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Nonmetallic Prefabricated Dowels: A Review of Compositions, Properties, Laboratory, and Clinical Test Results

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Nonmetallic prefabricated dowels; nonmetallic prefabricated posts; restoration of endodontically treated teeth; composition; properties; laboratory results; clinical results.

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Abstract

Purpose: Prefabricated dowels have become popular, and a wide variety of systems are available. Recently, in response to a need for tooth-colored dowels, several nonmetallic dowels such as carbon-fiber epoxy resin, zirconia, glass fiber-reinforced epoxy resin, and ultra-high polyethelene fiber-reinforced dowels are available. With a plethora of different materials and systems currently available for use, an overview of the scientific literature on nonmetallic dowels is indicated. This article reviews the current literature dealing with the compositions, properties, and laboratory and clinical test results of nonmetallic prefabricated dowels.
Methods: A comprehensive review of the literature was completed seeking evidence for the treatment of teeth with nonmetallic prefabricated dowels. A search of English language peer-reviewed literature was undertaken using MEDLINE and PubMed with a focus on clinical research articles published between 1996 and 2007. A hand search of relevant dental journals was also completed.
Results: The literature demonstrates that in vitro investigations demonstrated favorable physical and mechanical properties of these dowels; however, clinically, there has been a wide range of reported failure percentages.
Conclusion: Since there is considerable variation in reported failure percentages, longer-term studies are needed that present data regarding all types of complications that have been identified in the literature.

Using a dowel to restore a tooth whose natural crown is missing is not a recent dental treatment. In the Tokugawa era (1603 to 1867), the Japanese used wooden dental restorations designed to function like the modern dowel crown.[1] Pierre Fauchard in his book, *The Surgeon-Dentist, or, Treatise on the Teeth*, published in 1728, described a technique by which a silver post was used to retain a natural tooth crown or an ivory crown to a root.[2] In 1876, The Richmond Porcelain and Gold Collar Crown was introduced and was modified through the years to become a one-piece dowel and crown.[3,4] Root fractures and other difficulties encountered with these early treatments led to the development of cast dowels that continue to be used today.

Although modern endodontic, prosthodontic, and periodontal therapies have allowed patients to retain severely compromised teeth for longer periods of time, the restoration of these teeth remains a challenge. Despite a number of innovations and decades of research on dowels, failures still can occur when endodontically treated teeth are restored. Studies indicate that the most common dowel complications are post loosening and root fracture;[5-12] however, the overall clinical failure rate of dowels remains relatively low. Combined data from eight studies indicated that dowels had an average absolute rate of failure of 9% (7% to 14% range).[7-11,13-17]

Prefabricated dowels have become popular, and a wide variety of systems are available. Recently, in response to a need for tooth-colored dowels, several nonmetallic dowels such as carbon-fiber epoxy resin, zirconia, glass fiber-reinforced epoxy resin, and ultra-high polyethelene fiber-reinforced dowels have become available. The purpose of this article is to provide a synopsis of the available literature regarding these new nonmetallic prefabricated dowels, including their compositions, properties, laboratory test results, and clinical outcomes.

Methods

A comprehensive review of the literature was completed seeking evidence for the treatment of teeth with nonmetallic prefabricated dowels. A search of English language peer-reviewed literature was undertaken using MEDLINE and PubMed with a focus on clinical research articles published between 1996 and 2007. A hand search of relevant dental journals was also completed. Keywords included the following: carbon fiber-reinforced epoxy resin dowels, carbon fiber-reinforced epoxy resin posts, glass fiber-reinforced epoxy resin dowels, glass fiber-reinforced epoxy resin posts, polyethylene fiber-reinforced dowels, polyethylene fiber-reinforced posts, zirconia dowels, zirconia posts, along with combinations of the term composition, physical properties, mechanical properties, laboratory studies, and clinical studies. Available abstracts were reviewed, and full-text articles of selected abstracts obtained online or via the interlibrary loan program at Loma Linda University Library.

