration enhances the efficiency and effectiveness of dental procedures. The Waseda Asahi oral-rehabilitation robot was designed to deliver therapeutic massage for maxillofacial conditions, including temporo-mandibular joint disorders and dry mouth, particularly for the elderly population [11]. **[Figure 1]**

Fig: 1 Waseda Asahi oral-rehabilitation robot [39]

With the upgraded robotic system, the oral radiologist is not exposed to any radiation where the radiographic procedure is being performed. X-ray film/sensors positioning was performed by 6 Dof Robotic arm which showed excellent accuracy with no adverse effects. Robotic systems can provide assistance in positioning patients for optimal imaging angles and interpretation of detailed anatomy, which supports more effective treatment planning [12]. YOLO, a real-time object detection model, is known for its accuracy in identifying permanent teeth in panoramic radiographs. YOLOv4 has proven effective in detecting tooth germs and enables fast, automated tooth detection and numbering [13].

Endodontics

In operative dentistry CNN AI algorithm can detect the caries, root fractures, apical lesions and tooth wear on intraoral images [14].

Endomicrobot is a visually guided robotic system that performs probing, drilling, filing, cleaning and filling of root canals automatically. It has 5 degrees of freedom (x, y, z, x-z, y-z) planes includes micro position orientation and adjustment of device [14, 15]. **[Figure 2]**

A robot called Omni Phantom with a haptic virtual stimulator has been developed to perform endodontic procedures more efficiently [1].

A full-crown was prepared using a laser that removed the tooth layer by layer. The procedure was tested on extracted human teeth in a phantom model to explore its clinical use. Another research team also studied an automated tooth preparation system but used a high-speed hand piece attached to a robot instead of a laser [5].

AI-enhanced algorithms are being used to generate photorealistic 3D reconstructions of tooth anatomy, root canals, and orofacial lesions through a technique called cinematic rendering (CR). This method processes CBCT data with high dynamic range lighting to create realistic visualizations, enhancing diagnostic accuracy. In medicine, CR has been integrated with augmented reality headsets for interactive image manipulation, a concept that could benefit dentistry. Implementing this technology in dental education and clinical training could significantly improve learning and visualization. [16]

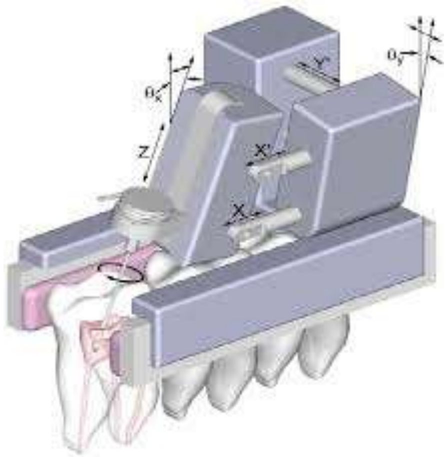


Fig 2: Endo Micro Robot [7]

Oral Surgery

With the development of technology, the role of AI and robots in oral and maxillofacial surgery includes applications in TMJ surgeries, implant surgeries, biopsy, removal of neoplasms or cysts and for the reduction and fixation of the fracture [17].

In 2010, Chen et al proposed the theoretical feasibility of robot-assisted orthognathic surgery. They introduced a method utilizing the six-degree-of-freedom MOTOMAN robot to perform bone cutting and drilling, guided by a programmed navigation system. Several robotic surgical systems equipped with integrated force sensors, such as ROBODOC, Active Constraint Robot (ACROBOT), and Bone Resection Instrument Guidance by Intelligent Tele manipulator (BRIGIT), have been used in arthroplasty. However, robotic-assisted fracture reduction and fixation are currently limited to long bone and pelvic fractures. Yang et al. demonstrated that robotic surgery may reduce the risk of intraoperative hemorrhage, positive margins, and postoperative functional nerve deficits compared to conventional transcervical surgery. Several robotic surgical systems, including ROBODOC, Computer-Assisted Surgical Planning and Robotics (CASPAR), and the Robotic Arm Interactive Orthopedic System (MAKO Surgical Corp RIO), have been widely used in orthopedic procedures such as arthroplasty [18].

