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Review

Comparing the Efficacy of Conventional and Customized Bracket Systems in Orthodontics

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Abstract

In fixed orthodontic treatment, the bracket system acts as the crucial interface between the archwire and the teeth, enabling controlled force application to guide tooth movement. Conventional brackets remain a foundational orthodontic treatment known for reliability, but their effectiveness depends on frequent archwire adjustments and potentially longer treatment times due to the manual nature of the process and inherent friction between the wire and bracket. Customized bracket systems, offering a personalized approach to teeth alignment that contrasts with traditional, prefabricated methods. Customized orthodontic brackets with precise slot dimensions and angulations are produced using a combination of computer-aided design (CAD), computer-aided manufacturing (CAM), 3D scanning, and sometimes 3D printing technologies and are designed to precisely fit an individual's unique dental structure, potentially improving treatment outcomes and efficiency. Clinical evidence comparing conventional and self-ligating brackets shows mixed results, with some studies suggesting advantages for one type or the other, but no definitive superiority in overall treatment outcomes. Although customized brackets might provide better torque expression, bond strength, and aesthetics, their uptake is constrained by increased expenses, more planning time, and inconsistent accessibility. Patient satisfaction typically improves with customized approaches; however, outcomes are still affected by the orthodontist's proficiency and the complexity. Although traditional brackets remain a cost-effective and accessible treatment option, customized CAD/CAM and 3D-printed devices signify a promising advancement for more precise and specialized orthodontic care. Future research must emphasize high-quality, long-term clinical trials to elucidate their underlying clinical advantages, cost-effectiveness, and influence on patient-reported outcomes.

Keywords: *Orthodontics, Customized Bracket, computer-aided design, 3D print, efficacy*

Introduction

Orthodontics is a specialized field of dentistry that focuses on diagnosing, preventing, and treating misalignments of the teeth and jaws, known as malocclusion and craniofacial anomalies (1). Its purpose is multifaceted, encompassing both functional and aesthetic improvements, with fixed appliances being the cornerstone of modern therapy. In the earlier era, this complex orthodontic issue was first tackled using non-programmed brackets made by hand in the early 20th century by pioneers such as Edward Angle, who invented the ribbon arch and edgewise appliance (2). Although it was innovative in its emphasis on force and torque control, this approach was later replaced by Andrews' straight-wire appliance (3).

Dr. Lawrence Andrews' straight-wire appliance revolutionized orthodontics by pre-programming the "six keys to normal occlusion" into bracket prescriptions, aiming to minimize wire bending and create precise outcomes. However, the system's reliance on average anatomical data limited its effectiveness, as individual variations in tooth morphology and bracket placement errors reduced precision. To address these limitations and enhance accuracy, indirect bonding techniques were developed to improve bracket placement (4). Studies suggest that indirect bonding does not consistently lead to fewer bracket placement errors than direct bonding, with some research finding no significant difference in accuracy (5). Furthermore, the natural variations in a patient's tooth anatomy are often a greater factor influencing bracket positioning than any differences between different pre-adjusted bracket systems themselves. While indirect bonding was intended to improve accuracy, it may not always achieve this, and errors can occur during the transfer from the model to the teeth. Although the straight-wire appliance improved treatment predictability, it could not fully accommodate individual variations in tooth anatomy. Concurrently, attempts to enhance aesthetics with ceramic and plastic brackets introduced new mechanical limitations, highlighting the need for customized and digitally engineered bracket systems (6, 7).

The advent of 3D printing, first conceptualized by Hideo Kodama in the 1980s, has opened new possibilities for individualized orthodontic care (8). Building on this technology, lingual and labial (or buccal) brackets can now be fabricated from metal, ceramic, or plastic using 3D printing techniques. Advances in 3D printing technology allow for the creation of customized brackets tailored to a patient's unique dental anatomy, using additive manufacturing processes. This digital workflow enables the direct fabrication of patient-specific brackets from materials like stainless steel, titanium, ceramic resins, and zirconia slurries (9, 10). This approach allows clinicians to design patient-specific brackets tailored to individual dental anatomy, potentially enhancing the accuracy of treatments (11). Customized 3D-printed brackets may also contribute to shorter overall treatment durations compared to conventional systems (12). These brackets can be produced either in-house, for example via the UBracket CAD system, or through commercial platforms such as KLOwen, Braces on Demand, and LightForce, providing flexibility in clinical application.

