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Modern orthodontic brackets: Innovations shaping contemporary fixed appliance therapy

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Abstract
Orthodontic brackets remain fundamental to fixed appliance therapy, acting as the primary biomechanical interface for controlled tooth movement. Recent advances in digital orthodontics, material science, and manufacturing technologies have driven the evolution of bracket systems toward greater precision, efficiency, and patient-centered care. These developments have transformed traditional, standardized appliances into highly customized and technologically advanced systems. This review synthesizes contemporary innovations in orthodontic bracket design, broadly categorized into technology-driven and bracket-specific advancements. Technology-based developments include three-dimensional printed customized brackets, CAD/CAM-generated patient-specific appliances, nano-coated brackets with antimicrobial properties, smart brackets capable of real-time force monitoring, self-healing polymer brackets, and modern self-ligating systems. These innovations aim to improve torque expression, reduce friction, enhance bonding reliability, minimize enamel demineralization, and optimize biomechanical efficiency. In parallel, bracket-specific innovations such as Pitts 21™, variable torque bracket systems, dual-slot and bidimensional brackets, and designer-shaped brackets like WildSmiles® illustrate how advanced engineering principles are translated into clinically practical solutions. These systems emphasize enhanced three-dimensional control, smile-driven treatment planning, improved patient comfort, and increased treatment predictability while maintaining compatibility with conventional orthodontic protocols. Given the rapid expansion of bracket technologies, available literature remains fragmented. This review consolidates current evidence and design concepts to provide an organized overview of modern orthodontic brackets and their clinical relevance. Collectively, these advancements signify a paradigm shift toward personalized, precise, and efficient fixed orthodontic therapy.

Keywords: Orthodontic brackets, digital orthodontics, smart brackets, self-ligating systems

Introduction
Orthodontic brackets remain the cornerstone of fixed appliance therapy, serving as the primary biomechanical interface through which forces are transmitted to teeth. Since Edward H. Angle's era, bracket design has evolved alongside advances in material science, engineering, and clinical philosophy. Over the past decade, technological innovation in orthodontics has accelerated, fueled by digital workflows, CAD/CAM customization, advanced polymer chemistry, surface engineering, and novel manufacturing techniques. These developments have expanded the diversity of available bracket systems and transformed approaches to diagnosis, biomechanics, and treatment delivery.

Conventional stainless-steel brackets continue to provide reliable mechanical performance; however, limitations in esthetics and customization have driven further innovation [1]. Ceramic brackets addressed aesthetic concerns but introduced challenges such as brittleness, friction, and debonding [2]. Lingual brackets offered invisibility but required advanced technical skill, often increasing chair side time and patient discomfort [3]. These challenges have prompted the development of next-generation bracket systems that integrate digital precision, superior material properties, and individualized architecture to meet both functional and aesthetic demands. Contemporary innovation in brackets encompasses two interrelated domains. First, technological advancements including 3D-printed customized brackets, CAD/CAM-designed bases, nano-coated brackets, smart brackets, self-ligating systems, and high-strength translucent polymers enable precise, personalized, and predictable tooth movement.

Second, bracket-specific or company-driven innovations, such as variable torque systems, dual-slot configurations, active or passive self-ligation, and creative bracket shapes (e.g., Pitts21, Damon Ultima, Activa, WildSmiles), translate these technologies into clinically practical solutions. Together, these developments are shifting orthodontics from standardized, mass-produced appliances toward patient-specific, individualized treatment. Despite the rapid emergence of these innovations, literature remains fragmented across studies and product reports. A comprehensive review is warranted to examine how these technological and company-driven advances integrate digital design, material science, and biomechanics, ultimately redefining contemporary orthodontic practice. This review aims to consolidate these developments and provide an organized perspective on the current state-of-the-art in bracket technology and its clinical applications.

Foundations of orthodontic bracket design

The history of orthodontic brackets stretches back to the early twentieth century, long before the advent of pre-adjusted systems. The foundational concept of a bracket-type appliance emerged with Edward H Angle’s ribbon arch appliance, which featured a vertical slot and represented one of the earliest attempts to secure an archwire to teeth, marking the first use of a bracket-like device in fixed orthodontic therapy. This innovation was followed by the edgewise appliance, in which the bracket slot was oriented horizontally to allow three-dimensional tooth movement when combined with appropriately bent rectangular archwires, this design laid the groundwork for all subsequent fixed bracket systems. Over the ensuing decades, several clinicians explored variations to enhance mechanics and predictability, including modifications in angulation and ligation methods, but these early brackets still required extensive wire bending and ligature ties to control tooth movement.