Microsurgery robots assist surgeons in operating on tiny structures with enhanced precision using magnifying instruments. These advanced systems enable super-microsurgical techniques to reconnect delicate nerves and vessels as small as 0.3–0.8 mm, which are extremely challenging to perform manually. [19]

Fig 3: Overview of Robotic surgery operating room [40]

Periodontics

Automated charting powered by AI can streamline the documentation process, improve accuracy, and provide a clear visual representation of periodontal health. AI-driven software aids in treatment planning by analyzing patient data, optimizing implant placement, and simulating outcomes. It enhances implantology by assessing CBCT scans to determine ideal implant size, position, and angulation while considering bone density and vital structures. These advancements improve precision, efficiency, and overall treatment success in periodontal care and implantology. [20]

Oral implantology

Robot-assisted dental surgery has become a significant advancement in dental implant therapy. Dental implant robots are classified into active, passive, and semi-active systems, depending on the degree of human-robot interaction [21].

Active robots enter and exit the mouth, prepares and plans the implant site independently e.g. YekeBot. Passive robots require operator to monitor the robotic arms during the procedures e.g. Yomi **[figure 4]**, Dentrobot. Semi-active robots automatically prepare implant site but requires operators' assistance e.g. Remebot [21].

In 2009 FDA approved robotic system YOMI for robot guided implant clinical procedures. Yomi obtain primary from CT scans and processes through dynamic software which enables surgeons to plan the procedures while considering critical anatomical structures such as nerves, sinus, teeth and sets precise surgical parameter [22].

Zhao et al. developed a modular implant robotic system utilizing binocular visual navigation based on visible light. This system operates in an "eye-to-hand" mode, enabling full observation of markers and handpieces within the camera's field of view, ensuring enhanced flexibility and stability [4].

Robotic-assisted systems enable real-time adjustments during procedures, allowing dynamic adaptation to the surgical environment. These systems offer high reproducibility, often achieving linear deviations of ≤1 mm and angular deviations of ≤1°. This level of precision enhances procedural safety and effectiveness by accounting for real-time anatomical changes, thereby minimizing the risk of complications [23].

The University of Coimbra in Portugal developed a dental implantology system using the ABB IRB2400/M98 robot. It features an industrial manipulator, force/torque sensors, and strain gauges for stress evaluation, enabling precise drilling and implant insertion. The robot, equipped with a tool changer, performs drilling and applies pressure to simulate mastication. Matlab-based software manages calibration, drill planning, load analysis, and data acquisition to optimize implant placement and jawbone stress analysis. [24]

Fig 4: Yomi Robot used to perform implant surgeries [7]

Prosthodontics

Robotics in prosthodontics has revolutionized the field by enhancing precise fabrication and placement of dental prosthetics, improving patient outcomes.

AI generated smile designing software analyzes the patient's facial features like symmetry, lips, eyes, tooth size and form, generates highly stimulated images thereby enhancing patients' satisfaction [2].

Teeth arrangement is one of the most important steps in CD fabrication. This can now be performed by the robotic system 6 degree of freedom, developed by the CRS Robotic Corporation, Canadian company. Components of this system includes computer, control system, electromagnetic gripper, light source device and light sensitive glue. With an advancement 84 DOF is developed, this can move 3-D along the dental arches and performs teeth arrangements [1, 25, 26]. The primary challenge limiting the widespread adoption of the system are its high cost and lack of knowledge regarding its operations **[Figure 5]**

Otani et al assessed the accuracy and precision of an automated robotic tooth preparation system for porcelain laminate veneers. The system utilized a 3D laser scanner to scan tooth models, allowing for the design of tooth preparation based on a 3D image, enhancing both safety and efficiency [27]. **[Figure 6]**