Bracket customization has marked a notable advancement in orthodontics, offering the potential for more precise and individualized treatment. Assessing the clinical efficacy of customized milled or 3D-printed brackets requires careful consideration of their mechanical and aesthetic properties, effects on treatment duration, and cost-effectiveness in comparison to conventional brackets. Accordingly, this review seeks to synthesize current evidence on CAD/CAM and 3D-printed customized bracket systems, contrast them with traditional brackets, and identify gaps in the literature that warrant further investigation.

Methods

A literature search was conducted in PubMed, Google Scholar, Cochrane and Science Direct using the keywords 'conventional orthodontic brackets,' 'customized orthodontic brackets,' 'CAD/CAM orthodontics,' '3D-printed orthodontic brackets,' 'digital orthodontics,' 'indirect bonding,' 'straight-wire appliance,' 'torque control in orthodontics,'

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'bracket placement accuracy,' 'treatment duration orthodontics,' 'patient satisfaction orthodontics,' and 'cost-effectiveness orthodontics.' These terms were used individually and in combination to identify relevant articles published in peer-reviewed journals.

Discussion

Conventional versus Customized Bracket Systems

In fixed orthodontic treatment, the bracket system acts as the crucial interface between the archwire and the teeth, enabling controlled force application to guide tooth movement (13). Conventional bracket systems have been a mainstay in orthodontic treatment for decades, serving as the foundational method for aligning teeth. However, the use of prefabricated brackets requires multiple adjustments and extended treatment times to achieve optimal alignment (14). They offer solutions for various orthodontic conditions such as crowded teeth, misaligned bites, and gaps between teeth. Their standardized design often requires significant manual adjustments (wire bending and finishing) to meet the unique needs of each patient's smile, which adds complexity to the treatment process. Customized orthodontic brackets with precise slot dimensions and angulations are produced using a combination of computer-aided design (CAD), computer-aided manufacturing (CAM), 3D scanning, and sometimes 3D printing technologies. They are designed to precisely fit an individual's unique dental structure, potentially improving treatment outcomes and efficiency (14). The main rationale for customization lies in improving the precision of tooth movement, minimizing mid-treatment adjustments, and potentially enhancing overall efficiency. While conventional systems remain the foundation of clinical practice, the emergence of customized systems has introduced new possibilities for greater accuracy and predictability, warranting closer examination of their efficacy in comparison.

Mechanical Properties

An orthodontic bracket's mechanical performance is crucial because its properties, such as rigidity and force delivery, directly impact the effectiveness and reliability of tooth movement. Optimal mechanical properties are necessary for consistent and predictable forces to achieve efficient tooth movement within the periodontal membrane, preventing undesired side effects like excessive tipping or unwanted root movement (15). Conventional brackets, while reliable, offer standard force delivery and torque expression based on generalized prescriptions, which may not fully accommodate individual variations in tooth morphology. Frictional resistance between archwire and bracket can also vary depending on material and slot precision, occasionally slowing tooth movement or necessitating additional adjustments (16). Customized orthodontic brackets, created using CAD/CAM and 3D printing, are designed to fit each patient's unique tooth anatomy, offering more precise force application, better torque control, and precisely optimized slot precision (10). This personalization leads to more effective and potentially faster tooth movement, improved treatment outcomes, and enhanced patient comfort. Customized orthodontic brackets can offer advantages over conventional systems by potentially demonstrating higher bond strength and durability due to their precise fit to the tooth, which can lead to more predictable clinical outcomes. While bond strength is influenced by numerous factors, including material and bracket design, the customized base design of these systems can create better micro-interlocking mechanisms with the adhesive, promoting greater retention and contributing to overall clinical reliability (17).

