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IP Indian Journal of Orthodontics and Dentofacial Research

Journal homepage: https://www.ijodr.com/

Review Article

Current landscape of orthodontic progress: Where we stand today! A comprehensive review

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ARTICLE INFO

Article history:
Received 28-12-2023
Accepted 01-02-2024
Available online 04-04-2024

Keywords:
Recent advances
Orthodontics
Diagnostic aids
Bonding
3D printing
Machine learning
CAT materials
Teledentistry
Robotic application

ABSTRACT

The orthodontic field has undergone a transformative evolution marked by recent advances, encompassing innovations in appliances, diagnostic aids, bonding, materials and AI. A notable progression includes the integration of 3D imaging systems and its application in the field of Orthodontics.

Over the past decade, orthodontics has experienced substantial growth propelled by advancements in brackets, bonding agents, technology, and the incorporation of mini-implants. The imperative for heightened efficiency in orthodontic clinics has spurred technological improvements aimed at facilitating superior, quicker, and more convenient patient treatment.

Recent breakthroughs in orthodontics have revolutionized clinical practices, elevating efficiency and broadening the array of available treatment options. These innovations contribute to increased patient throughput, enabling orthodontists to provide enhanced care. The continual evolution of orthodontic technologies ensures a dynamic and responsive field, marked by ongoing endeavours to refine and advance treatment modalities.

1. Introduction

Orthodontics stands as a dynamic and ever-evolving field, continually integrating cutting-edge technologies and pioneering treatments. As orthodontic professionals, it is imperative for us to stay abreast of these innovations, ensuring our patients have access to the latest and most exceptional options for achieving a radiant and healthy smile.

In response to evolving societal standards and technological progress, there has been a notable shift toward prioritizing both comfort and style in orthodontic treatments. The demand for inconspicuous and more comfortable solutions has witnessed a significant upswing.

The realm of orthodontics has seamlessly integrated into the technological revolution, marked by the advent of novel materials, digital imaging, and computerized treatment planning. These advancements have not only led to visually appealing solutions but also contributed to the reduction of treatment durations and enhancement of the overall patient experience.

Remaining well-informed about these progressive treatment options is of paramount importance. Whether you are a potential patient, a dental professional, or simply intrigued by the advancements in dental science, gaining insights into these innovations offers a glimpse into the future trajectory of orthodontic care.

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https://doi.org/10.18231/j.ijodr.2024.002
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2. Discussion

2.1. Current and emerging uses of technology in orthodontics

2.1.1. Diagnostic Aids

The realm of orthodontics has experienced a transformative surge in recent years, driven by groundbreaking advancements in diagnostic aids. These innovations have revolutionized the field, empowering orthodontists with unparalleled diagnostic capabilities for precise treatment planning and assessment. Here, we delve into the multifaceted landscape of diagnostic technologies that have reshaped orthodontics.

Virtual Orthodontic Approaches: Leveraging 3D imagery and four-dimensional face dynamics, virtual orthodontic patients can be created, allowing for in-depth investigations into soft and hard tissue dynamics.

A subspecialty of digital orthodontics known as "virtual orthodontics" makes use of a variety of cloud-based platforms and technologies, some powered by artificial intelligence (AI) and others not. These tools have the potential to enhance patient-doctor interactions in terms of communication, education, and practice efficiency.

In assessing the precision of virtual orthodontic setups for simulating treatment outcomes and their potential integration into orthodontic practice and education, a systematic search spanning January 2000 to November 2022 was conducted across five electronic databases: PubMed, Scopus, Embase, ProQuest Dissertations & Theses Global, and Google Scholar. The review, encompassing twenty-one articles, revealed a moderate risk of bias in all studies.

Data were categorized into three groups:

1. Virtual setup versus manual setup;
2. Virtual setup versus actual outcomes in clear aligner treatment;
3. Virtual setup versus actual outcomes in fixed appliance treatment.

