THE AESTHETIC POST AND CORE: UNIFYING RADICULAR FORM AND STRUCTURE

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Use of a post system for the rehabilitation of endodontically treated teeth requires traditional planning for the function of the restoration as well as a structural and aesthetic strategy for novel technologies in ceramic and composite dentistry. Contemporary material options have greatly expanded the clinician's ability to rehabilitate the coronoradicular complex. Transilluminating posts, bondable fabrics, and high-technology ceramics create exciting possibilities in post and core design. The use of bondable materials allows the practitioner to unify the structure and morphology of root systems to provide creative solutions to challenges heretofore unmet.

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The rehabilitation of the endodontically treated tooth requires therapeutic and aesthetic considerations that were not relevant in a discussion of treatment options as few as five years ago. These considerations now include the structural reinforcement of teeth that demonstrate significant composition loss, as well as the restorative requirements demanded by novel technologies in ceramic and composite dentistry. As a result of these aesthetic developments, translucency and natural optical characteristics have assumed increased importance in the cervical and radicular space of restored teeth.

There are limitless possibilities in dowel and core rehabilitation with transilluminating posts,1,2 bondable fabric,3 and high-technology ceramics.4 While these developments are at the earliest stages of published research, they have had a significant impact on the structural rehabilitation and aesthetics of endodontic restoration in clinical practice. The key to proper selection of an aesthetic and practical post system is thorough understanding of dentin behavior.5 This includes the research that has produced guidelines for the restoration of endodontically treated teeth6,7 and the science of dentin bonding, which has allowed new post technologies to unify morphology and structure for aesthetic objectives.8,9

**Dentin Behavior and the “Monocore” Concept**

Tissue biology and restorative materials must be considered prior to the restoration of radicular dentin. The “monocore” concept has evolved from clinicians’ attempts to create rehabilitations that mimic the behavior of dentin. This concept is akin to the newly emerging interdisciplinary materials science termed “biomimetics.” Inherent in the definition of biomimetics is the recovery or mimicking of the biomechanics of the original tooth by the restorative material.10 Dentin is substantially an isotropic material.5 Isotropic materials have identical physical, mechanical, elastic, and thermal properties when stressed. Traditional restorative techniques incorporated crownoradicular materials that were more diverse in their behavior when compared to dentin. Since many endodontically treated teeth are restored with numerous components (ie, dentin, cement, gold or stainless steel posts, composite resin or alloy buildups, metal or all-ceramic crowns), the potential for these materials to behave differently than dentin under dynamic load or thermal expansion may affect the resultant modulus of elasticity, tensile strength, and compressive strength. Dissimilarity promotes failure. Modulus of elasticity is the ratio of stress over strain, and is — in fact — a measure of stiffness rather than elasticity. The “monocore” should provide a modulus of elasticity approaching dentin. Metal has a significantly higher modulus,12 and use of a “monocore”...
provides the restoration with toughness or resistance to failure. If it can be soundly integrated to dentin, the monocore should demonstrate a fracture toughness and modulus similar to dentin (Table).

In the endodontically treated tooth, loss of pulp and physical structure creates a tooth with less water and collagen. It is this structural loss of matrix that causes the tooth to be more susceptible to fracture due to potential deformation under load. While the endodontic access has been shown to minimally weaken teeth, mesiodistocclusal MOD cavity preparations have been shown to reduce tooth stiffness by more than 60%. This significantly affects subsequent crown strength, and critical architectural features (eg, ridge and cusp anatomy) are lost. In addition, excessive removal of radicular dentin during endodontic therapy or post space preparation compromises root strength and creates significant reductions in radicular toughness. The post and core dilemma intensifies when the restoration is complicated by the need to provide increased function for both mastication and aesthetics. Lost tooth structure must be replaced, and the remaining structure must be protected from functional stress.

**Post Selection**

Traditional research has promoted guidelines for the restoration of endodontically treated teeth through laboratory and clinical studies. Maximum retention of the post and fracture resistance in the restored root are the criteria upon which selection of a post system is based. Multiple factors must be considered during selection of a post system. Crucial considerations include the amount of remaining tooth structure, the periodontal status, functional demands on the tooth, arch position, and opposing occlusion. Morphology, length, width, and curvature of the root(s) are also critical. The primary purpose of post or dowel placement is to support a core that can be used to retain the final restoration. Traditional post systems do not reinforce endodontically treated teeth and are not necessary when substantial tooth structure is present after teeth have been prepared.

In selecting an appropriate post system, treatment should attempt to establish: a) a stable post system that transfers the stress of mastication throughout the radicular root and into the periodontal attachment uniformly; b) a post system that does not focus stress in function or create it during placement; c) a stiff post system that resists deformation or permanent bending to protect the integrity of the crown margins and cement seal; d) a cementation process that provides optimal luting of the dowel to the radicular dentin; and e) a conservation of coronal tooth structure that allows adequate encasement of dentin by overcasting the "ferrule" effect.

