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Article

Assessment of Contemporary Fabrication Technologies for Post and Core Restorations—A Narrative Review

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Abstract: The primary objective of this current study is to conduct a comprehensive review of existing literature that discusses research on post and core restorations, covering aspects such as their composition, manufacturing methods, and clinical effectiveness. The methodology employed in this review encompasses the implementation of a well-defined search strategy, the establishment of criteria for inclusion and exclusion, and the selection of relevant studies to summarize their findings. To gather relevant literature published between 1993 and 2023, the research team conducted separate searches on PubMed, Scopus, and Embase databases. In total, 165 titles were initially retrieved from these electronic databases. By applying the predefined exclusion criteria, the researchers identified 73 articles that specifically address the conventional and computer-aided design/computer-aided manufacturing (CAD/CAM) technologies employed in post and core restorations. These restorations are frequently utilized procedures for repairing teeth that have undergone endodontic treatment and subsequently lost dental structure. The development of computerized technology for the creation of customized posts and cores has emerged as a straightforward and efficient alternative to traditional methods. The review encompasses a synthesis of papers discussing the various techniques and materials employed in constructing post and cores using CAD/CAM technology. Notably, different strategies for restoring endodontically treated teeth through CAD/CAM post and cores have been documented, revealing both direct and indirect approaches. The most mentioned materials for these restorations include zirconia, composite resin, and hybrid ceramics. While the available literature on CAD/CAM post and core procedures is somewhat limited, the review underscores the need for further research to explore the long-term outcomes and efficacy of this treatment approach.

Keywords: post and core restorations; CAD/CAM; semi-digital; prosthodontics; digital dentistry

1. Introduction

Customized cast post and core restorations are frequently employed to address severe tooth damage resulting from conditions like caries or bruxism [1]. The individualized design of these restorations proves particularly effective for elliptical or flared canals, where prefabricated posts may struggle to achieve optimal adaptation [2]. The heightened adjustability of custom-cast post and core configurations yields notable benefits in terms of their resistance to torsional stresses [3,4]. Such personalized posts and cores serve as stabilizing structures between the crown and root, especially valuable for single-rooted and premolar teeth that experience weakening due to reductions in tooth structure during both tooth and access preparation [5]. Similarly, these tailored restorations exhibit significant resistance against rotational stresses in multi-rooted teeth with substantial loss of tooth structure [6,7].

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An ideal post and core should exhibit attributes such as enhanced crown retention, biocompatibility, non-toxicity, and superior tensile strength, alongside resistance to the fatigue induced by occlusal and shear loads [8]. Additionally, a well-designed post should evenly distribute stresses across the adjacent root surface and extend apically to at least the height of the crown or two-thirds the length of the root [9,10]. This distribution of stress serves to manage occlusal loads and bolster resistance. Moreover, the color of the post and core should ideally match that of natural dentin, a particularly significant consideration for anterior tooth restorations [11,12].

The production of customized post and cores can be accomplished through either a direct approach utilizing a resin model or an indirect technique employing elastomeric impressions of the prepared canal [13]. This impression is subsequently replicated in gypsum by a laboratory technician, who crafts a wax pattern that is then cast into a gold alloy to create the post and core. On the other hand, the direct method entails the clinician using auto-polymerizing acrylic resin to shape an acrylic pattern [3]. This pattern is then dispatched to the laboratory for the stages of burnout and casting. The direct technique offers enhanced anticipatory capabilities for the clinician, as the cast post-and-core pattern is physically assessed and confirmed for its fit on the actual tooth before the casting procedure takes place [14]. The key advantage of using customized post and cores lies in their ability to fit a wide range of teeth, including those with oval canals, and their ease of removal during potential retreatment [15]. Furthermore, both the post and core function in unison, diminishing the likelihood of core separation [16]. Even when dealing with proclined teeth, the angulation of the core within cast post and cores can be adjusted to match the crown's contour [17].

A study conducted by Balkenhol et al. revealed that teeth restored with custom-cast post and cores exhibited a promising long-term prognosis, boasting a survival rate of 7.3 years [18]. Similarly, Dietschi et al. [19] and Maccari et al. [20] showcased high fracture resistance of teeth restored with custom-cast post and cores in similar experimental settings. However, it's important to note that cast metal posts demand additional chairside and laboratory time, contributing to higher treatment costs [21,22]. Customized cast post and core restorations offer a good solution for addressing significant tooth damage, showcasing a blend of historical significance and modern technological advancements that contribute to their clinical success and positive long-term outcomes.