Clinical Properties

Treatment Duration

Treatment duration and outcomes are prominently debated subjects when comparing CAD/CAM customized orthodontic brackets to traditional ones. The effect of CAD/CAM customized bracket systems on treatment duration has shown mixed results in the literature. CAD/CAM customized bracket systems have been associated with shorter treatment times and fewer archwire adjustments; the impact on American Board of Orthodontics (ABO)

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scores has shown varied results, with some studies demonstrating improvement and others showing no significant difference compared to standard indirect bonding (18, 19). Jackers et al. (19), found a 26% increase in treatment duration with noncustomized compared to customized appliances (497 ± 40.8 days and 393 ± 55.7 days, respectively, $P = 0.0002$). Although noncustomized systems showed a 26% longer overall treatment time, the quality of treatment was comparable to customized systems. Another prospective quasi-randomized study on custom CAD/CAM brackets (Insignia™) versus directly bonded self-ligating brackets found no significant differences in treatment outcomes (ABO scores), duration, appointment frequency, or archwire adjustments, suggesting that customized systems offer only modest improvements in clinical efficiency and may even increase bonding failures (20). Beyond overall treatment time, the duration of the finishing and detailing phase has also been evaluated by Jackers et al. (19) found that customized brackets significantly shortened this phase in both arches, with the maxilla averaging 142 ± 60.5 days versus 258 ± 73.4 days for conventional brackets (P = 0.0011) and the mandible 134 ± 59.4 days versus 226 ± 76.0 days (P = 0.0056) (19). However, treatment planning with customized appliances requires considerably more time upfront, according to Penning et al study (21). On the other hand, Penning et al. (21) stated that the orthodontist had a significant effect on treatment duration, quality of treatment outcome, and number of visits ($p < 0.05$). Compared to the noncustomized group, the customized group had more loose brackets, a longer planning time, and more complaints (21). These findings suggest that while customized brackets have the potential to streamline certain aspects of treatment—such as reducing the need for wire bending or minor mid-treatment corrections—their impact on total treatment time may depend on case complexity, operator experience, and the specific bracket system employed.

Treatment Outcome

A further important outcome is patient satisfaction, which includes comfort, appearance, and the entire course of therapy. Customized systems can provide better adaptability to individual dental architecture, lower bulk, and improved visual appeal, while conventional metal brackets may be correlated with discomfort, speech interference, and aesthetic problems. The use of 3D-printed customized orthodontic brackets significantly improves the quality of orthodontic outcomes compared to conventional brackets (12). However, Kaptaç and Ay Ünüva (22) reported that the conventional labial appliances and the customized lingual appliances showed the same trend with no significant difference in the reduction of the irregularity index values during 18 weeks of alignment. Moreover, there was no significant difference between the groups at four-time intervals in the arch length, intercanine width, and intermolar width.

Recent investigations have shown that CAD/CAM-assisted indirect bracket placement using medium-soft, transparent transfer trays found that mean linear deviations did not exceed 0.25 mm, and mean angular deviations remained below 1°, although some individual torque, tip, and rotation deviations were higher, particularly for maxillary incisors (23). These results indicate that CAD transfer trays can achieve highly accurate bracket placement, supporting the precision and predictability of customized orthodontic systems.

Lingual systems, as well as Invisalign treatment, can cause initial discomfort, speech problems, and tongue irritation, which might lower patient satisfaction early in treatment (24, 25). In contrast, the more visible labial brackets are preferred due to their familiar presence to patients and reduced impact on speech, which could improve long-term compliance compared to less visible alternatives like lingual braces or clear aligners.

CAD/CAM customized brackets offer improved accuracy in bracket placement, potentially leading to better orthodontic treatment outcomes, but success depends on factors like the bracket system, bonding technique, and the precision of the treatment plan. Clear aligners, a viable alternative, require careful consideration of torque control to achieve desired tooth movements, which can be a challenge due to the nature of the appliance.

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Patient Satisfaction

Patients treated with customized, 3D-printed orthodontic brackets often report higher satisfaction, primarily due to the potential for shorter treatment times, improved comfort from a personalized fit, and enhanced aesthetics compared to conventional, prefabricated brackets. The systematic review and meta-analysis by Palone et al. (26) found that CAD/CAM-based 3D-printed indirect bonding (IDB) trays, particularly soft-resin trays, offer high accuracy in a laboratory setting for bracket placement, with soft-resin trays showing favorable outcomes in terms of loss rate and usability compared to hard-resin trays. The study also compared CAD/CAM methods to traditional Polyvinyl Siloxane (PVS) or conventional silicone trays, indicating that both approaches can achieve good results (26).