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<th><strong>Elastic Moduli of Common Dental Materials</strong></th>
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<tr>
<td><strong>Dental Material</strong></td>
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<tr>
<td>Dentin</td>
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<td>Composite Resin</td>
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<td>Amalgam</td>
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<td>Type IV Gold</td>
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<td>Nonprecious NiCr</td>
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<td>Stainless Steel</td>
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<td>Alumina Ceramic</td>
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Contemporary post systems can be classified according to their different material and design characteristics. In the most traditional system, the cast or morphologic dowel is directly or indirectly fabricated to closely reproduce the morphology of the root canal space. A second system uses a preformed dowel that corresponds to the instrument used to refine the dowel space. This standardized dowel system should be selected for length and fit and can be passively cemented. The third system incorporates dentin-bonding techniques and materials to integrate the dowel system to the radicular wall via the micromechanical attachment between resin and demineralized/primed radicular dentin. The adaptation of a resin-enhanced system to the radicular dentin allows this approach to eliminate technique disparity between morphologic dowel fabrication, which requires laboratory participation, and the standardized chairside dowel systems used in a single visit. Since resin bonding techniques allow materials to assume an intimate adaptation to the morphologic shape of the root space, metal, ceramic, and glass-fiber dowels that can be bonded within a resinous matrix have been developed. Bondable fabric and carbon fiber systems have also expanded the available armamentarium.

Anatomical Considerations
Anatomic variations (e.g., developmental invaginations, narrow mesiodistal widths, proximal concavities) within the cervical and middle third of a high percentage of root forms must also be considered during post selection. Apical tapers and curvatures dictate post system constraints. The length, diameter, and surface configuration of traditional post systems have been extensively investigated with regard to retention and stress distribution. Although maximum retention and stress distribution can be achieved when the post is extended within morphologic constraints, an effective apical seal must be maintained. In other retention findings, parallel-sided posts were superior to tapered morphologic posts in large root diameters. The intimate adaptation of morphologic dowels in narrow root cross sections offers greater retention characteristics in these narrow, ribbon shapes.

In summarizing current guidelines for post length within morphologic constraints:

1) The post should approach two thirds of the root length.
2) Equal coronal and radicular post lengths should be achieved.
3) The post should be supported by bone in one half its radicular length.
4) The endodontic seal must be preserved (3 mm to 5 mm).

Surface modifications on dowels (e.g., serrations, altered textures) enhance cementation and retention characteristics, particularly in resin-bonded restorations.
preparation for placement. Wall thickness less than 1 mm predisposes the tooth to stress fracture. This is most critical in root morphologies with narrow mesiodistal dimensions (e.g., mandibular incisors, maxillary premolars) (Figure 1).

When making anatomic recommendations for post and core selection, careful attention must be paid to the root anatomy relative to apical curvature and tapers in determining shape and length of dowels. In roots with narrow cross sections and ribbon-shaped or oval canals, the attempt to create a round diameter for a prefabricated post is contraindicated. The round preparation exposes the root to extensive structural loss and potential fracture. The use of morphologic dowels will subsequently preserve structural integrity. Teeth that should be considered for the use of a morphologic dowel (as evidenced by narrow canal configurations) include mandibular incisors, maxillary and mandibular premolars, and the distal roots of mandibular molars (Figure 2).

The standardized preformed dowel has a round cross section and provides maximum retention when designed with parallel walls. While conservation of dentin must be of primary concern, roots with large cross sections and sufficient dentin are candidates for preformed dowel posts. These teeth include maxillary incisors, canines, and palatal roots of maxillary molars. Post systems that use dentin-bonded materials have the potential to eliminate disparity between morphologic dowels and preformed dowel systems. In oval or ribbon-shaped canal configurations, intraradicular resin bonding to dentin can eliminate the structural variable of root morphology and allow a bondable fabric or standard dowel to be resin cemented within all root configurations.

**Bonding Dowels to Radicular Dentin**
Criteria for successful bonding of post and cores to radicular dentin stipulate effective adhesion of resin composite, which is achieved by thorough penetration and coverage of dentin with resin priming and bonding agents. Multiple coats may be required following brief acidic conditioning to enhance resin penetration to the full depth of dentinal demineralization. The proper polymerization of this cohesive resin “hybrid layer” stabilizes the dentin interface against shrinkage stresses that occur when the bulk of the resin polymerization occurs.