Although statistically significant differences emerged between virtual setups and actual treatment outcomes, these disparities were deemed clinically acceptable.

The systematic review advocates for the implementation of orthodontic virtual setups in practice and education, citing their clinically acceptable accuracy. Nonetheless, the call for high-quality research remains imperative to validate the precision of virtual setups in faithfully simulating treatment outcomes.[1]

Beyond diagnostic aids, recent orthodontic advances extend to treatment modalities:

Nanotechnology in Orthodontics: Nanotechnology finds applications in orthodontics, including nanocoatings in archwires and smart brackets with nanomechanical sensors.

Significant advancements in nanotechnology have been made in several industries, most notably electronics. Nano electronics, as applied in the field of nanotechnology, describes electronic components and research aimed at enhancing features such as size, power consumption, and useful device display. IoT(Internet of Things) has been the subject of numerous scientific investigations, leading to new technical developments in recent years. With its rapid expansion, IoT is thought to be the most promising and advanced part of web-based technology. The detection and prevention of dental caries, periodontal diseases, oral malignancies, and other oral problems may be improved using the Internet of Dental Things (IoDT). In addition, IoDT is essential for data collecting and monitoring in the oral healthcare system, providing dentists with cutting-edge risk assessment methods. Smart orthodontic brackets' main objective is to control and regulate tooth movement more effectively. These innovative brackets are built upon advanced IoDT and nano electronics technology, enabling precise control over the direction, amount, and speed of tooth movement.[2]

Microsensor Technology: Microsensor technology aids in monitoring the wear of removable appliances, contributing to more precise treatment adjustments.

A commercial system called Sunrise System was recently described. It consists of a wearable sensor the size of a coin that is embedded with an IMU. Mandibular motion detection is made possible by the extraoral attachment of the sensor to the patient's chin. The tiny IMU sensor sends mandibular movement data to a specialised smartphone application, which at the conclusion of the recording instantly moves the data to a cloud-based infrastructure. A specialised machine learning system that automatically scores respiratory and sleep episodes is used for data analysis. This wearable sensor's ability to track mandibular motion has demonstrated promise for both treating bruxism and diagnosing OSA.[3]

The recent surge in diagnostic aids and treatment modalities has propelled orthodontics into a new era of precision, efficiency, and patient-centric care. These advancements underscore the commitment of the orthodontic community to staying at the forefront of innovation for the benefit of patients and the evolution of the field.[4]

3. Nanobioadhesion in Bonding

Nethivalavan et al. conducted a study to assess the efficacy of bioactive glass-based adhesives in preventing demineralization around orthodontic brackets and to evaluate their physical and mechanical properties as potential orthodontic bonding agents. Mesoporous bioactive glass (MBG) was synthesized using an enhanced sol-gel method, resulting in 12 experimental groups with varying surfactant-to-oil ratios. After six months of pH cycling in vitro to simulate oral conditions, properties were analyzed and compared with Transbond XT adhesive as the control.

SEM analysis revealed spherical morphology in MBG particles. The newly developed orthodontic bonding material (BG) exhibited favorable mechanical properties with a bond strength of 7.2 MPa, indicating suitability as a bonding agent. Subsequent SEM analysis after simulated salivary conditions showed reduced demineralization potential comparable to conventional bonding resin (TBXT), suggesting clinical acceptance.

The study's findings indicated that MBG-based adhesives effectively mitigated superficial surface demineralization during in vitro caries challenges, showcasing promising properties for orthodontic use. The optimal surfactant-to-oil ratio of 0.016514 demonstrated superior overall performance. The study concluded that the MBG-based adhesive demonstrated reduced demineralization effects and optimal physical and mechanical qualities for orthodontic applications.[5]

4. 3D Printing Technologies

3D printing has revolutionized orthodontics, employing various techniques such as Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Electron Beam Melting (EBM), Digital Light Processing (DLP), and PolyJet. FDM utilizes thermoplastics like ABS and PLA, offering minimal post-processing and a low layer thickness of 127 μm, ideal for orthodontic devices like retainers and aligners. SLS uses powder materials for support-free printing, while EBM focuses on metal powders like titanium for strong structures, particularly in orthopedics. DLP utilizes photopolymers for fast printing with a layer thickness below 30 μm, suitable for orthodontic working models. Inkjet 3D Printing (3DP/IJP) involves adding a binder liquid to a powder substrate, with PolyJet providing diverse material use.

