Review Article

Current perspectives on ceramic post and core systems

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Abstract

In spite of a large number of in-vitro and in-vivo reports, it is still unclear regarding the ideal restoration of endodontically treated teeth, which requires comprehensive knowledge of dental science, materials science and principles of mechanical engineering, including biomechanics. With the advantage of digital technology, CAD/CAM technology offers high precision restorations with less time consuming and an ability of processing high-strength ceramic such as zirconia, which provides both high esthetics and strength. The review focuses on current knowledge regarding the post and core system, classification of ceramics, CAD/CAM workflow for manufacturing the post and core system and pre-clinical testing of ceramics including bond strength testing and finite element analysis.

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Introduction

Appropriate root canal treatment followed by adequate coronal restorations is crucial for successful clinical outcome of endodontically treated teeth (Gillen, et al., 2011). A majority of endodontically-treated teeth have minimized coronal tooth structure The extensive loss of more than 50% of the coronal tooth structure, caused by dental caries, fracture or extensive cavity preparation, may indicate the use of additional radicular retentive, including radicular posts (Christensen, 1999). These result in enhanced retention and stability of the prepared samples (Coelho, et al., 2009). Currently, the concept of modern dentistry has undoubtedly changed the patient's treatment plan. For example, traditionally widely used metal posts do not meet the requirements of modern dentistry, largely because of disadvantages such as color, corrosion potential, non-adhesive bonding and high Young's modulus of elasticity which can eventually lead to root fracture. In order to overcome the disadvantages of metal post as well as improve the esthetic aspects of the restoration especially for the teeth those in esthetic areas, a wide range of non-metal posts and cores have been developed and become commercially available. These metal-free materials are also beneficial for those who have a history of metal allergy and they are environmental friendly. In addition to esthetic, health and environmental benefits, they offer the capacity of adhesive bonding to tooth tissue and core build-up materials, which potentiates the presence of the 'monoblock', a space-free single unit in which the loading stresses are evenly distributed and borne by all the monoblock components (Tay and Pashley, 2007).

Two major types of non-metal post and core systems can be classified based on the compositions of materials employed.

1. **Composite system** includes prefabricated glass-reinforced fiber posts with core build-up composites and prefabricated ceramic post with core build-up composites.

2. **Ceramic system** includes custom-made ceramic posts and cores manufactured by either CAD/CAM processing or press technique.

Basic and comprehensive knowledges on post-endodontic restoration were recently reviewed by Naumann et al (2018) and this is not the focus of the present review article. With the advantage of digital technology, CAD/CAM technology offers less time consuming and an ability of processing high-strength ceramic such as zirconia, which provides both high esthetics and strength.

Clinical performance of ceramic posts and cores was previously reported. Two clinical studies reported that the zirconia post showed a high survival rate, while zirconia posts with direct composite cores showed no failure after a mean clinical service of 57.7 months. However, a failure rate of approximately 30% of zirconia posts with indirect glass-ceramic cores (IPS Empress Cosmo) was observed after a mean clinical service of 46.3 months (Paul and Werder, 2004). Another clinical study reported a 100% success rate of zirconia posts after a mean observation period of 29 months (Nothdurft and Pospiech, 2006). This suggests clinical benefit of zirconia as an alternative post and core material. The clinical performance of other ceramic post and core systems remains lacking. Further studies are required to determine clinical outcome of all ceramic post and core systems before they become a standard procedure as with the metal post and core and the composite post and core systems.

Loss of retention is the most widely recognized clinical failure of post-retained restorations (Hatzikyriakos, et al., 1992). The cement thickness influences the retention of a post (Coniglio, et al., 2011). Root canals vary in shapes, and differences between the shape of the pre-fabricated post and the canal shape can result in increased cement thicknesses

(Paque, et al., 2010). Although no consensus has been established on the optimal cement thickness for post cementation, *in vitro* studies have reported the importance of cement thicknesses on the bond strength of fiber posts (Coniglio, et al., 2011; D'Arcangelo, et al., 2007). Moreover, unfavorable voids and gaps within the cement interface may appear since the application of adhesives in endodontically-treated root canals is highly sensitive (Grandini, et al., 2005; Naumann, et al., 2008). Voids within the cement layer might cause debonding by reducing contact bonded area between cement and dentine, impairing mechanical properties of cement and creating crack initiation sites.