A major leap in bracket evolution occurred with Lawrence F. Andrews’ straight-wire appliance, which incorporated specific tip and torque values into the bracket prescription itself, significantly reducing the need for wire bending and improving clinical efficiency [4]. Building on this, Roth’s modification adjusted these built-in values to emphasize improved occlusal outcomes and functional stability [5]. Around the same period, the Butterfly System was introduced with a low-profile, twin-wing design aimed at reducing common handling errors noted by orthodontic boards and enhancing patient comfort, hygiene, and aesthetics [6]. Subsequent innovations included self-ligating brackets, which incorporate built-in clips or doors to secure archwires without elastic ligatures, thereby reducing friction and potentially facilitating smoother tooth movement. Alongside these mechanical refinements, ceramic brackets were developed to meet rising aesthetic demands, offering a more discre*et al*ternative to metal while maintaining functional effectiveness. These evolutionary milestones have set the stage for the most recent advances in orthodontic bracket design-including digitally customized systems, novel materials, and smart technologies which continue to refine treatment precision, comfort, and outcomes in modern orthodontic practice.

Orthodontic bracket materials

Orthodontic brackets have evolved considerably in terms of material composition to balance strength, biocompatibility, aesthetics, and frictional behavior. Early brackets were fabricated exclusively from stainless steel alloys due to their excellent mechanical strength, corrosion resistance, and reliable torque expression. With increasing aesthetic demands, ceramic brackets primarily composed of alumina in either polycrystalline or monocrystalline form were introduced, offering improved appearance but with limitations related to brittleness and increased friction. Plastic and composite brackets were also explored; however, their lower strength and tendency for deformation restricted widespread clinical use. More recently, hybrid brackets combining metal slots with ceramic bodies have been developed to optimize aesthetics while maintaining mechanical efficiency. Advances in materials science continue to drive the development of novel bracket materials aimed at improving performance, patient comfort, and long-term clinical outcomes [7].

3D-Printed Customized Brackets

Conventional metal and ceramic brackets are produced via casting, injection molding, milling, or sintering, and both the material and manufacturing method affect bracket quality and force precision [8]. Even slight slot height variations increase archwire-slot play, reducing effective torque, which is critical in extraction cases for maintaining anterior torque and correcting bucco-lingual root positions. Advances in CAD/CAM technology enable biocompatible, additively manufactured resin brackets that offer superior accuracy and customization. 3D printing allows patient-specific, aesthetic brackets, optimizing in-out positioning, torque, and angulation. Accurate placement is crucial, as deviations may alter crown torque, root-bone relationships, and increase risks such as fenestration or dehiscence [9]. Digital design and rapid prototyping produce functional, individualized brackets, reducing wire adjustments, improving treatment predictability, and accommodating unique prescriptions for complex movements.

In recent years, the demand for discreet and aesthetic treatment, especially among adults, has driven the development of fully customized 3D-printed lingual brackets. These systems cover most of the lingual surface, enabling precise tip and torque adjustments while minimizing variability that complicates finishing in conventional lingual orthodontics [10]. Patient-specific arch wires and bracket bases improve biomechanical efficiency, and the low-profile design enhances comfort and esthetic appeal. Overall, 3D-printed labial and lingual brackets offer superior accuracy, customization, and treatment predictability compared with conventional methods. Erfan Bardideh *et al.* [11] highlighted that CAD/CAM-generated brackets perform comparably to conventional systems in treatment quality and appointment frequency, while offering clear advantages in efficiency and overall treatment duration. Beyond accuracy and customization, CAD/CAM-based 3D-printed brackets support more predictable, patient-specific appliance design, reduce chairside adjustments, and streamline fixed orthodontic therapy.

Nano-Coated Orthodontic Brackets

Bracket bonding in orthodontics can lead to plaque accumulation, enamel decalcification, white spot lesions, and caries. To address this, nano-coating technologies have been applied to bracket surfaces to enhance antibacterial properties. Nanoparticles commonly silver (Ag), zinc (Zn), copper (Cu), or their oxides are deposited, often via physical vapor deposition, ensuring uniform coating without compromising mechanical integrity [12].

Silver nanoparticles (AgNPs) are highly effective against *Streptococcus mutans*, inhibiting biofilm formation and protecting enamel [13]. Silver-palladium (Ag-Pd) coatings further improve wear resistance while maintaining antibacterial activity. Other nanoparticles, such as gold-oxoborate, titanium dioxide (TiO_2), and nitrogen-doped TiO_2, reduce bacterial adherence with minimal cytotoxicity [14]. Combinations, like TiO_2 nanotubes with methacryloyloxyethylphosphorylcholine (MPC), show superior antimicrobial efficacy [15]. Suvetha Siva *et al* [16]. confirmed that coatings with Ag, Ag-Pd, Ti, ZnO, and CuO significantly reduce colonization by *S. mutans, S. sobrinus, L. acidophilus, A. actinomycetemcomitans, A. viscous*, and *C. albicans*, as well as corrosion, compared to uncoated brackets. These nano-coated brackets are especially beneficial for high-risk patients, minimizing plaque, preventing enamel demineralization, and reducing white spot lesions.