Recent advances, particularly in Stereolithography (SLA), have transformed orthodontic model manufacturing, allowing accurate reproduction without traditional impressions. 3D-printed models find applications in creating precision orthodontic appliances like retainers and aligners. Studies compare different 3D printing technologies, emphasizing differences in precision and accuracy. Despite concerns, 3D printing proves beneficial in orthodontic diagnosis, treatment planning, and appliance customization.

In a 2023 AJODO study by Gianluigi Fiorillo et al., a CAD-CAM indirect bonding technique utilizing a customized 3D-printed transfer tray and a flash-free adhesive system demonstrated high accuracy in orthodontic bonding. The in vivo evaluation on 106 teeth showed an overall bonding inaccuracy of 0.35 mm, below the clinical acceptability limit. This study highlights the potential of 3D printing for precise orthodontic applications, emphasizing the importance of adhering to scientific and manufacturer recommendations for continued advancements in the field.[6,7]

A further development included the launch of the initial orthodontic Computer-Aided Design (CAD) software, enabling the on-site creation and printing of personalized brackets known as Ubrackets. (Coruo, Limoges, France).[8]

The synergy of in-office bracket customization is embodied in the Ubrackets CAD software, enabling orthodontists to design and produce personalized brackets on-site, eliminating the need for external services. The process involves intraoral scanning, customized bracket design in the Ubrackets software, 3D printing, and a post-printing procedure, such as UV curing or debinding-sintering for zirconia brackets. This in-house approach to designing and printing customized orthodontic brackets is an emerging trend likely to shape the future of orthodontics, facilitated by the precision of Ubrackets software.[9]

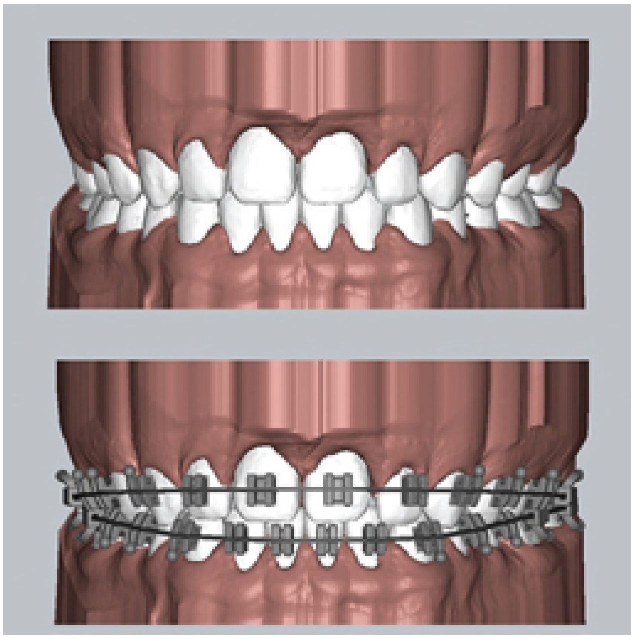

Figure 1: Customized bracket using ubracket software[8]

4.1. *Properties of 3D printable materials with clinical significance for intraoral application in orthodontics*