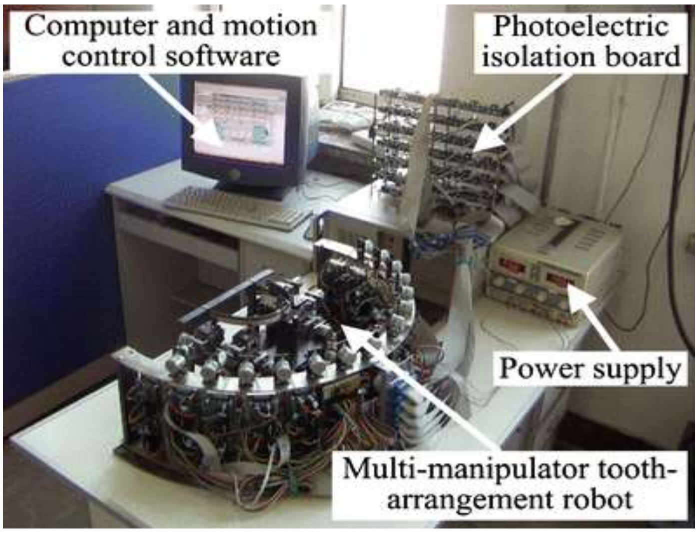


Fig 5: 6 degree of freedom Robot, developed by the CRS Robotic Corporation [41]

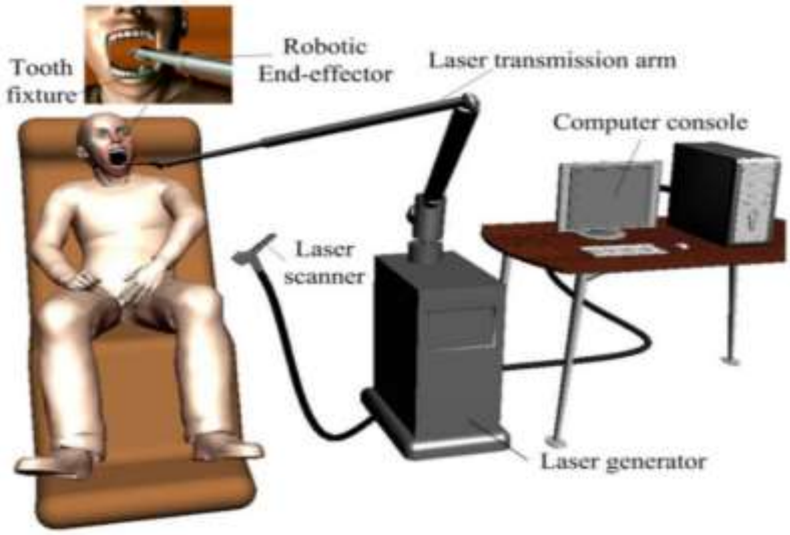


Fig 6: Robot visual representation of Robotic Crown Preparation System [1]

Orthodontics

Robotics in orthodontics has made it possible to perform complex tasks with high precision and efficiency [24].

Arch wire bending system

Suresmile arch wire bending robot works on the CAD/CAM principle for better accuracy and efficiency to adjust fixed orthodontic appliance [25].

The MOTOMAN UP6-based arch wire bending robot, consisting of a computer and an arch wire bending actuator, analyzes various factors, including bending position, curve enhancement points, kinematics, and bending characteristics [11, 25, 28, 29].

In 2011, Alfredo Gilbert introduced the Lingual Arch wire Manufacturing and Design Aid LAMBDA for designing and bending arch wires. The LAMBDA robot operates solely on the x and y axes, making it a compact and straightforward system. However, it has limitations, as it cannot bend arch wires with a closed loop [11, 25, 28, 29, 30, 31]. **[Figure 7]**

NiTi arch wires can be bent without losing their phase-changing ability due to an integrated heater that raises the temperature to 600°F. Since the robot performs only first-order bending, the Hiro Bracket placement system is used for second and third-order adjustments, reducing costs and giving orthodontists more control.[31]

Clear aligners

The clinical procedure begins with precise impression taking, followed by scanning the poured casts to create a virtual 3D model. The orthodontist analyzes the model and makes necessary adjustments to address the specific malocclusion using specialized software. Once the treatment plan is finalized, a series of aligners are automatically printed and provided by the manufacturing company for the patient to wear throughout the treatment period [30].