The fracture strength of root dentin and post and core assembly is very important to sustain mechanical stability of endodontically treated teeth (Hayashi, et al., 2008). Post-dentin adaptation represents an important role in the bio-mechanical performance of endodontically treated teeth (Schwartz, 2006). It is a proven concept that close adaptation and minimal tooth structure removal provide a long term success of endodontically treated teeth (Sorensen and Engelman, 1990). In many cases root canal morphology is oval shaped rather than circular or canal preparation could be oval form, resulting in increased cement thickness and/or decreased post-root dentine wall adaptation.

Some root canal shapes, such as C-shape and ellipse-shape, have challenged dentists in obtaining acceptable bond strength between the post and dentine due to the unfavorable canal configuration (Dietschi, et al., 2008; Tay, et al., 2005). A number of key factors influencing the post-root dentin strength were evaluated, such as the pretreatment of root dentin (Coniglio, et al., 2008; Ohlmann, et al., 2008), the influence of different root canal regions (Wang, et al., 2008; Zhang, et al., 2008), the type of resin cement and adhesive (Radovic, et al., 2008; Zicari, et al., 2008), the adhesive application modes, the translucency of the fiber post (Faria e Silva, et al., 2007; Goracci, et al., 2008), the filler content of the cement (Carvalho, et al., 2009), the cement thickness (Hagge, et al., 2002; Perez, et al., 2006) and the fiber post surface treatments (Monticelli, et al., 2008). To date, no studies evaluated the influence of the fiber post shape on the post-root dentin strength but it is likely that radicular posts with closely imitated prepared root canal shape results in high adaption of the post to root can wall, thus decreasing the debonding failure rate of the restoration. As mentioned earlier, close adaptation of ceramic post and core system produced using digitally-oriented workflow with CAD/CAM technology will help overcome the retention failure of non-metal post and core system. Moreover, most ceramic surface can be etched and the resulting roughen surfaces are advantageous for enhancing the adhesion of ceramic post to root dentin. A range of surface modification methods have been proposed to improve ceramic-resin cement bonding. However, it has been suggested that abrasive technique using airborne-particles could make the ceramic surface more susceptible to low temperature degradation. Other pretreatment methods, including laser, and infiltration coating, and other coupling agents, have also been investigated. Under clinical setting, most ceramics, except zirconia, can be etched with hydrofluoric acid under clinical setting, resulting in a roughen surface for better bonding, and the bond on an etched surface appears to be strong and reliable. Because the etching procedure can be easily performed either in the dental laboratory or chairside, etchable glass ceramics are good candidates as non-metal post and core materials in current clinical practice (Hopp and Land, 2013). This further emphasizes the importance of ceramic post and core system which will be the focus of the present review.

Classification of dental ceramics

Ceramics are defined as inorganic, non-metallic materials made by heating raw minerals in high temperatures (Rosenblum and Schulman, 1997). Ceramics and glasses are brittle, which means that they exhibit high compressive strength but low tensile strength, and therefore display low fracture toughness, compared to other dental materials. As restorative materials, dental ceramics have disadvantages mostly due to their inability to withstand functional forces present in oral cavity. As a result, they had limited application initially in the posterior regions. In order to overcome these disadvantages, new types of dental ceramics have been continuously developed. Currently, several types of dental ceramics have been available commercially and can be classified according to their microstructures (glass-to-crystalline ratio) into 4 categories (Shenoy and Shenoy, 2010).

Category 1-glass-based systems (mainly silica)

This category includes materials that contain mainly silicon dioxide (silica or quartz) and various amounts of alumina. Aluminosilicates found in nature, also known as feldspars, are modified in a number of ways to create the glass used in dentistry.

Category 2-glass-based systems (mainly silica) with crystalline fillers

Different types of crystals are added or grown in the glassy matrix to create this type of ceramics. This category is further subdivided into 3 groups because of varying amounts of different types of crystals in glassy matrix. The primary crystal types currently used are leucite, lithium disilicate or fluoroapatite.

Subcategory 2.1-low-to-moderate leucite-containing glass

Subcategory 2.2-high leucite-containing glass

Subcategory 2.3-lithium-disilicate glass ceramic

Category 3-Crystalline-based systems with glass fillers

Infiltrated ceramics are made through the process called slip-casting which condense an aqueous porcelain into a porous core of alumina. These pores are later infiltrated by molten glass via capillary action at high temperatures.

Category 4-Polycrystalline solids

This ceramic material is formed by directly sintering crystals together without any matrix to form a dense air-free, glass-free, polycrystalline structure which is well known for its superior mechanical properties. Unlike glassy ceramics, polycrystalline ceramics cannot be pressed as a fully dense material into slightly oversized molds. Polycrystalline ceramics are formed from powders that can be packed only to 70% of their theoretical density. Hence, polycrystalline ceramics shrink around 30% by volume when made fully dense during firing. For the final prostheses to fit well, the amount of shrinkage needs to be accurately predicted and compensated.