Deficiencies and failure of the dentin resin interface occur due to the incomplete surface coverage of primer. This situation is remedied by multiple coats of primer.
Incomplete impregnation of collagen fibers can also cause failure due to extreme conditions of surface wetness or dehydration, and incomplete penetration to the full depth of the demineralized dentin can also be detrimental.\textsuperscript{29}

Once smear layer removal (EDTA) is completed, brief acidic conditioning (no longer than 15 seconds) is initiated, and resin primer and adhesive layers are added to provide complete coverage. The presence of a distinct adhesive resin (two-step, fourth-generation product) between the hybrid zone and the intraradicular resin appears to function as a flexible intermediate layer to counteract stress and polymerization shrinkage. Placement of primers, adhesives, and resins within intraradicular areas is technique-sensitive, and leakage may occur within the hybrid layer if adequate penetration does not occur.\textsuperscript{29}

**A Caveat**

Bond strength — like the description of dentinal strength — relates to the total energy that is required to fracture the resin-dentin bond. While static evaluations have been performed to investigate increasing loads, continuous long-term testing under subthreshold loads with thermal cycling is not established in the research. Clinical usage of dentin bonding techniques has produced effective and dramatic outcomes for the dental profession at large. While industry has provided products to improve the delivery of restorative care, it is crucial to observe long-term clinical outcomes in order to be apprised of whether radicular dentin behaves like coronal dentin in nonvital restorations following endodontic treatment.

Dentin bonding has become a clinically accepted and practical procedure. With effective treatment planning for dowel placement, dentin-resin bonding provides retention for restoration as well as reinforcement characteristics that are extremely beneficial in the treatment of structurally weakened teeth. These procedures also provide morphologic intimacy in oval and narrow canal shapes, an aesthetic and functional alternative to metal-only dowels, and a modulus of elasticity similar to dentin.

While aggressive intraradicular preparation for an insertion path for dowel placement will weaken the tooth structures, this negative effect may not be manifested for years. Many anterior teeth evidence structural loss due to immature development, carious involvement, or a previous dowel and core, which results in a significantly more challenging clinical restoration. In addition, these teeth often require restoration for aesthetics with novel ceramic and composite systems that render the restorations indistinguishable from natural teeth. If the intraradicular restoration of a tooth includes a metallic post, dark shadows can penetrate a thin-wall root with minimal gingival covering. Corrosion via coronal leakage of a prior metallic post can also create altered and stained radicular dentin that must first be bleached and then restored. Contemporary ceramic crowns require the use of dentin-replacement core systems that unify, reinforce, and replace structures through adhesive bonding to create an aesthetic “monocore.”

**Morphologic and Aesthetic Post Systems**

Various technical options are currently available to provide a rehabilitation dowel with the intimacy of adaptation to the canal morphology and the aesthetics required by contemporary crown materials. Each choice has its own risks and benefits, and all are valued innovations in adhesive dentistry.
Figure 14A. Composite resin materials and polyethylene fiber were condensed into the canal. 14B. Postoperative view following definitive restoration.

Figure 15. Preoperative occlusal view demonstrates the presence of fractured restoratives that caused ultimate failure.

Light-Transmitting Posts
Innovative systems have recently been developed to rehabilitate structurally weakened, aesthetically compromised teeth. These systems (eg, Luminex, Dentatus USA, New York, NY) offer smooth light-transmitting posts to be used in conjunction with light-transmitting technologies and adhesive composite systems (Figures 3 and 4). The incorporation of light-transmitting posts allows adhesives and composite resins to be simultaneously cured to the full depth of the post space. These systems provide a centered post space within a bonded composite that functions as a dentin replacement and structural reinforcement. Post spaces of a predetermined size and depth can be created and can then be treated with a same-diameter metal post (eg, Classic Metal Post, Dentatus USA, New York, NY), which is designed to be removed should endodontic retreatment become necessary (Figure 5). The composite resin assumes an intimate adaptation to the intraradicular space and eliminates any shadow of the metal post through the root and gingiva.

Current research indicates that the depth of cure provided by a light-transmitting post is sufficient to meet all presenting clinical situations. In a study of structurally weakened teeth, resin-reinforced dowel systems provided up to 50% more resistance to fracture than conventional morphologic cast post and cores. In a corroborating study, use of the light-transmitting post system increased flexural strength by approximately 50% over controls that did not use the system. Additional research has found retention of posts in flared canals was significantly improved by using this system.

Light-transmitting post systems allow the restoration of endodontically treated teeth with a light-cured adhesive system that actually reinforces and strengthens the modulus of elasticity of resin approaches that of dentin. These systems allow unlimited working time for proper adhesion, adaptation, and coronal seal of the intraradicular space. The dentin structure is subsequently unified, and metal posts can be aesthetically concealed. The centered metal post adds rigidity to the system and can be removed by ultrasonic vibration and counterclockwise rotation for retreatment of the root canal. Potential disadvantages of these systems include corrosion of the centered metal post, failure at the dentin bonded interface, and/or incomplete concealment of the metal post.

