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**International Journal of Research Publication and Reviews**

Journal homepage: www.ijrpr.com ISSN 2582-7421

# A Review on Emerging Technologies in Orthodontics

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**ABSTRACT**

Orthodontics, the branch of dentistry dedicated to correcting misaligned teeth and jaws, has witnessed remarkable advancements in recent years, driven by emerging technologies. These innovations have not only transformed the field but also improved patient experiences and treatment outcomes. This comprehensive review explores the latest emerging technologies in orthodontics, covering digital imaging and diagnostics, treatment planning, orthodontic appliances, and patient engagement. The article discusses the impact of these technologies on orthodontic practice, highlighting their advantages, challenges, and future prospects

Keywords: orthodontics, emerging technologies, digital imaging, artificial intelligence, 3D printing

## INTRODUCTION

Orthodontics, a specialized branch of dentistry dedicated to the detection, prevention, and treatment of tooth irregularities, has undergone a remarkable transformation in recent years. This growth is due to emerging technologies incorporated into dental implants the industry is largely.[1] These technologies include digital imaging, artificial intelligence, 3D printing, augmented reality, teledentistry, and more.[2] This comprehensive review aims to explore and elucidate several aspects of emerging technologies in dentistry. We will explore the various applications of this technology, from accurate diagnosis and treatment planning to remote patient engagement to customized instruments. In addition, we will discuss the benefits of this technology, such as higher treatment accuracy, improved productivity, and improved patient outcomes. However, it is necessary to address the challenges and considerations associated with implementing these innovations, including ethical and legal concerns.[3] As we navigate this exciting wave of emerging technologies in orthodontics, it is clear that these developments hold great promise. Dentists are not only empowered with state-of-the-art equipment, but also with the ability to provide more personalized and patient-centered care. Dentistry is rapidly evolving in the digital age, and dentists who embrace and adapt to these technological changes are well positioned to deliver superior results.

## ADVANCEMENTS IN IMAGING TECHNIQUES AND DIGITAL TECHNOLOGY IN ORTHODONTICS

CBCT was introduced in dental radiology in 1998, offering several advantages over traditional 2D imaging techniques.[4] It provides a 3D representation of dental and craniofacial structures, eliminates magnification errors and projection artifacts, and allows for effective management of superimpositions. CBCT data is interoperable in Digital Imaging and Communications in Medicine (DICOM) format, facilitating diagnosis, modeling, and appliance manufacturing.[5] Moreover, CBCT exposes patients to lower radiation compared to medical CT devices. Its applications in orthodontics include 3D cephalograms, evaluation of root resorption, assessment of alveolar bone volume for TAD placement, TMJ evaluation, airway assessment, and 3D superimposition. Digital scanning of dental arches has gained prominence, replacing traditional impressions in various orthodontic applications. It facilitates treatment planning, indirect bonding tray fabrication, customized appliance design, clear aligner technology, orthognathic surgery simulation, and wafer construction.[6] Digital scanning offers numerous advantages, including accuracy, permanent digital storage, reduced patient discomfort, streamlined workflows, and efficient data transfer. T-scan is a digital occlusal technology that records real-time, quantifiable occlusal force and contact time sequencing. It helps orthodontists document occlusion, identify interferences, recognize high forces, verify proper occlusion, and ensure stable treatment outcomes. 3D facial scanners provide a detailed topography of facial surfaces, enabling quantitative and qualitative assessments of growth, development, and craniofacial anomalies. Various methods, such as stereophotogrammetry and Moiré topography, are employed for this purpose.[7] Prediction imaging software aids in orthognathic surgery planning by simulating surgical outcomes. These software programs offer tools for cephalometric analyses, surgical procedure simulations, and treatment planning. Some well-known software includes Quick Ceph, Dentofacial Planner, Vistadent, Orthodontic Treatment Planner (OTP), and Dolphin Imaging.[8]