Detailed information regarding the fabricating techniques, including conventional powder slurry technique, casting technique, press technique, infiltration technique and CAD/CAM technique, was previously reviewed (Tanthanuch and Patanapiradej, 2007), and will not be the focus of the present review.

Surface modification of a ceramic post and core system can be performed and is known to influence the performance of the post and core. Improving performance of ceramic post and core, ceramic surface can be modified with various treatments. Tribochemical silica coating has been reported to enhance the ceramic bonding to resin, but airborne-particle abrasion could cause the ceramic surface more vulnerable to low temperature degradation. Other surface treatment methods include laser modification, infiltration coating and other coupling agents. Most ceramics, except zirconia, can be etched with hydrofluoric acid under clinical setting, resulting in a rough surface for bonding, and the bond on such an etched surface has been shown to be strong and reliable. Because the etching procedure can be easily performed either in the dental laboratory or chairside, etchable glass ceramics are good candidates as non-metal post and core materials in current clinical practice (Hopp and Land, 2013).

Summarized CAD/CAM manufacturing process of ceramic post and core system

Several machinable ceramic systems have been developed along with CAD-CAM (Computer Aid Design/Manufacturing) system (Sailer, et al., 2007). A number of intraoral scanner systems have been introduced and used to obtained 3D data for further design and processing of dental prostheses using CAD/CAM. To the best of our knowledge, current commercially available intraoral scanners are, however, incapable of directly scanning all the detail of the prepared post space. An indirect method may be used to obtain a 3D digital model of the post and core. Following the post space preparation, a resin pattern of the post and core can be fabricated directly from the post space intra-orally. Figure 1 shows a resin pattern of post and core. The finished resin pattern can be scanned using a scanner to achieve a digital file in the CAD software, followed by machining with a compatible milling machine. Then final restoration is finished and polished before try in appointment.

CAM technology can be classified to additive technique and subtractive technique. Ceramic post and core can be fabricate with subtractive technique, cutting the contour out from solid block by milling machine (Zarina, et al., 2017). A recent review article by Zarina R and colleagues comprehensively summarizes the evolution, components and materials used for fabrication of prosthesis using CAD/CAM technology.

Pre-clinical assessment of ceramic post and core system

Pre-clinical consideration for the use of post and core may be evaluated by the bond strength of adhesive systems used to cement ceramic posts and root canals. In addition, biomechanics assessment of the post and core system is one of powerful tools to examine stress distribution and maximum stresses. One of the most well-known analytical system to study biomechanics is finite element analysis (FEA). These two key assessments are discussed below.

Figure 1: Resin pattern of post and core

Assessment of Bond strength

Adhesive systems are selected based on their bond strengths achieved while testing in laboratories. The shear and/or tensile bond strength are usually measured. However, conventional shear and tensile bond systems often demonstrate cohesive failure in dentin or resin at the bonded interface when stressed (Phrukkanon, et al., 1998). To reduce the flaws, micro bond strength tests were introduced. They are the most commonly used bond-strength tests and can be categorized into three types (Sirisha, et al., 2014a).

1.1 Micro-shear (μSBS) test

In a microshear bond test, two materials are connected via an adhesive agent and loaded in shear until fracture occurs. It is the most widely used test as no further specimen processing is required after the bonding procedure (Sirisha, et al., 2014b).

1.2 Micro-tensile (μTBS) test

In a tensile bond test, load will be exerted on either sides of the test specimen (Gokce, et al., 2007). The advantages of this test are that it involves better economic use of teeth, the better stress distribution at the true interface, the ability to test irregular surfaces and very small areas, and the ease in microscopic examinations of the failed bonds due to smaller areas. The disadvantages are further specimen processing or the actual preparation of the micro-specimens is required after the bonding procedure, difficulty in measuring bond strengths lower than 5 MPa, easily damaged specimens, and loss or fracture of post-fracture specimens (Sirisha, et al., 2014a).

1.3 Micro-push out (μPO) test

In a push out test, load is applied through a plunger mounted in the universal testing machine. The plunger must provide near complete coverage of the testing material without touching the root canal wall. This method is useful to test adhesion of root canal sealers and retention of posts luted in root canals (Sirisha, et al., 2014b).