Results

Carbon fiber-reinforced epoxy resin dowels

Composition and properties

The carbon fiber-reinforced epoxy resin dowel system (CF) was developed in France in 1988 by Duret and Renaud[18-20] and first introduced in Europe in the early 1990s.[21-23] The matrix for this dowel is an epoxy resin reinforced with unidirectional carbon fibers parallel to the long axis of the dowel. The fibers are 8 μm in diameter, and uniformly embedded in the epoxy resin matrix. By weight, the fibers comprise 64% of the dowel and are stretched before injection of the resin matrix to maximize the physical properties of the dowel.[18,24,25] The dowel is reported to absorb applied stresses and distribute these stresses along the entire channel.[26] The bulk of the carbon fiber is made from polyacrylonitrile by heating it in air at 200°C to 250°C and then in an inert atmosphere at 1200°C. This process removes hydrogen, nitrogen, and oxygen, leaving a chain of carbon atoms and forming carbon fibers.[27]

The carbon fiber-reinforced dowel has been reported to exhibit high fatigue strength, high tensile strength, and a modulus of elasticity similar to dentin.[21,24,28-30] The dowel was originally radiolucent; however, a radiopaque dowel is now available. Radiopacity is produced by placing traces of barium sulfate and/or silicate inside the post. Mannocci et al[31] radiographically examined five types of fiber dowels. They found that only two of the five dowels had uniform radiopacity. Finger et al[32] examined the radiopacity of seven fiber-reinforced resin dowels and found CF posts had an acceptable radiopacity.

The dowel is also available in different shapes: double cylindrical with conical stabilization floors or conical shapes (Fig 1).

The surface texture of the dowel may be smooth or serrated. Studies have indicated that serrations increase mechanical retention although the smooth-sided dowel also bonds well to adhesive dental resin.[30,33] The surface of the dowel has a roughness of 5 to10 μm to enhance mechanical adhesion of autopolymerizing luting materials, and the dowel appears to be biocompatible based on cytotoxicity tests.[29,34]

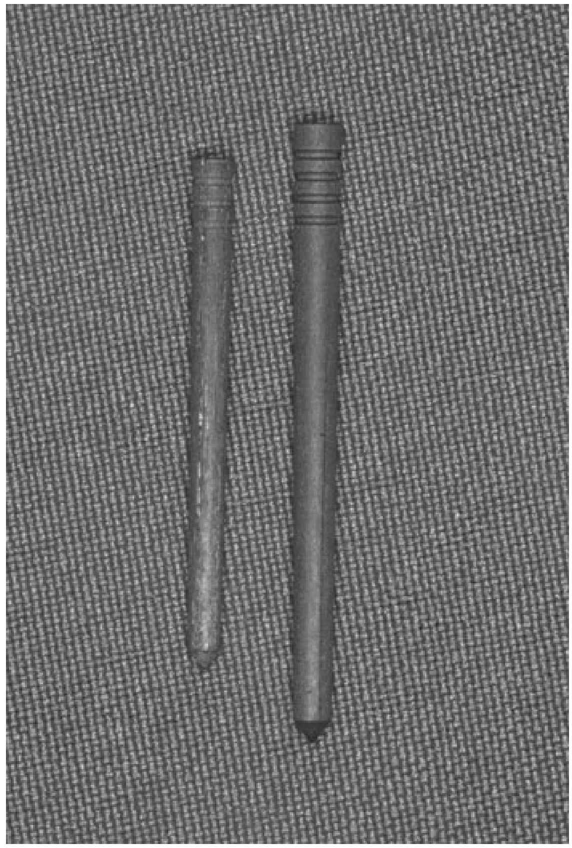

Figure 1 Carbon fiber-reinforced epoxy resin dowels.

Laboratory test results

Physical property tests of CF dowels have produced contrasting results; some studies found them to be stronger than metal dowels,[25,28] whereas other studies determined their strength was comparable[25,28] or inferior[35-37] to metal dowels.