## EVOLUTION OF 3D PRINTING AND LATEST ORTHODONTIC APPLIANCE INNOVATIONS

3D printing, pioneered by Wilfried Vancraen in 1990, has revolutionized manufacturing. This technology allows the creation of three-dimensional objects, prototypes, and production parts from virtual models. In orthodontics, 3D printing has opened up new possibilities for creating dental appliances and models efficiently and accurately. Rapid prototyping (RP) is a key application of 3D printing in orthodontics.[9] RP involves building a 3D model layer by layer, based on a computer-aided design (CAD). This process begins with the creation of a 3D CAD model, which is then deconstructed into cross-sectional layers. These layers are used to guide the 3D printing process, resulting in the physical creation of the object, often referred to as a prototype. Various methods of RP exist, including stereolithography, fused deposition modeling, selective laser melting, and inkjet printing.[10] Align® Technology, Inc., introduced Invisalign in 1998 as an innovative orthodontic tooth movement system. Invisalign involves the use of clear, sequential aligner appliances to straighten teeth and achieve a proper occlusion.[11] The process begins with an initial diagnosis and treatment plan created by an orthodontist. Patient data, including radiographs, impressions, and bite registrations, is sent to Align® Technology. Using this data, 3D models are generated, and the treatment plan is divided into stages. The orthodontist reviews and approves these stages, after which a series of dental models is produced from photosensitive thermoplastic material.[12] These models are used to manufacture a series of clear Invisalign aligners. Patients wear each aligner for a specified period before moving on to the next in the series. While Invisalign offers several advantages, including aesthetics and comfort, it has some limitations. It cannot achieve orthopedic changes, and adjustments for tooth eruption and significant arch changes during growth are not possible.[13] Additionally, any changes to tooth morphology during treatment, such as restorations, can affect the treatment's success. The system also does not consider root positioning at the end of the treatment.

## ADVANCEMENTS IN ORTHODONTIC APPLIANCES AND BRACKETS

In 1998, Align® Technology, Inc., introduced Invisalign as a revolutionary orthodontic treatment method. Invisalign employs a series of clear, sequential aligners to gradually straighten teeth and achieve an ideal occlusion.[14] The treatment process begins with an initial diagnosis and treatment plan created by an orthodontist.[15] Patient data, including radiographs, impressions, and bite registrations, is sent to Align® Technology. Utilizing this data, 3D models are generated, and the treatment plan is divided into stages. The orthodontist reviews and approves these stages, after which a series of dental models is produced from photosensitive thermoplastic material. These models are used to create the final product: a series of clear Invisalign aligners. Patients wear each aligner for 1-2 weeks before progressing to the next stage. While Invisalign offers advantages such as aesthetics and comfort, it has limitations. It cannot achieve orthopedic changes, and it does not accommodate tooth eruption or significant arch changes during growth. Any changes in tooth morphology during treatment, such as restorations, can affect the success of subsequent aligners. Additionally, Invisalign does not consider root positioning at the end of treatment.[16] Orthodontic brackets play a vital role in transmitting orthodontic forces to the teeth. Traditional metal brackets offer superior performance but may lack aesthetic appeal. To address this concern, newer bracket systems have been developed. Ceramic brackets, including polycrystalline and single-crystal alumina brackets, offer excellent aesthetics. They have minimal water absorptivity, better mechanical properties, and biocompatibility. However, they may be susceptible to bracket wing fracture and tooth wear during treatment. Plastic brackets made from polycarbonate provide aesthetic appeal. However, they have limitations, including issues with torque capacity, deformation, and wear resistance. Self-ligating brackets come in two types: active and passive. These brackets incorporate a mechanical device to close the edgewise slot, reducing friction between the archwire and bracket. Active self-ligating brackets provide an active seating force on the archwire, while passive brackets offer more space for the archwire without pressing against it.[17] These brackets promote faster alignment, space closure, and improved occlusal outcomes while reducing friction and treatment time. Benefits of self-ligating brackets include reduced clinical forces, quicker alignment, better torque expression, enhanced patient comfort, improved hygiene, and overall superior treatment outcomes.[18]

## ORTHODONTIC MOBILE APPS

Clinicians Apps:

Orthodontic Update app offers access to the latest publications and updates in the field of orthodontics, keeping clinicians informed about recent developments. Abstracts of articles can be read through this AJODO app, aiding orthodontic professionals in staying up-to-date with research.