Stress distribution prediction using finite element analysis (FEA)

Different post and core systems also generate different types of stress to root dentin complex. Finite element analysis (FEA) is a numerical procedure for analyzing complex structures and has been widely used and applied in multidisciplinary researches such as engineering, medical and dental researches. When choosing the appropriate mathematical model, it is considered as a time and cost effective solutions compared with other research methodologies. Additional benefits of FEA include low operating costs, short processing time and information provision that cannot be tested by experimental studies, including stress distribution. Moreover, FEA has been applied in many studies of various areas in dentistry by helping clinician understand the stress concentration in different areas of the post and root dentin complex. Such FEA-derived data can help select the most suitable treatment option for individual patient. Furthermore, FEA is a useful tool when analyzing sophisticated systems that are difficult to standardize in *in vitro* and *in vivo* studies. It has also been used to evaluate the impact of the material type, such as glass fiber and zirconia ceramic, and the external configuration of the dowel (smooth and serrated) on the stress distribution of teeth restored with varying dowel systems (Silva, et al., 2009). In FEA, the biomechanical conditions that lead to fracture can be determined by the stress state in the sample. FEA can analyze experimental studies that different test parameters and standards are used in the experimental studies., which can be assessed by FEA. Figure 2 shows simulated finite element models and stress distribution analysis.

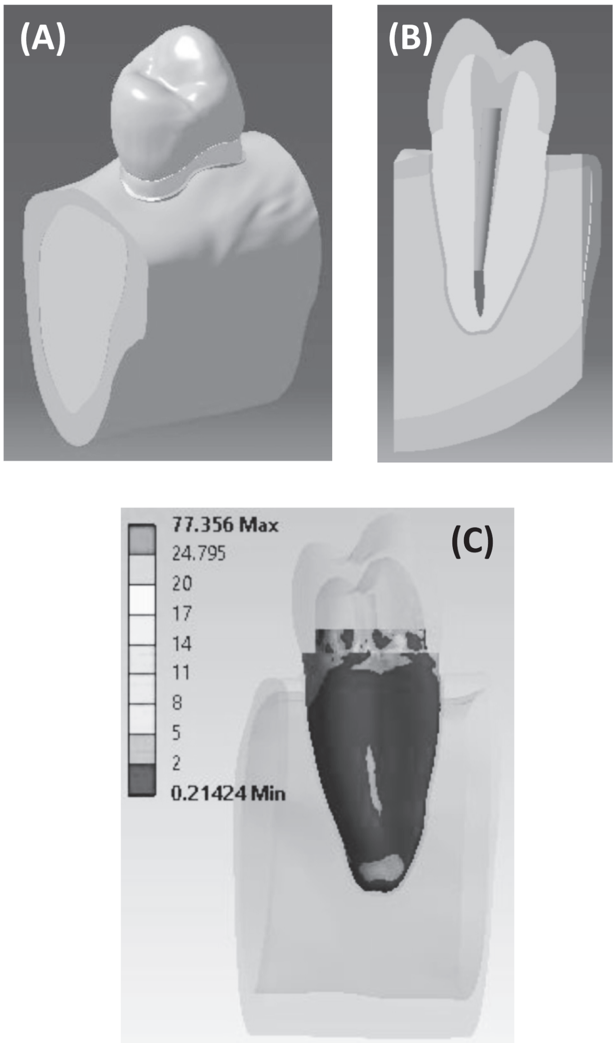

Figure 2: Simulated finite element models and stress distribution analysis. An example of a 3D simulated model of a maxillary premolar restored with post and core and crown (A), and its longitudinal section is also shown in (B). An example of the stress distribution analysis from finite element study, demonstrating a differentially distributed stress on remaining tooth structure under an applied force, is shown in (C).

Conclusion

In addition to adequate root canal instrumentation and three-dimensional obturation, clinical success of endodontically treated tooth depends on appropriate coronal restoration. Two major types of non-metal post and core systems can be employed. CAD/CAM technology offers an ability of processing high-strength ceramic, which provides both high esthetics and strength. The preparation of the esthetic ceramic post and core system using digitally-oriented workflow with CAD/CAM technology helps overcome the retention failure of non-metal post and core system and is therefore a promising alternative to the conventional system due to its high esthetic, good mechanical properties, close adaptation to root dentin with minimized cement thickness and less time consuming. Although good clinical performance of zirconia post and core system was reported, clinical performance of other ceramic post and core systems remains lacking. It is therefore of importance to determine long-term clinical outcome of all ceramic post and core systems before they can be routinely used.

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