Smart Brackets

Smart brackets are advanced orthodontic appliances that provide real-time, quantitative monitoring of forces and moments on each tooth. They incorporate a CMOS-based micro-sensor system within the bracket body; when forces deform the bracket, piezoresistive or strain-gauge elements detect stress and convert it into electrical signals. Data is transmitted wirelessly to a digital interface, allowing clinicians to visualize force magnitude and direction instantly, enabling precise biomechanical control and reducing risks such as unwanted tooth movement, root resorption, and prolonged treatment. Research prototypes using multi-sensor microchips have demonstrated accurate 3D force-moment measurements, though wire-bracket contact variability remains a challenge. Innovations include telemetric ceramic smart brackets with CMOS sensors and micro-coils for wireless data transfer, and semi-spherical elastic sensors embedded in aligners to quantify deformation-based forces. Miniaturized sensing arrays within the bracket base show strong agreement between simulated and actual forces, supporting clinical feasibility [17, 18].

Recent developments integrate smart brackets with the Internet of Dental Things (IoDT) and nanoelectronics, enabling remote monitoring and highly personalized force adjustments. Future models may achieve automated, self-regulating force delivery, representing a significant step toward precision-driven orthodontics [19].

Self-Healing Brackets

Self-healing materials have recently emerged as a potential advancement in orthodontic brackets. Huyang *et al.* [20] introduced self-healing dental composites (SHDC), where crack formation triggers the release and polymerization of reparative glass ionomer cement, effectively sealing defects. A similar strategy can be applied to polymer-based brackets: nanoscale microcapsules filled with auto-polymerizing monomers rupture upon fracture or microcrack formation, initiating in situ polymerization. This allows the material to autonomously seal cracks, reducing bracket failure and enhancing the durability of aesthetic polymer brackets. Although still experimental, self-healing bracket systems hold promise for improving the resilience and longevity of future orthodontic appliances.

Self-Ligating Brackets

Self-ligating brackets (SLBs) differ from conventional brackets by incorporating an integrated sliding clip that holds the arch wire in place, eliminating the need for elastomeric or steel ligatures.

Technological advances have further refined SLB performance. Modern systems offer improved torque and angulation control, stronger and more durable clips, and lower-profile designs to enhance patient comfort. Widely used metal SLBs include Damon® ultima, BioQuick®5 (Figure 1), 3M™ SmartClip™, and Wave SL®, while passive systems such as In-Ovation® C/R provide enhanced control with smoother mechanics. Next-generation designs like the Carrier SLX incorporate occlusal-opening doors and visual positioning guides, whereas Empower® 2 features micro-etched bonding bases that increase bond strength by 15-30%, along with a more robust clip for improved wire retention. Ceramic options, such as QuicKlear, offer better aesthetics with rounded edges, reduced profile, and reinforced clips for increased strength.

Self-ligation concepts have also extended to lingual orthodontics. Systems such as STb, ALIAS, In-Ovation L, Harmony, 2D, Clippy L, and eBrace apply self-ligating principles to the lingual surface to improve mechanics and reduce friction. Comparative studies demonstrate that self-ligating lingual brackets exhibit lower passive play and superior torque expression compared with conventionally ligated lingual brackets, [21] and that ALIAS brackets generate significantly lower friction than systems like Clippy L and 2D when tested with different archwire sizes [22]. These findings highlight the growing relevance of self-ligation across both labial and lingual orthodontic modalities.

Variable Torque Brackets (BaTR System)

Achieving ideal axial inclinations is essential for optimal smile aesthetics, root positioning, and post-treatment stability. Traditional methods, including pre-adjusted edgewise brackets and torquing auxiliaries, often provide fixed torque values that may not suit individual cases. Adjusting torque through wire bends or auxiliaries can be imprecise, time-consuming, and may cause gingival irritation or compromise adjacent teeth.

The BaTR (Brackets for variable Torque and Rotation) system (Figure 2) addresses these limitations by offering six customizable torque options within a single bracket. Its design incorporates four occluso-gingival legs that can be bent, folded, or trimmed to achieve ±5°, ±10°, or ±20° torque variations. Modifying the legs changes the orientation of the bracket slot relative to the tooth surface, allowing precise torque expression when a rectangular archwire is engaged. This flexibility enables clinicians to deliver patient-specific torque adjustments without the need for multiple bracket prescriptions.