Patients Apps:

Bracemate is designed for patients, it provides emergency information and guidance for addressing orthodontic issues. Patients can also select the colours of modules for their braces. Brace Reminder sends notification reminders for brace tightening appointments, helping patients maintain their treatment schedule. Dental Monitoring app enables remote monitoring of patients and educates them on capturing quality images of their teeth for assessment. Trayminder Aligner Tracker assists patients in tracking aligner wear time, provides reminders for switching to the next aligner, and documents progress with teeth selfies.

Educational Apps:

Glossary of Orthodontic Terms is a dictionary app for students, offering explanations of orthodontic terminology. Orthodontic Guide provides information about the orthodontic specialty and available treatment options. Interceptive Orthodontics app offers a step-by-step guide for early intervention in cases of ectopic eruption of maxillary canines and molars.

Doctor-Patient Communication Apps:

Doctor Smile Orthodontics facilitates patient education and motivation, improving the doctor-patient relationship. Dolphin MyOrthodontist helps orthodontists connect with patients, manage appointments, view account balances, and provide media for patient education. My Orthodontist offers information about orthodontists, FAQs, office hours, and directions to the practice.

Clinical Support Apps:

Oneceph is used for cephalometric analysis. iModel Analysis supports the analysis of study models. REM Orthodontics allows the shopping of orthodontic materials.[19]

## NANOTECHNOLOGY IN ADVANCING ORTHODONTIC TREATMENT

Nanoparticles, such as inorganic fullerene-like nanoparticles of tungsten sulfide (IF-WS2), act as dry lubricants, reducing frictional forces between orthodontic wires and brackets. These coatings enhance the efficiency of orthodontic treatment.[20] Polymer nanocomposites with silica nano-fillers, measuring 0.005-0.01 microns, reduce polymerization shrinkage and improve mechanical properties, including tensile and compressive strength.[21] This enhances the durability of orthodontic adhesive. Elastomeric ligatures embedded with nanoparticles can deliver anticariogenic, anti-inflammatory, and antibiotic drug molecules, contributing to oral health during orthodontic treatment. Shape memory nanocomposite polymers produce esthetic orthodontic wires with shape memory properties. These materials offer clarity, color options, and resistance to staining, providing patients with aesthetically pleasing appliances. Metal nanoparticles in the size range of 1-10 nm exhibit biocidal activity against bacteria. Integrating dental materials with nanoparticles or coating surfaces helps prevent microbial adhesion, reducing biofilm formation.[22] Nanomechanical sensors integrated into orthodontic brackets provide real-time information about the force applied by the bracket on the tooth. Nano chips encapsulated in low-profile brackets enable precise force monitoring. Biocompatible coatings like titanium nanotubes enhance initial osseointegration and serve as an interfacial layer between newly formed bone and temporary anchorage devices (TADs). Microsensors embedded into removable appliances wirelessly monitor wear and compliance. They provide valuable data on patient adherence to treatment regimens, aiding orthodontists in optimizing care.[23]