The fracture resistance of extracted teeth restored with CF dowels has been extensively evaluated. Several studies[28,35,37,38-41] indicate CF dowels are less likely to cause root fracture than metal dowels; however, two studies[42,43] found no significant difference in tooth fracture resistance, and one study[38] reported a significantly higher fracture threshold for cast metal dowels.

Multiple studies[42,44-47] determined there was a decrease in the strength properties of CF dowels after thermal cycling and cyclic loading. Additionally, contact of CF dowels with oral fluids reduced their flexural strength values.[34,46,47]

A proposed advantage of fractured CF dowels is their purported ease of removal.[37,48-52] A removal kit has been suggested[48-51] for dowel removal with a recommendation that it be a single-use item.[49]

Clinical outcomes

Twelve studies have clinically evaluated CF dowels with a wide range of failure percentage being reported (Table 1). Failure rates have ranged from zero after a mean postplacement

Table 1 Clinical studies for carbon fiber-reinforced epoxy resin dowels (CF)

Lead author	Study length	Dowels placed	CF dowels placed	% of clinical failure	Types of failure
Wennström J, 1996	3 to 4 yrs	173	173	1.73%	2 root fractures, 1 dowel fracture
Fredriksson M, 1998	2 to 3 yrs (mean 2.7)	236	236	0%	5 extracted teeth as a result of dubious treatment
Ferrari M, 2000[57]	1 to 4 yrs (mean 3.8)	200	100	5%	3 excluded (noncompliance), 2 periapical pathology
Ferrari M, 2000[56]	1 to 6 yrs (mean 3.8)	1304	1055	2.8%	30 failures (dowel debonding and periapical pathology) number for each type of failure not specified
Glazer B, 2000	6 months to 4 yrs (mean 2.3)	59	59	7.7%	2 periapical pathology, 1 dowel debonding, 1 crown debonding
Mannocci F, 2002	1 to 3 yrs	117	117	6.5%	3 dowel debonding, 4 marginal gap formation
King PA, 2003	1 to 8 yrs (mean 7.3)	27	16	28.5%	4 dowel debonding
Hedlund SO, 2003	1 to 4.9 yrs (mean 2.3)	65	65	3%	2 dowel debonding
Tidehag P, 2004	5 to 9 yrs (mean 7.2)	642	642	10%	dowel debonding crown debonding
Mannocci F, 2005	1 to 5 yrs	219	110	10%	10 secondary caries
Segerstrom S, 2006	1 month to 10 yrs (mean 6.7)	99	99	35%	3 dowel debonding, 14 root fractures, 10 periapical pathology, 5 periodontitis, 3 unknown diagnosis
Ferrari M, 2007	7 to 11 yrs	985	775	7.2%	11 crown debonding, 14 root fractures, 10 periapical pathology, 5 periodontitis, 3 unknown diagnosis

time of 2.7 years[53] to a high of 35% after a mean postplacement time of 6.7 years.[54] Other reported failure rates were: 1.73% after 3 to 4 years,[22] 3% after a mean time of 2.3 years,[55] 2.8% after a mean time of 3.8 years,[56] 5% after a mean time of 3.8 years,[57] 7.2% after 7 to 11 years,[58] 7.7% after a mean time of 2.3 years,[59] 10% after a mean time of 7.2 years,[60] 10% after 1 to 5 years,[61] 6.5% after 1 to 3 years,[62] and 28.5% after a mean time of 7.3 years.[63]

The types of failures have been dowel loosening, periapical pathology, root fracture, crown debonding, secondary caries, periodontitis, dowel fracture, tooth extraction for unspecified reasons, and unknown reasons for failures.

Dowel loosening was reported in seven of the 12 studies,[55,56,59,60,62,63] whereas there was no reported loosening in five studies.[22,53,57,58,61] Of the studies that reported dowel loosening, only five[54,55,59,62,63] quantified the number of dowels that loosened. In these five studies, the following dowel loosening data were provided: 1 of 59 dowels loosened,[59] 2 of 65 dowels loosened,[59] 3 of 99 dowels loosened,[54] 4 of 27 dowels loosened,[63] and 3 of 117 dowels loosened.[62]

Periapical pathology was reported in five[54,55,57-59] of the 12 studies with 2 of 100,[35] 2 of 59,[59] 10 of 99,[54] and 10 of 775[58] failures occurring via this means. One study[56] indicated periapical pathology was encountered, but the number of failures produced from this source was not identified.