The BaTR system also increases bonding surface area due to the extended legs, improving bracket adhesion, while these legs act as visual guides for accurate axial placement. It is fully compatible with standard MBT bracket kits, allowing selective use on teeth that require additional torque. By combining simplicity, precision, and versatility, the BaTR bracket system represents a significant advancement in customizable orthodontic treatment, reducing chairside adjustments and improving clinical efficiency [23].

Pitts 21™ Bracket System: Biomechanical Innovation and Aesthetic Integration

The Pitts 21™ bracket system (Figure 3), developed by Dr. Thomas R. Pitts, emphasizes a *facially driven approach*, integrating smile aesthetics with precise orthodontic biomechanics. Its 0.021″ × 0.021″ square slot and progressive slot architecture allow early control of torque, tip, and rotation, improving treatment predictability while using lighter forces.

A key feature is Smile Arc Protection (SAP), which guides bracket positioning to preserve the natural curvature of the incisors relative to the lower lip, enhancing smile aesthetics. Design innovations such as smooth rounded edges, a sliding door for stability, and the Base Lock Plus pad improve patient comfort and bonding strength. The bracket's progressive slot depth balances control and flexibility across the arch, providing more freedom for posterior teeth while maintaining anterior control [24].

Pitts 21™ incorporates structured clinical protocols, including Active Early mechanics, ELSE (Early, Light, Short Elastics), and PRACM (Panorex Reposition and Adjust Case Management), to guide wire sequencing, force application, and bracket positioning. Finite element analysis studies demonstrate enhanced torque expression with reduced slot play, which is particularly advantageous for controlling root positioning. The system also reduces the need for frequent wire adjustments and helps maintain anchorage efficiently. Additionally, its design supports easier integration of auxiliaries such as elastics, enhancing overall treatment versatility. By combining precise biomechanical control with aesthetic-driven planning, Pitts 21™ enables predictable, efficient, and patient-friendly orthodontic outcomes [25].

Dual Slot Bracket System

Building on the principles of the bidimensional technique, Dr. Daniel J. Rinchuse and Dr. Donald J. Rinchuse introduced refinements to Gianelly's original concept, leading to the development of the Dual Slot system. This system employs 0.018-inch slots for anterior teeth and 0.022-inch slots for posterior teeth, allowing differential control within the same arch. A single 0.018″ × 0.025″ stainless steel archwire is used during retraction mechanics. The complete engagement of the archwire within the anterior 0.018-inch slots minimizes wire-slot play, thereby enhancing three-dimensional control of anterior tooth position, particularly torque and root angulation. In contrast, the larger posterior slot provides relative freedom for sliding mechanics, facilitating efficient space closure while maintaining anchorage. This dual-slot configuration combines precise anterior control with posterior flexibility, improving biomechanical efficiency during orthodontic treatment [26].

Double slot Bracket System

The double slot bracket (Figure 4) is a bidimensional appliance featuring two parallel bracket slots positioned centrally on the bracket body one measuring 0.018 inches and the other 0.022 inches, allowing dual slot functionality in a single unit. This design enables the simultaneous use of two archwires of differing dimensions, which expands the range of biomechanical strategies available to the clinician. The double-slot configuration offers versatility in working with archwires of varying thicknesses and alloys, providing flexibility for individualized treatment mechanics. Although the system supports the use of two wires concurrently for complex mechanics, it can also function with a single archwire in conventional fashion, yet still permits a variety of controlled tooth movements. An important benefit of this double-slot arrangement is its facilitation of controlled vertical adjustments, allowing the orthodontist to perform vertical tooth movements more simply and predictably. By offering two integrated slots within each bracket, the Double slot system combines the advantages of both 0.018″ and 0.022″ slot mechanics, enhancing clinical flexibility while reducing the need for frequent bracket changes or multiple appliance sets [27].

WildSmiles® Designer-Shaped Orthodontic Brackets

WildSmiles® Braces (Figure 5) has introduced an innovative range of orthodontic brackets that combine established biomechanics with enhanced aesthetics to improve patient motivation and compliance. These brackets are uniquely designed in custom shapes such as Mickey, heart, star, flower, and other decorative forms, making them especially appealing for pediatric and adolescent patients. The Mickey-shaped bracket is one of the most prominent designs and is available in designer color options, including the Onyx series. WildSmiles brackets are designed for the upper anterior segment (U3-3) and are offered in both MBT and Roth prescriptions, with 0.018-inch and 0.022-inch slot sizes, allowing easy integration into standard orthodontic treatment protocols. Clinically, these brackets are well suited for early and interceptive orthodontic treatment, where improved cooperation is essential, while also being compatible with comprehensive fixed appliance therapy when combined with conventional brackets. By maintaining standard slot dimensions and prescriptions, WildSmiles brackets preserve mechanical efficiency while providing a personalized and patient-centered treatment experience [28].