The above review examined the available evidence on 3D printable materials and techniques for orthodontic appliances, with a focus on clinically relevant material properties. Out of 669 initially retrieved citations, 47 articles were included in the qualitative review. Most articles presented proof-of-concept clinical cases detailing the digital workflow for various appliances. Aligners fabrication through 3D printing, particularly using Dental LT Clear Resin (Formlabs) and Tera Harz TC-85 (Graphy), was extensively investigated. However, there was a lack of standardized protocols for testing mechanical properties and assessing biocompatibility, particularly considering intraoral conditions' impact on eluents release. Aesthetic properties of 3D-printed appliances and evidence on 3D-printed metallic appliances were found to be limited. The review underscores the need for international standards in laboratory testing and calls for further clinical trials to strengthen the scientific evidence on 3D printable orthodontic materials and techniques.[10]

4.2. Teledentistry

In the realm of orthodontics, teledentistry has swiftly materialized as a tangible reality, particularly bolstered by the advent of orthodontic aligners. This innovative approach integrates virtual checkups, leveraging remote monitoring technology to assess treatment progress without the need for in-person appointments. Teledentistry in orthodontics serves a myriad of purposes, encompassing diagnosis, planning, consultation, monitoring oral hygiene, coordinating with elastics, and assessing alignment or correcting malocclusion post-orthopedic appliance use.[11–13]

A recent study highlighted that 60% of American orthodontists have adopted teledentistry, with 45% planning to incorporate it into their treatment routines.[14] The COVID-19 pandemic prompted the introduction of virtual treatment monitoring, with subsequent studies demonstrating the practicality of teledentistry in emergency situations and its potential applicability in regular circumstances.[15–17]

A scoping review emphasized the diverse applications of teledentistry in orthodontics, including ceph allometric diagnostic apps, reminder apps, and remote monitoring via apps.[18] While models generated from photos and videos are clinically accurate, proper patient training is essential for obtaining adequate images. Motivating patients throughout treatment is crucial to prevent non-cooperation.[19]

Remote monitoring has proven effective for rapid maxillary expansion, showing comparable outcomes to traditional assessments. Patients express preferences for remote follow-up, and continuous monitoring enhances cooperation, precision, and optimal aligner use.[20–22] Meta-analysis indicates that teledentistry during orthodontic treatment with aligners reduces the time to start refinement and the number of face-to-face visits, offering a convenient option for patients.[23–25]

5. Machine Learning

Artificial Intelligence (AI) has been a prominent focus in scientific research, impacting daily life (Abhimanyu et al., 2020; Dolci, 2017; Wang et al., 2020; Yanhua, 2020). AI involves computers learning from data inputs to find optimal, adaptive solutions independently of humans (Legg & Hutter, 2007; Visvikis et al., 2019), evolving into the distinct field of machine learning (ML).

Figure 2: Tele-dentistry in Orthodontics[26]

In *Landmark Identification,* various AI algorithms are employed.

1. The Active Shape Model (ASM) captures shape and grey profile variations in lateral cephalograms (Yue et al., 2006).
2. A customized open-source CNN deep learning algorithm demonstrates comparable precision to experts using high-quality data (Kunz et al., 2020).
3. You-Only-Look-Once version 3 (YOLOv3) shows clinically insignificant detection errors and superior reproducibility (Hwang et al., 2020; Park et al., 2019).
4. A hybrid approach combines 2D ASM and 3D knowledge-based models for improved accuracy and speed (Montúfar, Romero & Scougall-Vilchis, 2018).
5. Entire image-based CNN, patch-based CNN, and variational autoencoder achieve high accuracy in 3D landmark annotation with limited CT data (Yun et al., 2020).
6. VGG-Net, trained with diverse 2D images, forms stereoscopic craniofacial structures (Lee et al., 2019).

For *Cervical Vertebrae Stage Determination,* various AI algorithms exhibit different precision, with artificial neural networks (ANN) recommended for overall stability (Kök, Acilar & Izgi, 2019).