Root fracture occurred in three of the studies[22,54,58] where 2 of 173,[22] 14 of 99,[54] and 14 of 775[58] roots fractured. Crown debonding was reported in three studies,[58-60] and dowel fracture was reported in one study.[22]

Glass fiber-reinforced epoxy resin dowels

Composition and properties

The glass fiber-reinforced epoxy resin dowel (GF) is made of glass or silica fibers (white or translucent). Glass fiber dowels can be made of different types of glasses: electrical glass, high-strength glass, or quartz fibers.[39,64] The commonly used fibers are silica-based (50% to 70% SiO_2), in addition to other oxides.[65]

The GF dowel is available in different shapes: cylindrical, cylindroconical, or conical (Fig 2). An in vitro assessment of several GF dowel systems indicated that parallel-sided GF dowels are more retentive than tapered GF dowels.[66]

The composition of the glass fibers in the matrix tends to play an important role in the strength of the dowel. Newman et al[45] compared the fracture resistance of two GF dowels containing different weight percentages of glass fibers. They found that the higher content of glass fibers in the dowel contributed to the greater strength displayed by the tested dowel.

Laboratory test results

The flexural strength of GF dowels is not related to the type of glass fiber used. One study[67] evaluated the flexural strength of carbon-fiber, quartz-fiber, and glass-fiber dowels. It was found that the dowels behaved similarly because of the same concentration and type of the epoxy resin used to join the fibers together. The yield strength of GF, titanium, and zirconia dowels was also evaluated in vitro.[68] The yield strength was significantly higher for the zirconia and titanium dowels when compared with GF dowels.

Two studies[69,70] indicated that the tensile bond strength between the composite resin core material and the GF dowel is less than that developed with a titanium dowel. Other studies[62,71] indicated there was a good adhesive bond between the GF dowel and composite resin cements. The bonding of the core to the dowel can be improved by treating the dowel with airborne-particle abrasion.[72] Similar results were obtained by treating the surface of the dowel with hydrogen peroxide and silane or hydrofluoric acid and silane.[73,74]