Fig 1: BioQuick® 5 self-ligating orthodontic bracket (FORESTADENT) showing clip and archwire engagement. Image courtesy: FORESTADENT (https://www.forestadent.com).

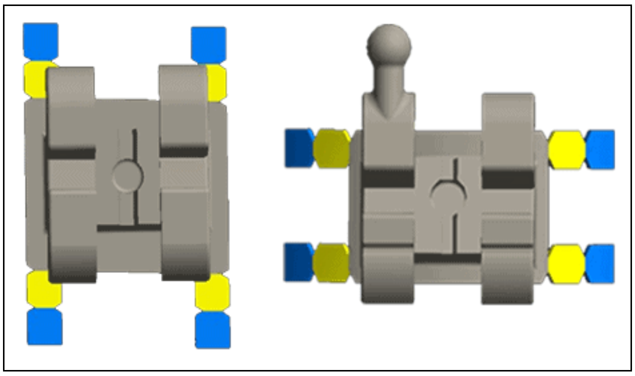

Fig 2: BaTR orthodontic bracket showing the adjustable leg design for torque and rotation customization. Image courtesy: EzeeBraces (https://ezeebraces.com)

Fig 3: Pitts 21 self-ligating bracket. Image courtesy: OC Orthodontics, https://www.ocorthodontics.com/pitts21

Fig 4: Koden Duploslot (double slot) orthodontic bracket showing dual.018″ and.022″ slots. Image courtesy: KODEN (https://kodenindia.com/dupslot-brackets.html)

Fig 5: WildSmiles® designer orthodontic brackets. Image courtesy: WildSmiles Braces (www.wildsmilesbraces.com)

Fig 6: InBrace® lingual invisible orthodontic system showing robotically bent custom wire on lingual brackets. Image courtesy: InBrace® (https://inbrace.com)

Fig 7: Brava® by Brius™ showing the insertion and engagement of the independent mover arms on lingual surfaces of teeth. Image courtesy: Brius Technologies (https://brius.com)

Next-generation customized lingual systems: InBrace and Brava

The In Brace system (Figure 6) features reconceptualized brackets designed to work with the IN Brace Smart wire. This bracket-Smart wire complex utilizes Gentle Force technology, enabling teeth to move predictably in all six degrees of freedom, including opening and closing spaces, effectively on autopilot from day one. The system delivers gentle, continuous forces through programmed non-sliding mechanics. Friction-free space closure is achieved because the In Brace bracket design prevents the Smartwire from sliding, allowing precise and controlled tooth movement throughout treatment [29].

The Brava plus System (Figure 7) by Brius simplifies lingual orthodontics through its combination of specialized brackets and an AI-engineered palatal wire. This wire is designed to move teeth in all six degrees of freedom simultaneously, applying programmed, precise forces without sliding gates or ligature ties. Brava Independent Movers can fully engage in less than two minutes per arch, significantly reducing chairside time. The AI integration ensures efficient, predictable, and synchronized tooth movement while maintaining patient comfort. Brava offers a fast, accurate, and highly automated approach to lingual orthodontics, making treatment more accessible and efficient for both clinicians and patients [30].

Conclusion

Orthodontic brackets have evolved far beyond their conventional designs, integrating advanced materials, digital workflows, and biomechanical innovations to enhance both clinical efficiency and patient experience. Contemporary systems including 3D-printed labial and lingual brackets, CAD/CAM-customized appliances, nano-coated brackets, smart and self-healing designs, self-ligating systems, and next-generation lingual technologies like InBrace and Brava offer unprecedented precision, customization, and predictability in tooth movement. These innovations reduce chairside adjustments, optimize force delivery, minimize complications such as enamel decalcification and root resorption, and expand aesthetic and functional options for patients.

By combining digital design, material science, and engineering principles, modern bracket systems facilitate personalized, patient-specific treatment modalities, marking a paradigm shift from standardized mass-produced appliances to individualized orthodontic therapy. Continuous technological advancement and rigorous clinical validation are essential to fully harness the potential of these innovations. Ultimately, the integration of these cutting-edge systems into clinical practice promises more efficient, predictable, and patient-centered orthodontic outcomes, setting the stage for the future of fixed appliance therapy.

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