Fig 7: LAMBDA Robot used in arch wire bending [42]

Forensic Odontology

AI is transforming forensic science by enhancing autopsy analysis, injury detection, and postmortem interval estimation. It aids forensic experts in age and sex estimation, facial recognition at crime scenes, and fingerprint matching with databases. AI-driven forensic toxicology and DNA analysis streamline investigations, improving accuracy and efficiency. Gunshot analysis benefits from AI algorithms that identify firearm types and shot counts, while digital forensics leverages AI to uncover hidden evidence. These advancements, often combined with robotics, accelerate forensic processes and improve investigative outcomes. [32]

Deep learning methods like CNN and R-CNN have been utilized for automatic tooth detection in dental radiographs for identification purposes. A modified EfficientDet-D3 network demonstrated high accuracy in detecting natural teeth (99.1%), implants (96.8%), treated root canals (81.2%), and prostheses (80.6%). This highlights CNN's effectiveness in analyzing dental features for forensic and clinical applications. [33]

Nanorobots

Nanotechnology-driven robots, or nanorobots, have revolutionized dentistry by enabling precise and minimally invasive treatments. These microscopic devices play a crucial role in tooth repair, targeted drug delivery, cavity preparation and restoration, orthodontic realignment in a single visit, and managing dentin hypersensitivity. They also assist in endodontic and conservative procedures, local anesthesia administration, and robotic dental applications. One such innovation, dentifrobots, can scan both supra- and subgingival surfaces to effectively remove calculus. By breaking down organic substances into harmless byproducts, they contribute to enhanced oral hygiene and preventive dental care [7, 34]

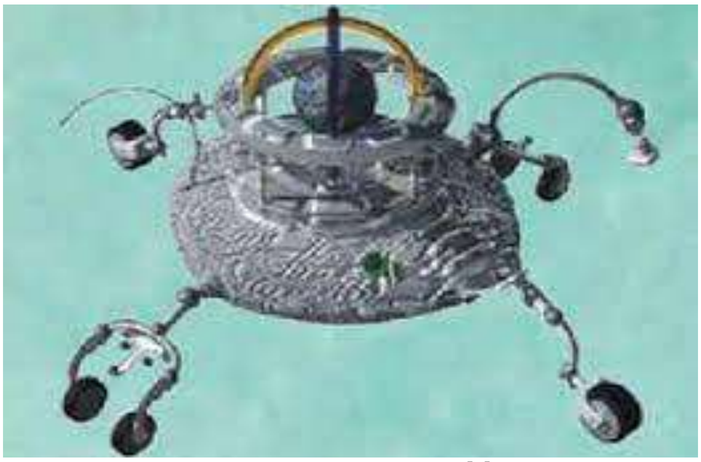


Fig 8: Nanorobots [7]

Fig 9: Showa Hanako Patient Robot [7]

Safety Concerns in AI Robotics [35, 36]

A**. Physical Safety Risks**

Collision Hazards: AI-driven robots working alongside humans (cobots) pose a risk of accidental contact, which can cause injuries.

Unpredictable Behavior: AI-based robots, especially those using reinforcement learning, may develop unexpected actions that are hard to anticipate.

Failure or Malfunction Risks: A robotic system's failure in industrial or medical settings could lead to life-threatening situations.

B. **Cybersecurity and Data Integrity**

Cyber Attacks: Robots connected to networks and cloud services are vulnerable to hacking, leading to data breaches or operational disruptions.

Data Poisoning: Manipulated training data can cause robots to behave incorrectly or fail critical tasks.

AI Model Vulnerabilities: Adversarial attacks can trick AI-based robots into making incorrect decisions, affecting navigation and object recognition.

C. **Psychological and Social Safety**

Human Over-Reliance on Robots: Trust in AI-based decisions may lead humans to neglect their judgment, increasing risks in critical applications.

Workplace Stress and Anxiety: The integration of AI robots in industries can lead to performance pressure, fear of job loss, and long-term mental health concerns.

Humanization Issues: Over-humanizing AI robots can create misleading emotional attachments, affecting decision-making in workplaces and healthcare.

D. **Regulatory and Compliance Challenges**

Lack of Universal Standards: Existing safety regulations primarily focus on physical risks but do not fully address cybersecurity or ethical concerns.