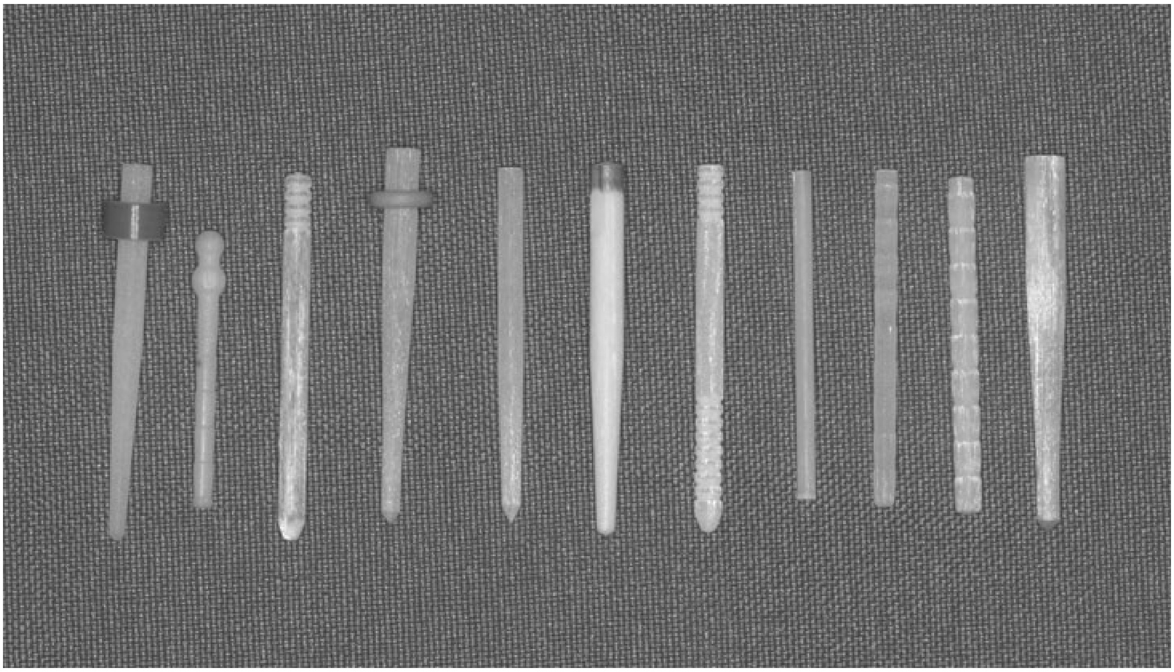

Figure 2 Designs and shapes of available glass fiber-reinforced epoxy resin dowels.

Similar to CF dowels, GF dowels have been shown in multiple studies[45,75-77] to be less likely to cause fracture of the root at failure; however, studies[40,78-81] have discussed the importance of the presence of a ferrule effect in achieving a high success rate.

Clinical outcomes

Eight studies have clinically evaluated GF dowels, and a wide range of failure percentages have been reported (Table 2). Failure rates have ranged from zero after a mean post-placement time of 2.3 years[82] to a high of 11.4% after 1 to 2 years.[83] Other reported failure rates were: 1.7% after 2.5 years,[77] 4% after 2.5 years,[84] 4.4% after a mean time of 3.8 years,[56] 6.2% after 2 years,[81] 7.4% after 2 years,[85] and 11% after 7 to 11 years.[58]

The types of failures have been dowel loosening, periapical pathology, root fracture, crown debonding, dowel fracture, core failure, restoration fracture, and unknown reasons for failures.

Dowel loosening was reported in six of the eight studies,[56,58,77,81,83,85] whereas there was no reported loosening in two studies.[82,84] Of the studies that reported dowel loosening, only five[58,77,81,83,85] quantified the number of dowels that loosened. In these five studies, the following dowel loosening data were provided: 5 of 210 dowels loosened,[58] 2 of 205 dowels loosened,[77] 7 of 225 dowels loosened,[81] 2 of 105 dowels loosened,[83] and 7 of 162 dowels loosened.[85]

Periapical pathology was reported in five[56,58,81,84,85] of the eight studies with 11 of 210,[58] 7 of 225,[81] 4 of 100,[84] and 5 of 162[85] failures occurring this way. One study[56]

Table 2 Clinical studies for glass fiber-reinforced epoxy resin dowels (GF)

Lead author	Study length	Dowels placed	GF dowels placed	% of clinical failure	Types of failure
Ferrari M, 2000	1 to 6 yrs (mean 3.8)	1304	249	4.4%	11 failures (dowel debonding and periapical pathology) number for each type of failure not specified
Malferrari S, 2003	2.5 yrs	205	205	1.7%	2 dowel debonding, 1 fractured restoration
Monticelli F, 2003	2 yrs	225	225	6.2%	8 dowel debonding, 6 periapical pathology
Naumann M, 2005	1 to 2 yrs	105	105	11.4%	2 dowel debonding, 1 root fracture, 7 dowel fracture, 1 core failure, 1 other
Grandini S, 2005	2.5 yrs	100	100	4%	4 periapical pathology, 5 partial loss of restoration
Naumann M, 2007	2 to 3 yrs (mean 2.3)	87	41	0%	No failures
Cagidiaco MC, 2007	2 yrs	162	162	7.4%	7 dowel debonding, 5 periapical pathology
Ferrari M, 2007	7to 11 yrs	985	210	11%	5 dowel debonding, 6 crown debonding, 11 periapical pathology, 1 root fracture