In Teeth-Extraction Decision-Making, a two-layer neural network provides a detailed plan for orthodontic treatment (Jung & Kim, 2016). Supervised ML techniques demonstrate good accuracy in predicting extraction patterns, emphasizing the importance of cephalometric and demographic indicators (Leavitt et al., 2023). The study suggests future research avenues for enhanced accuracy, including larger sample sizes and clinician consensus.[27]

6. Clear Aligner Materials

Amidst the rapid advancements in biomaterials and computer-aided design (CAD) and manufacturing (CAM), clear aligner therapy (CAT) has emerged as a promising alternative to traditional Fixed appliances (FAs) in orthodontics.[28] The materials employed for manufacturing clear aligners include polymers such as polyester, polyurethane, co-polyester, polypropylene, polycarbonate, ethylene vinyl acetate, and polyvinyl chloride.[29–31]. Evolving from single-layered to third-generation multilayered materials, these aligners often comprise both hard and soft layers, providing elasticity for smooth seating and durability for strength[32].

Align Tech emphasizes the importance of new materials offering enhanced elasticity and consistent forces for improved clinical efficacy.[33] A study comparing two types of aligner materials demonstrated structural modifications leading to increased hardness and hyper-plasticity, with no significant difference in clinical outcomes assessed by the Peer Assessment Rating (PAR) score reduction.[29,34]

Polymer blends, incorporating different polymers like polyester, polyurethane, and polypropylene, aim to enhance the mechanical properties of clear aligners. Studies on polymer blending reveal improved mechanical and chemical properties, ultimately enhancing clinical performance.[30,35–39] Blending ratios significantly influence the features of the polymer blend, with specific ratios showing superior mechanical properties and sustainable orthodontic forces.[30,38] The ratio used to blend the polymers has an enormous effect on the blend's characteristics. For instance, blending PETG/poly carbonate (PC)/TPU at a ratio of 70/10/20 resulted in better mechanical properties in comparison to other blending ratios, and was shown to exhibit sufficient and sustainable orthodontic forces than other commercialized products. Similarly, PETG/PC2858 blended at a 70/30 ratio, expressed the best combination of tensile strength, impact strength and elongation at break.

In the world of 3D printed aligner materials, direct printing offers advantages over thermoforming processes, providing better geometric accuracy, precision, fit, efficacy, mechanical resistance, and reproducibility.[40] Materials utilized for 3D printing in orthodontics include acrylonitrile-butadiene-styrene plastic, stereolithography materials, polylactic acid, polyamide, glass-filled polyamide, silver, steel, titanium, photopolymers, wax, and polycarbonates.[41] Graphy introduces Tera Harz TC-85, a photopolymer material for 3D printing clear aligners, offering biocompatibility, transparency, and durability in various colours.

Bioactive materials integrated into clear aligners contribute to novel approaches in orthodontics. A randomized clinical trial compared clear aligners, self-ligated brackets, and conventional brackets in terms of oral hygiene, revealing no significant differences. However, modifications enable clear aligners to be used as a long-term drug delivery system for patients with P. gingivalis infection.[42,43] Coating aligners with gold nanoparticles (AuDAPT) exhibits antibacterial effects, slowing biofilm formation and presenting favorable biocompatibility.[44] Cellulose-based clear aligner material loaded with essential oils, such as cinnamaldehyde, demonstrates antimicrobial properties.[45]

In the context of 3D printed orthodontic splints, Raszewski et al.[46] introduced materials enriched with bioactive glass fillers, showcasing desirable bioactive properties. Additionally, innovations in aligner materials, such as shape memory polymers, direct 3D printed clear aligners, and bioactive materials combined with clear aligner materials, hold promise for advancing CAT applications.[47]

Environmental responsibility in aligner manufacturing and use is highlighted, emphasizing the need for biodegradable materials and aligner technologies that align with sustainability goals.[48] Overall, the continuous evolution of aligner materials and technologies reflects a dynamic landscape in orthodontics, pushing the boundaries of innovation for improved patient outcomes.