Throughout more than two and a half centuries, historical accounts bear witness to the intriguing evolution of embedding posts within fractured tooth roots. This practice can be traced back to the ingenious mind of Pierre Fauchard, a luminary in the realm of modern dentistry, who first introduced this concept in the early months of 1728 [23]. Building upon this foundation, French dentist Claude Mounton, in 1745, contributed to the narrative by detailing the idea of affixing a gold crown to a gold post implanted within the root structure [24]. As time progressed into the 19th century, there emerged a shift from the use of metal poles to wooden posts, a development driven by both innovation and necessity. However, this transition encountered a significant setback owing to wood's susceptibility to moisture absorption, a characteristic that inevitably led to expansion and the perilous occurrence of root fractures [25].

Fast-forwarding through the pages of dental history, we encounter the contributions of C.M. Richmond, an American dental visionary. Richmond's legacy was marked by the introduction of what is now known as the "Richmond crown." This innovative creation embodied a single-piece, post-retained crown that not only displayed a porcelain facing but also fulfilled the role of a bridge retainer, underscoring the convergence of practicality and artistry in dental restoration [26]. A monumental leap in the realm of dental innovation occurred in the 1930s, a period marked by the emergence of custom-cast posts and cores as a groundbreaking development [27]. This novel approach entailed the fabrication of the post and core as distinct entities, effectively diverging from the traditional amalgamation. This departure from convention yielded a marked improvement in the marginal adaptation of the final restoration, ushering in a new era of precision and efficacy in dental restorative techniques [28]. This historical trajectory underscores not only the evolution of materials and techniques but also the enduring quest for refining dental treatments to enhance patient outcomes and oral health.

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2. Material Choices for Fabricating Post and Core Restorations

The selection of materials for crafting post and core restorations encompasses a broad classification into metallic and non-metallic options [20]. When it comes to custom cast post and cores, these are typically fashioned from gold alloys like type III and IV, silver-palladium alloys, or base metal alloys [29,30]. Among these choices, cast gold post and cores stand out as superior due to their remarkable success rates, advantageous mechanical properties, and straightforward manufacturing process [31]. On the other hand, base metal alloys offer a cost-effective alternative, although their stiffness in comparison to dentin can elevate stress levels within the tooth structure [32,33]. Additionally, there's a concern regarding the potential release of harmful chemicals due to the breakdown of base metal alloys [34,35]. Retrospectively, analysis reveals a success rate ranging from 89% to 98.5% for cast post and cores [36].

The increasing emphasis on achieving aesthetic excellence has sparked the development of ceramic post and core solutions, presenting an alternative to traditional cast options [37]. Notably, castable glass ceramics and glass-penetrated ceramics have garnered attention in this regard [38]. Furthermore, zirconia posts have gained prominence, particularly for teeth with considerable coronal structure loss [39]. Zirconia posts, first introduced in 1995, have demonstrated their capacity to elevate aesthetics and translucency, closely mimicking the appearance of natural teeth [34]. These posts have also exhibited remarkable fracture resistance, surpassing the capabilities of cast metal and glass fiber posts combined with composite resin cores [40]. However, it's crucial to acknowledge that zirconia's high modulus of elasticity can potentially exert amplified stress on root dentin, thereby increasing the risk of root fractures [41]. Moreover, ensuring a secure attachment to acid-resistant zirconia and facilitating the retrieval of zirconia posts in case of treatment failure pose considerable challenges [42].

Using a search strategy, defining inclusion and exclusion criteria, finding studies; selecting studies; and collecting pertinent data to summarize the results were all part of the methodology. To gather literature published between 1993 and 2023, PubMed, Scopus, and Embase databases were searched. The search criteria were "Post and core restorations" [Mesh] OR “Indirect restoration” OR ‘’CAD/CAM fabrication" OR "Digital dentistry" OR "Post and core" AND "CAD/CAM" [Mesh].