Machine Learning Complexity: AI models continuously evolve, making traditional certification and safety validation methods inadequate.

Legal Liability Gaps: Current laws do not clearly define responsibility in the event of an AI-related accident or failure.

Advantages of using robotics and AI in dentistry [6, 37]

Improved Precision: Dental robots can perform procedures with exceptional precision, reducing the margin for error. This is particularly crucial for delicate procedures like dental implant placement and root canal therapy.

Reduced Error Rates: Automation through robotics minimizes the potential for human error during procedures, leading to more predictable and consistent outcomes. This can result in fewer complications and the need for fewer corrective procedures.

Reduced Cross-Contamination: Automation through robotics can reduce the risk of cross-contamination in dental offices by minimizing the need for instrument exchanges during procedures.

Future Advancements: As technology continues to evolve, dental robots are likely to become even more advanced, offering new capabilities and benefits to both patients and practitioners.

Customization: Some robots are equipped with AI and machine learning capabilities, enabling personalized treatment plans based on a patient's unique dental anatomy and needs.

Enhanced Diagnostics: Robots integrated with advanced imaging technology can provide dentists with detailed 3D images and real-time data, improving diagnostic accuracy and treatment planning.

Data Collection and Analysis: Robotic systems can collect and analyze data during procedures, offering dentists real-time feedback and insights that can aid in decision-making and post-procedure evaluation.

Limitations of robotics in dentistry [6, 14, 37]

Cost of Technology: The acquisition and maintenance of advanced dental technologies, including robotics and AI systems, can be expensive.

Accessibility and Equity: Ensuring equitable access to Dentoronics is a significant challenge. Remote and underserved communities may have limited access to the necessary infrastructure and technology.

Job Displacement: The automation of certain dental tasks by robots and AI may raise concerns about job displacement among dental professionals, such as dental assistants.

Data Security: The collection and storage of patient data, especially when integrated with AI and remote systems, raise concerns about data security and the potential for data breaches.

Training and Education: Dental professionals need proper training to use Dentoronics effectively. Integrating technology into dental education curriculum and continuous professional development is essential. Ensuring that practitioners are well-prepared to use these technologies is crucial for patient safety and positive outcomes.

Future trends in Dentoronics

Dental robotics is currently shifting from computer-assisted procedures toward full automation, though research publications and case reports in this field remain limited. For the technology to become more standardized, widely applied in clinical practice and education, and highly intelligent, advancements in structures, sensors, control systems, and related technologies are essential. By 2030, projections suggest that nearly 20 million robots will exist, with automation possibly replacing around 51 million jobs. While robots may not dominate the world, their role in everyday life is expected to expand significantly. This is especially relevant in healthcare, where advancements in artificial intelligence and machine learning are transforming human-robot interactions [1,38] .

More sophisticated AI algorithms will enable greater precision in disease detection, enhance predictive analytics for oral health, and offer personalized treatment recommendations. Chairside 3D printing will become more common, allowing for same-day restorations and reducing the need for multiple patient visits. As AI-driven robotics become integral to dental practice, regulatory bodies will establish comprehensive guidelines to maintain patient safety. Additionally, digital tools and virtual reality will enhance patient education and engagement, making dental care more interactive and accessible. The fusion of AI and robotics in dentistry will streamline workflows, improve treatment efficiency, and elevate patient care standards. To fully realize these benefits, ongoing research and technological innovation will be critical.

Conclusion

Dentistry is advancing into a new era of data-driven and robotic-assisted care. While AI, ML, and robotics have yet to bring significant breakthroughs in dental research, Dentoronics holds great promise in areas such as robotic dental assistants, oral surgery, orthodontics, and material testing. Dentists must work alongside robotics, not only as operators but as decision-makers who ensure precision, patient safety, and ethical considerations in dental care. While automation may shift certain tasks, it will not replace the need for skilled professionals; instead, it will redefine their roles, emphasizing supervision, patient care, and technical expertise. However, challenges like high costs, complex operability, limited sensory perception, and inadequate manipulation capabilities still hinder widespread adoption. Future practitioners must embrace digital advancements, enhance human-robot interaction skills, and adapt to the evolving landscape of healthcare technology.

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