7. Robotic Application in Orthodontics

Orthodontics, a field focused on improving the efficacy of patient treatments, has not been exempt from this technological revolution.[49]

Defined as the "intelligent connection between perception and action," robotics, an interdisciplinary field merging computer science and engineering, has become an integral part of various industries, including orthodontics.[50] The versatility of robots, characterized by mechanical construction, electrical components, and computer programming, is evident across diverse applications.[51]

In the context of orthodontics, the implementation of robots has become particularly relevant in response to the challenges posed by the COVID-19 pandemic. Robotic assistants have the potential to alleviate the workload on human assistants, allowing them to focus on tasks requiring social interaction, diagnosis, treatment planning, and high cognitive demands[52]

The digitization of orthodontic records and the advent of 3D simulations have paved the way for robotic applications in accurate X-ray imaging, 3D cephalometric annotation, and simulation of various aspects of the stomatognathic system.[53–62] Nanotechnology, encompassing nanomaterials, nanobiotechnology, and nanorobotics, has contributed to efficient treatment outcomes, including the acceleration of tooth movement and the development of smart brackets with integrated

Figure 3: Application of robotics in the field ofOrthodontics[49]

nanomechanical sensor systems.[63–71]

Robots have also made significant contributions to implant placement and maxillofacial surgeries, enhancing precision and efficiency. The surge in demand for aligners has led to the development of robotic systems for the efficient fabrication of custom-made orthodontic appliances, showcasing advancements in scanning and automation technology.[72,73]

Furthermore, robotics has played a vital role in the education and training of orthodontic professionals. Training robots designed for dental education have been explored since 1969, providing heuristic value by simulating actual mastication and facilitating the exploration of different scenarios.[74–79]

The last decade has witnessed remarkable progress in robotic wire bending and the customization of CAD/CAM appliances, exemplified by the development of robots such as Sure Smile, Incognito, LAMDA, Insignia, and BRIUS appliances.[80–90] These robots contribute to the accuracy and efficiency of arch wire bending, a crucial aspect of fixed orthodontic treatment.[91]

As technology advances, the incorporation of machine learning (ML) and artificial intelligence (AI) into robotic systems has further enhanced their capabilities. ML enables robots to self-improve based on large amounts of data, while AI facilitates autonomous and symbolic task planning, enabling robots to adapt to new circumstances.[92,93]

Over-all robotics has ushered in a new era of data-driven and robot-assisted medicine in orthodontics. The integration of AI and ML has led to significant improvements in precision and treatment success. However, challenges remain, including the need for increased intuitiveness, broader educational efforts, and the introduction of affordable systems to fully integrate robotics into orthodontic practices. Areas such as arch wire bending, simulative robots, and surgical robots have seen significant research, while assistive robots, patient robots, and automated aligner production robots require further scientific investigation.[93] The orthodontic field is poised for continued advancements as technology evolves, with the potential for broader applications and enhanced patient care.

8. Conclusion

The fields of dentistry and orthodontics are experiencing rapid transformations, poised to enhance the quality, precision, and cost-effectiveness of care. While the integration of patient biology into treatment decisions has trailed behind technological innovations, the convergence of omics, targeted biologics, bioactive agents, smart drug delivery, and deep clinical phenotyping with big data and AI is set to drive significant advancements in our profession. Looking ahead, the combined impact of recent breakthroughs and the forthcoming wave of innovation in materials, 3D technologies, smart devices, AI, and omics paints a compelling vision for the future of precision orthodontics.

9. Source of Funding

None.

10. Conflict of Interest

None.

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Cite this article: Saha S, Subbarayalu M, Iyer Ramana Ramya Shree N, Mahendra S, Raju AS, Chandrashekar BS, Mahesh CM, Ansari N. Current landscape of orthodontic progress: Where we stand today! A comprehensive review. *IP Indian J Orthod Dentofacial Res* 2024;10(1):3-10.