Articles written in English and published between 1993 and 2023 on post and core restoration techniques, clinical studies and in vitro studies, and articles reporting different fabrication techniques, clinical performance, or quality assessment with conventional and CAD/CAM post and core restorations were the inclusion criteria for selection (Table 1). This period of time, between 1 January 1993 and 31 May 2023, was selected particularly, due to the increase in clinical and in vitro studies during these years. Articles that failed to incorporate items described in the inclusion criteria or described data that had previously been included, were excluded.

Table 1. Articles included in the study.

Author’s Name	Article Type	Year of Publication	Method of Fabrication	Applied Materials
Passos et al.	In vitro study	Pattern resin made and scanned	Milling	Hybrid Ceramic
Lee et al.	Clinical case	Direct scan	Milling	Nano Ceramic
Eid et al.	In vitro study	Direct scan	Milling	Hybrid Ceramic
Libonati et al.	In vitro study	Pattern resin made and scanned	Milling	Nano-ceramic composite resin
Kanduti et al.	In vitro study	Direct scan	3D Printing	Hybrid Ceramic
Spina et al.	Clinical case	Pattern resin made and scanned	Milling	GFR Composite

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Chen at al.	In vitro study	Direct scan	Milling	Base metal Co - Cr alloy
Marghalani et al.	In vitro study	Direct scan	3D Printing	GFR composite
Liu et al.	In vitro study	Pattern resin made and scanned	Milling	Hybrid ceramic
Sipahu et al.	Clinical case	Impression was taken and scanned	Milling	Zirconia
Eid et al.	In vitro study	Direct scan	3D Printing	Zirconia
Hendi at al.	In vitro study	Direct scan	3D Printing	Zirconia
Awad et al.	Clinical case	Impression was taken and scanned	Milling	GFR composite

This narrative review's search technique included three stages: examining titles, abstracts, and the final selection of publications for full-text analysis. Three reviewers individually sorted articles from databases, and any variations in selection were discussed until a consensus was established. Articles that did not fulfill the predefined inclusion criteria were excluded with the consent of the reviewers. The same reviewers independently reviewed the abstracts of the papers chosen in the second stage, and the articles chosen for the final analysis were received in full text. The whole text of the obtained 73 articles was evaluated in the third and final stage.

3. Comparison between CAD/CAM and Traditional Methods for Post and Core Fabrication

The integration of computer-aided design and computer-aided manufacturing (CAD/CAM) technology has sparked a revolutionary transformation across the landscape of dental restoration, reshaping the very foundations of how restorative procedures are approached [43]. Within this digital embrace, a plethora of benefits unfold, each contributing to the elevation of dental craftsmanship [31]. Precision is elevated to new heights, as CAD/CAM technology operates with meticulous accuracy, leaving minimal room for errors. Consistency is assured through standardized production protocols, ensuring that each restoration adheres to the same exacting standards [18]. The efficiency of the restoration creation process receives a substantial boost, making the journey from digital design to tangible restoration swifter than ever before. Quality control becomes an empowered endeavor, with digital oversight enhancing the assessment of every intricate detail [6]. And perhaps most notably, the capacity to materialize complex structures gains unprecedented traction, enabling the creation of dental restorations that were once confined to the realm of imagination [44].

In its essence, CAD/CAM technology encompasses two fundamental approaches: additive and subtractive manufacturing. The additive pathway, a marvel of modern engineering, brings structures to life by building layer upon layer, each precise deposition contributing to the emergence of intricate forms [3]. In contrast, the subtractive methodology revolves around the art of material removal, sculpting the desired shape by carefully chiseling away. This dichotomy serves as a testament to the versatility that lies at the heart of CAD/CAM technology, offering practitioners a choice in their pursuit of precision [45].

Within the realm of subtractive manufacturing, mechanical robustness is the hallmark of the restorations brought to life [1]. However, this prowess is tempered by the price of material wastage, a reality where a staggering 90% of prefabricated block material often ends up discarded, an unavoidable consequence of the subtractive process [46]. On the flip side, additive manufacturing emerges as the beacon of efficiency, celebrated for its ability to craft intricate structures with an eye for precision while minimizing material wastage. This feature, coupled with the rise of CAD/CAM technology, has prompted a thorough exploration of its capabilities in the realm of custom post and core production [47]. Researchers like Awad and Marghalani blazed a trail in 2007, igniting a journey of discovery that continues through subsequent studies [48,49]. This expedition into the potential of

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CAD/CAM technology for crafting custom post and cores unfolds through a series of in vitro experiments and case reports, each offering insights into the burgeoning possibilities of this technological marvel [50,51]. As the path forward unfurls, the fusion of dental expertise and digital precision promises to redefine the boundaries of dental restoration, carving a future where innovation and tradition harmoniously coexist [52].

