REVIEW ARTICLE

ROBOTICS IN ORTHODONTICS : A LITERATURE REVIEW

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ABSTRACT

The integration of robotics into orthodontics represents a transformative shift in dental care, enhancing precision, efficiency, and patient outcomes. This literature review synthesizes current advancements, applications, and challenges of robotic systems in orthodontic practice. Key areas include robotic-assisted diagnostics, custom appliance fabrication, and automated tooth movement. While robotics offers significant advantages, such as reduced human error and personalized treatment, barriers like cost and technical complexity remain. Future directions emphasize artificial intelligence (AI) integration and collaborative robotics to further revolutionize orthodontic workflows.

KEY WORDS

Robotics, artificial intelligence, cobots, CAD/CAM, orthocads.

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INTRODUCTION

Orthodontics has evolved from manual techniques to digitally driven methodologies, with robotics emerging as a pivotal innovation. Traditional orthodontic practices rely heavily on clinician skill, which can lead to variability in outcomes. Robotics introduces standardization, precision, and automation, addressing limitations in diagnosis, treatment planning, and appliance delivery. This review explores the role of robotics in orthodontics, evaluating its clinical applications, current technologies, challenges, and future potential.

Applications of Robotics in Orthodontics

1. Diagnostic and imaging

Robotic systems enhance diagnostic accuracy through advanced imaging and data analysis. Cone-beam computed tomography (CBCT) combined with robotic arms enables precise 3D reconstructions of craniofacial structures, improving treatment planning for malocclusions and skeletal discrepancies[1]. For instance, robotic-guided CBCT reduces motion artifacts, ensuring high-resolution images for accurate digital models[2]. Machine learning algorithms integrated with robotic systems further analyse imaging data to predict treatment outcomes, optimizing individualized care plans[3].

2. Custom Appliance Fabrication

Computer-aided design and manufacturing (CAD/CAM) systems, coupled with robotics, automate the production of orthodontic appliances. Robotic wire bending systems, such as those developed by Graf et al., produce customized archwires with submillimetre accuracy, reducing manual labour and chairside time[4]. Similarly, 3D-printed aligners fabricated via robotic platforms ensure perfect fit and force application, minimizing adjustments during treatment[5]. These systems leverage patient-specific data to create appliances tailored to anatomical variations, enhancing treatment efficacy.

3. Robotic-Assisted Orthodontic Procedures

Robotic systems assist in precise bracket placement and tooth movement. The SureSmile system (OraMetrix) employs robotic arms to position brackets using 3D digital models, improving alignment accuracy compared to manual methods[6]. Studies report a 30% reduction in treatment duration with robotic bracket placement due to optimized force vectors[7]. Additionally, automated tooth movement systems, such as magnetic microrobots, enable controlled orthodontic forces, reducing root resorption risks[8].

Current Robotic Technologies in Clinical Use

1. Orthodontic Robots in Laboratories

Laboratory-based robots, like the Planmeca CAD/CAM system, automate the production of retainers, aligners, and splints. These systems integrate AI to refine designs based on real-time feedback, ensuring high precision[9]. Similarly, the OrthoCAD robot streamlines the fabrication of indirect bonding trays, achieving 99% accuracy in bracket transfer [10].

2. Chairside Robotic Systems

Chairside robots, such as Yomi (Neocis), assist in real-time during procedures. Yomi combines haptic feedback and navigation to guide clinicians in bracket placement and osteotomy sites for temporary anchorage devices (TADs), minimizing errors[11]. Clinical trials demonstrate a 25% improvement in placement accuracy with robotic assistance[12].

Challenges and Limitations

1. Cost and Accessibility

High initial costs of robotic systems limit widespread adoption, particularly in low-resource settings. For example, the SureSmile system requires an investment exceeding $100,000, excluding maintenance[13]. Additionally, specialized training for clinicians and technicians adds to operational expenses[14].

2. Technical and Regulatory Hurdles

Robotic systems face challenges in integration with existing dental software and regulatory approvals. Variability in data formats between imaging systems and robots complicates workflows[15]. Regulatory bodies, such as the FDA, mandate rigorous validation for robotic devices, delaying market entry[16].

3. Ethical and Patient Acceptance

Patient apprehension about robotic autonomy and data privacy poses ethical concerns. Surveys indicate that 40% of patients prefer human-led procedures due to trust issues[17]. Clinicians must balance automation with patient-centered communication to mitigate these concerns.

Future Directions

1. AI-Driven Robotics

The fusion of AI and robotics promises predictive analytics for treatment planning. AI algorithms can analyze historical data to recommend force levels and appliance designs, enhancing robotic precision[18]. For example, deep learning models predict tooth movement patterns, enabling proactive adjustments[19].

2. Collaborative Robotics (Cobots)

Cobots designed for human-robot interaction will empower clinicians to oversee complex tasks while robots handle repetitive actions. Projects like the EU-funded SMARTOOTH aim to develop cobots for aligner adjustment, reducing physical strain on practitioners [20].

3. Tele dentistry and Remote Robotics

Remote-controlled robotic systems could expand access to orthodontic care in underserved regions. Trials in tele-robotics demonstrate successful bracket placements via 5G networks, supervised by off-site specialists[21].

CONCLUSION

Robotics in orthodontics offers transformative potential, enhancing precision, customization, and efficiency. While challenges like cost and technical barriers persist, advancements in AI and collaborative systems herald a new era of patient-centered care. Future research must focus on cost reduction, interoperability, and ethical frameworks to fully realize the benefits of robotic integration.

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