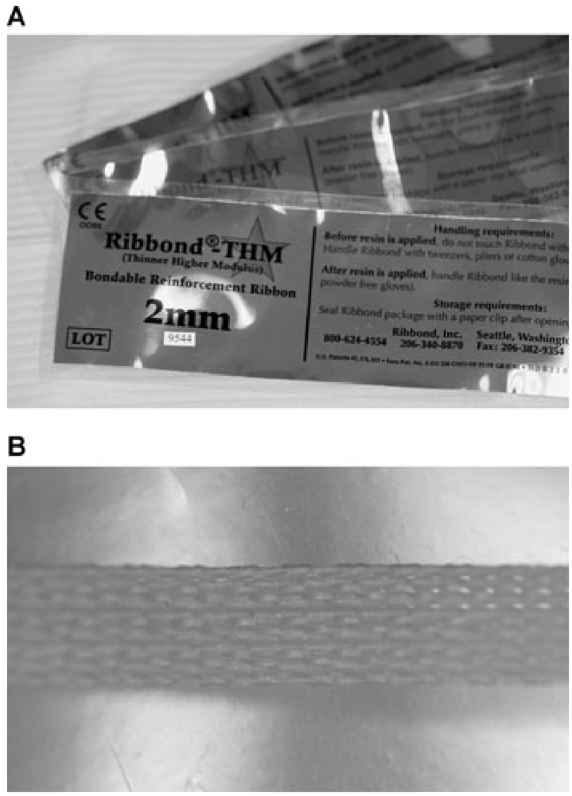

Figure 3 (A) Polyethylene fiber-reinforced dowel, Ribbond®- THM. (B) Close-up of polyethylene fiber-reinforced dowel material.

indicated periapical pathology was encountered, but the number of failures produced from this source was not identified.

Root fracture occurred in two of the studies,[58,83] where 1 of 210[58] and 1 of 105[83] dowels fractured. Crown debonding was reported in one study[58] and dowel fracture in one study.[83]

Polyethylene fiber-reinforced dowels

Composition, properties, and laboratory test results

Polyethylene fiber-reinforced dowels (PF) are made of ultra-high molecular weight polyethylene-woven fiber ribbon (Ribbond, Ribbond Inc, Seattle, WA). It is not a dowel in the traditional sense; it is a polyethylene-woven fiber ribbon coated with a dentin bonding agent and packed into the canal, where it is then light polymerized in position.[86–88] The Ribbond material has a three-dimensional (3D) structure due either to a leno weave or a triaxial architectural design (Fig 3A, B). These designs are composed of a great number of nodal intersections that prevent crack propagation and provide mechanical retention for the composite resin cement. When PF dowels were compared with metal dowels in the laboratory, the fiber-reinforced dowels reduced the incidence of vertical root fracture. The addition of a small-size prefabricated dowel to the PF dowel increased the strength of the dowel complex; however, the strength of the PF dowel did not approach that of a cast metal dowel.[86]

When compared to other fiber-reinforced composite dowel systems, the PF dowels were also found to protect the remaining tooth structure.[45] These results may be attributed to the manufacturer's recommendations not to enlarge the root canals, not to remove undercuts present in the root canal, and form a 1.5- to 2-mm crown ferrule. The presence of a large volume of core material and a sufficient dentin bonding area coronally seems to greatly affect the mean load-to-failure value of PF posts.[45] Eskitascioglu et al[89] evaluated two dowel systems using a fracture strength test and a finite element analysis. They found that stress accumulated along the cervical region of the tooth and along the buccal bone. Minimum stress was recorded within the PF dowel system. They suggested that the PF dowel could be advantageous for the restoration of teeth with apical resection.

The use of PF dowels to restore endodontically treated teeth appears to be a promising alternative to stainless steel and zirconia dowels with respect to microleakage.[90] Usumez et al[90] compared in vitro the microleakage of three esthetic, adhesively luted dowel systems with a conventional dowel system. They found that the PF dowels and the GF dowels exhibited less microleakage compared to zirconia dowels.