3.1. Semi-Digital Indirect Approach

The semi-digital approach to post and core fabrication stands as a bridge between traditional craftsmanship and cutting-edge technology [53]. It employs the foundation of a digital scan of a wax or resin pattern or even an impression of the post space [54,55]. Once this digital blueprint is established, the subsequent steps unfold in a realm where precision and innovation converge [56,57]. Through the deployment of milling or additive manufacturing techniques, the cast post and core restoration take shape, embodying the marriage of digital accuracy and tangible craftsmanship [58,59].

The pioneering stride into the world of CAD/CAM fabrication of zirconia post and cores found its roots in this semi-digital method, where a digital scan of an acrylic resin pattern paved the way for a breakthrough [60,61]. Another avenue within this approach revolves around the meticulous creation of a resin pattern, capturing the intricate anatomy of the post-area [62]. This pattern then embarks on a journey of digitization, machining, and sintering, culminating in the crafting of a one-of-a-kind ceramic post and core, an embodiment of digital precision and handcrafted finesse [63]. The exploration doesn't end here, as variations emerge in the form of patterns generated from auto-polymerizing resin, followed by subsequent steps of scanning and intricate machining [47].

A divergent iteration in this creative continuum takes shape through the capture of an impression of the cast. A digitized wax pattern, serving as a digital surrogate for the tangible world, takes center stage during the scanning process [58,64]. In the spirit of constant advancement, a recent breakthrough has materialized in the form of scanning a polyvinyl siloxane impression, a precursor to milling a nanoparticle-filled resin block. This progressive technique optimizes chairside efficiency, outshining traditional methods anchored in acrylic-resin patterns [43].

Not to be overshadowed, the indirect route of CAD/CAM post and core fabrication embarks on a different yet equally impactful journey. It begins with the creation of an impression of the post space, a critical step that captures the blueprint of the tooth's intricate structure [65]. This impression transforms into a cast made from scannable stone, a tangible precursor to the digital realm. Guided by this stone cast, the design and milling of the post and core commence, bringing together the physical and digital realms in a harmonious union [60].

3.2. Digital Direct Approach

The entirely digital or direct technique revolves around an optical impression of the post space, achieved through either a digital scan of compatible scan posts coupled with canal-preparing drills, or an intraoral direct scan of the root canal space [66]. Subsequently, a restoration design is generated using software and then manufactured through milling or additive processes [9]. The use of direct digital technology substantially minimizes the clinical timeframe required for crafting chromium-cobalt alloy restorations. This approach effectively eliminates inaccuracies stemming from volumetric alterations in impression materials and plaster used for models, as well as volume fluctuations in wax and composite models [21]. The comprehensive digital method not only saves chairside time but also streamlines laboratory processes by avoiding inaccuracies associated with impression materials and pattern substances like resin and wax [67].

However, despite its advantages, 3D printing does present some challenges. Issues such as polymerization, shrinkage, high resin, and machinery costs in comparison to conventional fabrication methods, and the potential for surface roughness due to layered resin deposition leading to toxic waste production, are still areas of concern [20].

The prevalent 3D-printing techniques employed in the creation of 3D-printed dental restorations are stereolithography (SLA) and digital light projection (DLP). Distinct differences lie in the materials utilized and the layering methodology to construct a 3D object. SLA is favored over DLP for its precision in producing intricate structures and smooth surfaces [32]. Nevertheless, SLA comes with certain limitations like limited durability and low fracture resistance. On the other hand, DLP outperforms SLA in terms of speed and material efficiency, thereby contributing to cost reduction [14].