## ROBOTICS IN ORTHODONTICS

In the realm of orthodontics, robotics has emerged as a transformative force with a wide array of applications. These encompass the entire spectrum of orthodontic diagnosis, management, and simulation, presenting a new era in patient care and education. Advanced parallel robots facilitate precise dental articulation, reducing chairside time for dentists. Robotic systems with skulls improve the accuracy of 3D imaging by studying head movement effects. Machine learning-based methods enable automatic annotation of critical landmarks in 3D cephalometric images. Remotely controlled mandibular positioners streamline the treatment process for obstructive sleep apnea. Robotic technology addresses dental anxiety in children, employing technopsychological distraction techniques. A software simulation system allows for interactive orthodontic procedure simulations, while various robots replicate human chewing behavior and jaw movements. In the realm of education, humanoid patient simulation systems enhance dental students' familiarity with real patients, while robotic orthodontic bonding practice aids in iterative learning. Medical emergency robots prepare students for handling emergencies, and the ROBOTUTOR effectively educates patients in tooth-cleaning techniques. Robotics also enhances the precision of arch wire bending and custom CAD/CAM appliance manufacturing. Furthermore, nanorobotic dentifrice offers cost-effective calculus debridement, while nanosensors remotely monitor appliance wear. In maxillofacial surgery, robots improve precision in implant placement and various surgical procedures. Orthodontic aligner production benefits from robotic automation. Finally, rehabilitative robots are employed for safe and effective treatment of temporomandibular disorders (TMD). These multifaceted robotic advancements are revolutionizing orthodontics, delivering enhanced precision, efficiency, and patient care across the board.[24]

## ARTIFICIAL INTELLIGENCE IN ORTHODONTICS

Artificial intelligence (AI) serves as the technological backbone for a wide range of applications across various facets of our daily lives. AI, often associated with "machine learning," involves the use of specialized algorithms that analyze sample data to generate mathematical models capable of making predictions without explicit programming for each task. In recent years, the increased availability of computing power has enabled AI algorithms to tackle more complex medical challenges. Some AI applications have shown remarkable potential in aiding medical decisions and, in some cases, outperforming human clinicians in diagnostics. Consequently, there has been a surge in scientific publications aimed at integrating AI into routine orthodontic practices. Studies assessing the accuracy of AI-based cephalometric analysis demonstrate promising results, with most achieving landmarks within an acceptable 2 mm tolerance limit for clinical purposes. While these findings are encouraging, concerns exist regarding the commercial availability of AI solutions with unclear scientific bases, emphasizing the need for rigorous scientific evaluation. The cervical vertebral maturation (CVM) method, based on lateral cephalometric X-rays, offers a non-invasive approach to assess skeletal age. AI algorithms have been developed to automate CVM stage determination, showing variable success rates. Further research is needed to improve accuracy, especially for stages around the growth peak. AI can aid in decision-making regarding orthodontic extractions, considering factors such as crowding, tooth position, and overjet. Several AI algorithms have achieved high accuracy in predicting the need for extractions and even extraction patterns. However, limitations include the omission of critical factors like fillings, endodontic treatments, and periodontal issues, as well as the subjective nature of expert input used for training. AI has the potential to assist in deciding whether orthognathic surgery is necessary. Algorithms trained on patient data and expert assessments have shown promise in predicting the

need for surgery, with some achieving accuracy rates exceeding 90%. However, these models have limitations, as they may not consider all relevant factors influencing surgical decisions. Additionally, their applicability to diverse patient populations remains untested. The integration of AI into orthodontics holds great promise for improving diagnostics, decision-making, and treatment planning. It offers potential benefits for both inexperienced and experienced clinicians, including time savings and quality assurance. However, challenges persist, such as the need for extensive and diverse training data, potential biases in commercial AI solutions, and the imperative for ongoing scientific validation. While AI may not replace human expertise in the foreseeable future, it is poised to complement orthodontic practices, enhancing patient care and treatment outcomes. Collaboration between AI vendors and the scientific community is crucial to ensure the reliability and validity of AI applications in orthodontics. Further research is needed to refine and generalize AI solutions for broader clinical use.[25]

## CONCLUSION

The integration of emerging technologies in orthodontics has ushered in a new era of precision, efficiency, and patient-centered care. From digital diagnostics to customized appliances and remote monitoring, these innovations are reshaping how orthodontic treatments are planned and delivered. Despite challenges, the future holds exciting prospects for further advancements in materials, artificial intelligence, and patient engagement. Orthodontists who embrace these emerging technologies are well-positioned to provide the best possible care to their patients and contribute to the continued evolution of the field.

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