Table 3 Clinical studies for polyethylene fiber-reinforced dowels (PF)

Lead author	Study length	Dowels placed	% of clinical failure	Types of failure
Turker SB, 2007	1 to 6 yrs (mean 2.9)	42	2.4%	1 dowel debonding

Clinical outcomes

One study[91] has clinically evaluated PF dowels (Table 3). The failure rate was reported to be 2.4% after a mean time of 2.9 years. In this study 1 of 42 dowels loosened. Dowel loosening was reported to be the only cause of failure of the PF dowel.

Zirconia dowels

Composition and properties

The trend toward the use of all-ceramic crowns has encouraged manufacturers to explore the development of all-ceramic dowels.[92–95] A tooth-colored ceramic avoids the discoloration of tooth structure that can occur with metal dowels and produces optical properties comparable to all-ceramic crowns.[96–99] One type of all-ceramic dowel is the zirconia dowel, composed of zirconium oxide (ZrO_2), an inert material used for a range of applications. Its high fracture toughness, high flexural strength, and excellent resistance to corrosion encouraged orthopedists to use it at articulation surfaces.[100] Studies have suggested that zirconia specimens transplanted in animals were very stable after long-term aging, and there was no apparent degradation of the specimens.[100,101–104]

Zirconia (tetragonal zirconium polycrystals, TZP) exhibits phase transformation. Low-temperature degradation of TZP is known to occur as a result of spontaneous phase transformation of tetragonal zirconia to monoclinic phase during aging at 130°C to 300°C, possibly within a water environment. It has been reported that this degradation leads to a decrease in strength due to the formation of microcracks accompanying the

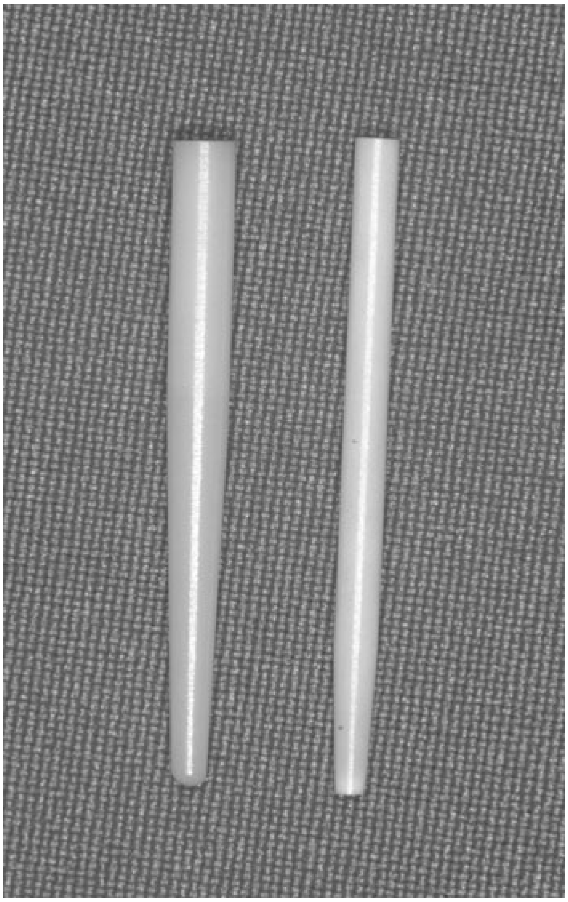

Figure 4 Available shapes of zirconia dowels.

phase transformation. To inhibit this phase transformation, certain oxides (magnesium, yttrium, or calcium oxide) are added to fully or partially stabilize the tetragonal phase of zirconia at room temperature. This mechanism is known as transformation toughening.[95,101,105-107]

The type of zirconia used for dental dowels is composed of TZP with 3% mol yttrium oxide (Y_2O_3) and is called Y-TZP (Yttrium-stabilized tetragonal polycrystalline zirconia).[95,108] Y-TZP is composed of a dense fine-grained structure (0.5 μm average diameter) that provides the dowel with toughness and a smooth surface.[106,108,109]

The dowel is extremely radiopaque and biocompatible, possesses high flexural strength and fracture toughness, and may act similar to steel.[101-105,110-119] In addition, the dowel has low solubility[116] and is not affected by thermocycling.[44] The dowel is available in a cylindroconical shape (Fig 4).