Various materials have been employed for crafting CAD/CAM post and cores [68]. Older studies commonly milled zirconia blocks to create these restorations, whereas newer reports have leaned towards glass-fiber reinforced composites [22,34]. Resin-based post and cores offer a compelling alternative by combining the benefits of traditional custom-made posts and prefabricated fiber posts [12]. Their modulus of elasticity closely resembles that of dentin, potentially leading to more repairable fractures compared to zirconia. Additionally, resin-based materials don't require sintering, allowing for precise fabrication while also reducing production time and cost [60].

Novel materials have emerged by blending ceramics with composite resin, resulting in a hybrid material that boasts the mechanical properties and color stability of ceramics alongside the elasticity and robustness of resin composites [68]. Examples include Enamic, composed of 75% feldspathic porcelain and 25% composite resin, and Lava Ultimate, which incorporates composite resin and 80% nano-ceramic particles [69]. Emerging materials like Polyetheretherketone (PEEK) have been explored, owing to their low modulus of elasticity that reduces stress concentration and root fracture risk [58].

A retrospective study found that cast post and cores for single crown restorations had a success rate of 89% to 98.5% after at least seven years of installation. These cast posts and cores can be used to prepare numerous abutments and in patients with significant tooth wear [35]. However, because of their higher modulus of elasticity than dentin, custom-made posts and cores increase the risk of root fracture. They may also cause discoloration in the thin gingival and bone tissue, resulting in a less attractive appearance [36]. Furthermore, if the crown thickness is less than 1.6 mm, the color of the core may influence the outcomes of the translucent ceramic crown [37].

Moustapha et al. conducted a study to determine which digitalization approach provided milled post and cores with the best adaptability [62]. Direct or entirely digital processing using an intraoral scanner, according to reports, results in better adaptability than indirect digitalization of patterns or impressions. Although the direct digitalization technique has an advantage over the indirect technique, recording the limited root canal space during post and core scanning can be problematic at times [70].

Multiple research investigations have highlighted a strong association between the effectiveness of restored teeth and the factors encompassing the design, method, and material employed in custom post and core fabrication [5,6,43,48]. In a recent study by Liu et al., findings indicated that CAD-CAM milled post and cores crafted from a cobalt-chromium alloy could serve as a viable substitute for the conventional casting approach in metal post and core fabrication [57]. Nevertheless, it's noteworthy that the retention capabilities of CAD/CAM milled or printed post and cores remained unexamined and untested in the study.

As the field of dental restoration continues to evolve, the selection of suitable materials for post and core fabrication plays a pivotal role in achieving both functional and aesthetic goals [31]. The balance between mechanical properties, biocompatibility, and long-term stability remains a critical consideration, driving the exploration of innovative materials and manufacturing techniques that can ultimately enhance the longevity and success of these essential dental restorations [14].

4. Discussion

The purpose of this study was to undertake a narrative review concerning inquiries into post and core restorations, encompassing their composition, fabrication methodologies, and clinical outcomes.

Numerous reports underscore the capabilities of the CEREC system's intraoral camera, which demonstrates an impressive capacity to scan post-space lengths reaching up to 10 mm [53–58]. Consequently, research endeavors often adopt a standardized approach, utilizing a 9 mm post-space

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preparation length for scanning purposes [65]. However, it's noteworthy that when confronted with post gaps surpassing the 10 mm threshold, the prudent course of action leans toward the adoption of an indirect technique for constructing CAD/CAM post and cores.

The evolution of digital dentistry has aimed at enhancing workflow precision and expediting the production process [71]. Initially, the application of CAD-CAM technology for customized posts primarily revolved around scanning plaster models derived from traditional impressions [57]. Alternatively, some researchers proposed an alternative digital approach, wherein a conventional silicone impression is scanned for milling a personalized CAD-CAM post and core [25]. Multiple investigations indicate that both traditional impressions and stone replicas can be successfully digitized with a high degree of reliability [41]. The direct acquisition method was deemed more efficient, accurate, and less invasive compared to indirect techniques [5]. However, achieving precise intraoral scans necessitates the operator's expertise, experience, and knowledge, and the final outcomes could be influenced by patient-specific variables like intraoral moisture, tongue movement, and saliva flow [62].