A study on Insignia customized brackets versus Damon conventional brackets found that the customized group had fewer loose brackets, less pain, and potentially shorter treatment durations, leading to improved overall patient satisfaction (27). This contrasts with other findings where customized systems were linked to higher rates of loose brackets and longer initial treatment planning. The effectiveness of customized systems appears to depend on factors such as the specific digital technology used and the patient's orthodontic case.

Customized brackets improve patient comfort and acceptance due to their discreet appearance and reduced friction, as some types, like self-ligating braces and lingual braces, are less noticeable and can be more comfortable than traditional metal brackets. Lingual braces are particularly discreet because they're placed on the back of the teeth. The development of customized designs and materials, such as tooth-colored ceramic brackets, also enhances their aesthetic appeal.

Cost-Effectiveness and Accessibility

Customized CAD/CAM and 3D-printed bracket systems offer potential clinical advantages. However, these advantages are accompanied by higher initial costs, and while some studies show positive results, others find similar overall effectiveness to traditional brackets. The complexity of the digital design process can also be a barrier to widespread adoption, highlighting the need for more research into the long-term clinical performance and cost-effectiveness of these newer technologies. The fabrication process, digital scanning, and customized design increase material and laboratory expenses, making these systems less accessible in some clinical settings, particularly in low-resource environments. While some studies suggest reduced treatment durations, others find similar results to traditional systems, and increased material and lab expenses limit their accessibility, especially in resource-limited settings. Hence, since the cost of customized appliances is considerably higher than that of the non-customized appliances, further well-designed RCTs are required to determine the real clinical effectiveness of customized appliances. In contrast, conventional brackets are widely available, cost-effective, and require less specialized equipment, making them more accessible and practical for routine orthodontic practice. Therefore, although customized systems may enhance treatment precision and patient experience, their adoption is often limited by economic and logistical factors.

Future Directions and Clinical Recommendations

Artificial intelligence (AI) is revolutionizing orthodontics by creating personalized treatment plans, improving diagnostic precision, and enhancing the efficiency of orthodontic devices like AI-driven aligners. AI also enables remote monitoring, making treatment more accessible and reducing the need for frequent in-person visits (28). While challenges such as data privacy exist, AI's ongoing development promises more patient-centered and effective orthodontic care in the future.

Despite the promising advancements in CAD/CAM and 3D-printed customized bracket systems, further high-quality, long-term clinical studies are needed to fully establish their efficacy, cost-effectiveness, and impact on treatment outcomes compared to conventional systems. Future research should focus on optimizing bracket design for improved torque and rotational control, evaluating the benefits across

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different malocclusion types, and assessing patient-reported outcomes such as comfort, satisfaction, and quality of life. Clinically, orthodontists should weigh the potential advantages of customized systems—such as improved alignment accuracy, reduced finishing time, and enhanced patient experience—against higher costs, increased planning time, and the need for specialized equipment. Integration of digital workflows should be considered in practices aiming to enhance precision, while conventional brackets remain a reliable and accessible option for routine treatment. These recommendations highlight a balanced approach, promoting evidence-based adoption of customized systems where clinically justified.

Conclusion

While customized orthodontic brackets offer potential benefits like increased precision and shorter treatment times, conventional systems remain the standard due to their lower cost, accessibility, and well-established reliability. Customized brackets, using technologies like CAD/CAM and 3D printing, provide a higher level of personalization, but evidence is still mixed regarding their overall superiority, with higher costs and planning requirements limiting their widespread use.

Disclosure

Conflict of interest

There is no conflict of interest.

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Ethical considerations

This study is a review of previously published literature and does not involve any original data collection involving human or animal subjects. Therefore, ethical approval was not required.

Data availability

Data that support the findings of this study are embedded within the manuscript.

Author contribution

All authors contributed to conceptualizing, data drafting, collection, analysis and final writing of the manuscript.

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