Laboratory test results

The zirconia dowel has a smooth surface configuration with no grooves, serrations, or roughness to enhance mechanical retention. As a result, the zirconia dowel does not bond well to composite resins and may not provide the best support for a brittle all-ceramic crown.[69,120-123] Dietshi et al[122] found that these dowels also have poor resin-bonding capabilities to dentin after dynamic loading and thermocycling due to the rigidity of the dowel. In a cyclic loading test performed in a wet environment, Mannocci et al[123] found that the survival rate of zirconia dowels compared to fiber dowels was significantly lower.

In vitro studies[69,59,124,125] indicate that the smooth surface configuration of untreated zirconia dowels leads to failure at the cement/post interface. The vast majority of the cement remained in the root and was not attached to the zirconia dowels. Wegner and Kern[126] evaluated the bond strength of composite resin cement to zirconia dowels. They found that the long-term bond strength of the composite resin cement to zirconia dowels is weak. Several studies[126-129] found that acid etching and silanization of zirconia dowels does not improve the strength of the resin bond to the zirconia-based material because of little or no silica content in the dowel; however, tribochemical silica coating was found to increase the bond strength of composite resin to the zirconia dowel.[130,131] Oblak et al[132] compared the fracture resistance of prefabricated zirconia dowels after different surface treatments. They found that airborne-particle-abraded dowels exhibited significantly higher resistance to fracture than those ground with a diamond instrument.

The use of heat-pressed glass instead of composite resin to form the core has been suggested.[114,115,133] This approach may improve the physical properties of the all-ceramic dowel.

When the mechanical properties of zirconia dowels were evaluated, it was reported that these dowels are very stiff and strong, with no plastic behavior.[112,114] Pfeiffer et al[68] found that the zirconia dowel had a significantly higher yield strength compared to titanium and GFR dowels.

Several studies[37,134,135] indicate that many commonly used dowels exhibit higher fracture resistance than zirconia dowels. In addition, if they fracture, the retained segment may not be retrievable, and the tooth would therefore not be restorable.[39,135]

Clinical outcomes

Two studies[136,137] have clinically evaluated zirconia dowels (Table 4). One study had no failures after a mean time of 2.4 years.[134] In one study, the failure rate was reported to be 9% after a mean time of 4.8 years. Dowel loosening was reported to be the only cause of failure of the zirconia dowel.

Table 4 Clinical studies for zirconia dowels

Lead author	Study length	Dowels placed	% of clinical failure	Types of failure
Paul SJ, 2004	1 to 9 yrs (mean 4.8)	145; Group 1: 79 direct composite, Group 2: 34 glass-ceramic core	Group 1: No failures Group 2: 9%	Group 2: dowel debonding
Nothdurft F, 2006	8 months to 3.6 yrs (mean 2.4)	30	0%	No failures

Conclusions

Clinical practice trends have recently included nonmetallic prefabricated dowels such as carbon fiber-reinforced epoxy resin dowels, glass fiber-reinforced epoxy resin dowels, polyethylene fiber-reinforced dowels, and zirconia dowels. This literature review on in vitro investigations demonstrates favorable physical and mechanical properties of these dowels; however, clinically, there has been a wide range of reported failure percentages. Dowel loosening was reported in 16 of the 23 studies, making it the most commonly reported complication. Other complications (periapical pathology, root fracture, crown debonding, periodontitis, dowel fracture, and secondary caries) were reported less frequently than dowel loosening. A number of factors, such as the ferrule effect from the final restoration, humidity of the mouth, altering temperature changes, and fatigue loading, would likely play a role on the retentive strength of all prefabricated dowels in clinical service. Dowels with adequate ferrule substantially aid in preventing root fractures. It has been reported that a dowel does not strengthen a tooth, but it also does not weaken a tooth when there is a 2-mm ferrule.[138] Since there is considerable variation in reported failure percentages, longer-term studies are needed to present data regarding all the types of complications identified in the literature.

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