An insightful in vitro exploration ventured into the mechanics of CAD/CAM post and cores crafted through direct scanning of the post space, polyether impression scanning, or plaster model scanning. This analytical voyage encompassed measurements of post-retention, cement layer thickness, and nano leakage [59]. The findings unveiled a hierarchy in post retention favoring direct scanning posts and cores, while cement thickness and nano leakage remained generally consistent across the different approaches [71].

Delving into the mechanical realm, an in vitro investigation set its sights on evaluating the push-out bond strength and fracture resistance of various materials deployed in CAD/CAM post and cores. The roster of materials included hybrid ceramic (Enamic), nano-ceramic composite resin (Lava Ultimate), and an experimental glass-fiber reinforced epoxy resin [68,71]. Impressively, the bond strength across the tested materials emerged as comparable. However, a distinctive pattern emerged in fracture resistance, with nano-ceramic composite resin reigning supreme, while hybrid ceramic and glass-fiber reinforced resin showcased parallel values. This dynamic was attributed to the nano-ceramic material's modulus of elasticity, which harmonized closely with that of dentin [72]. Moreover, the use of a resin cement seal contributed to more effective biomechanical force distribution, thereby elevating fracture resistance. Intriguingly, all materials demonstrated fracture resistance exceeding the typical adult occlusal force exerted during function, which commonly ranges from 70N to 150N [68].

The investigative landscape tilts toward the realm of indirect manufacturing for CAD/CAM post and cores, as highlighted by the majority of documented studies [70,72,73]. While the allure of directly scanning the root canal area lies in its expediency and straightforwardness, the need for indirect methods becomes evident when dealing with teeth boasting extended or diminutive root canal spaces [56–60].

Recent in vitro examinations have ventured into comparisons between milled and 3D-printed Co-Cr alloys against their cast post and core counterparts [50–52]. However, the clinical application of CAD/CAM-manufactured Co-Cr alloy remains noticeably absent from the discourse, a void potentially linked to the inherent aesthetic challenges posed by metal alloys, especially when contrasted with the array of alternatives boasting superior aesthetic qualities [71].

Utilizing computer-aided design and computer-aided manufacturing (CAD-CAM) technology, fabricated posts offer a harmonious amalgamation of benefits from conventional custom posts and prefabricated fiber posts [34]. The incorporation of CAD-CAM fabricated post and core restorations has been proposed, with specific attention to CAD-CAM fabricated zirconia post and cores garnering research focus [51,71]. Nonetheless, the challenge of retrieving fractured zirconia posts, leading to irreversible tooth failure, adds complexity to their application [72].

Recent advancements have witnessed the integration of resin-based materials into the realm of computer-aided design and computer-aided manufacturing (CAD-CAM) techniques for restoring endodontically treated teeth [10]. The crucial role of restoration adaptation in achieving clinical success has been underscored [24]. CAD-CAM post and core restorations, renowned for their precision, facilitate minimal composite resin cement application, potentially enhancing adhesion to dentinal walls [46]. The meticulous fitting of CAD-CAM-designed posts within the canal not only boasts high esthetic appeal but also accommodates cases with limited coronal remnants and supports extensive prostheses. In comparison to traditional methods, the standout advantage of CAD-CAM techniques lies in the swiftness of restoration preparation, though comprehensive clinical studies are indispensable to assess their durability over prolonged periods [73].

Acknowledging the boundaries of this study, it's essential to note that one of the key limitations is the challenge of discerning the distinct attributes of various materials. The prevailing dataset leans heavily on clinical reports, predominantly favoring milled zirconia and glass-fiber-reinforced composites as the subjects of analysis. Therefore, a call to action resonates within the scientific community, urging for a more comprehensive exploration of diverse materials and their mechanical characteristics, as the quest to uncover their full potential persists.

5. Conclusions

The utilization of CAD/CAM technology within the field of dentistry has expanded beyond its traditional realms of crowns, inlays, onlays, and dentures. The increasing triumph of employing CAD/CAM-fabricated post and cores has unveiled a novel avenue, presenting itself as a viable alternative to conventional techniques. While these post and core restorations showcase commendable attributes such as remarkable fracture resistance, robust bond strength, adaptive qualities, and pleasing aesthetics, it's worth noting that the realm of in vivo investigations in this domain remains relatively limited. Consequently, the imperative arises for a series of comprehensive long-term studies to lend substantial validation to the insights gleaned from the existing array of clinical reports.

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