Ceramic (Zirconium) Dowel Systems
The use of bonded ceramic in endodontic rehabilitation dowel systems is a new innovation that can be used as a direct or indirect technique. A bonded ceramic post with a direct composite core is an aesthetic option when a dowel is indicated and half of the coronal dentin is preserved. Ceramic dowels are promoted for the anterior region where light conduction is critical. Since root morphology in the anterior maxillary arch is generally round or ovoid, traditionally shaped posts with high compressive strength are indicated. Since bonding to dentin is the primary clinical challenge, zirconium post selection should occur under circumstances required for any standardized post when aesthetics is of concern (Figures 6 through 12). In addition, zirconium root canal posts have been shown to be more rigid than stainless steel posts. Aesthetic zirconium ceramic posts are available in traditional shapes and can be used in round root cross-sections. They are radiopaque, biocompatible, and mechanically rigid, and can be bonded to a
variety of ceramics using resin luting materials as well as composites.

Due to their smooth shapes, ceramic post systems may, however, require enhanced retention with bonded cements. Zirconium posts are often stiffer than dentin and may concentrate occlusal forces in the root. The retrievability of ceramic posts depends on the medium by which the post is cemented. While ultrasonic removal is possible when traditional cements are used, adhesive resin cements render these dowels virtually unremovable. Bonded ceramic dowels are a viable choice in the aesthetic zone where radicular structure is sufficient. Risks involved with the use of posts include a lack of endodontic retreatment options. The ceramic-resin interface is tough and relatively impenetrable to current removal strategies.

_**Fiber Resin-Bonded Post Systems**_

The recent introduction of a manufactured dowel with glass fiber incorporated in composite resin is a further evolution of the aesthetic standardized dowel post (FibreKor, Pentron Laboratory Technologies, Wallingford, CT). In addition, another glass and composite system (Luscent Anchors, Dentatus USA, New York, NY) allows for transillumination and intraradicular bonding of the post in a single step.

Operator placed fibers have been used successfully in a diverse range of clinical applications from periodontal splints and bonded FPDs to composite dentistry and provisional prosthodontics. Fiber-reinforcing material is made from high-strength polyethylene fiber. The fiber is chemically inert, biocompatible, and can absorb and disperse shock energy. It is woven, and the various weaves impart a directional reinforcement that allows a distribution of stress. The leno-weave of fiber (Ribbond, Ribbond Inc, Seattle, WA) is crosslinked and lock-stitched, which allows for manageability and structural integrity when embedded in composite resins.

The placement technique allows for insertion of the fiber within bonded intraradicular resin and requires no removal of radicular dentin to achieve an intimate fit (Figures 13 and 14). The use of fiber-reinforced composite resins to rehabilitate an endodontically treated tooth is new and has been characterized as a technique of value in reinforcement and aesthetics. In order to ensure successful restoration using these materials, one half of the clinical crown structure should be present, and a post space should be created that would have (at minimum) equal coronal and radicular lengths to match similar guidelines for traditional post systems. The reinforcement fiber should be selected for the widest width [3 mm to 4 mm] that the canal space can receive, and the manufacturer’s recommendations must be followed for product handling and placement. A resin-laminated post can then be created with as much fiber as possible placed into the canal space. All resins must be dual-cured, and use of adjunctive light curing is strongly recommended.

The use of fiber-reinforced resin-bonded post systems eliminates the need for removal of the intraradicular dentin, and the bonded adaptation provides resistance, form, and antirotational features. Since the system does not require a straight path of insertion, there is an intimate conformity to canal undercuts and morphologic irregularities. Resin research has also shown the ability of fabrics to limit the propagation of cracks within the composite resin.

In the selection of a fiberreinforced resin-bonded post system, sufficient coronal structure must be available within the canal to support adequate ferrule for the restoration and to resist shear forces during function. In thin or narrow canals, sufficient care must be taken to place the fiber fully into the resin matrix. Although operator placed fiber-reinforced resin-bonded systems are the least rigid of the aforementioned treatment options and are only faintly radiopaque, these posts can provide enhanced aesthetics when applied in certain clinical situations.

**Conclusion**

The aesthetic benefits of the highlighted systems have improved the practitioner’s ability to provide coronal restorations for materials through aesthetic intraradicular rehabilitation. In the selection of the appropriate system to address morphologic or aesthetic considerations, various risk factors that can contribute to material or dentin failure must
be considered. The primary risk factors that cause failure are rarely elucidated, and material limitations (e.g., retreatment options) are seldom identified. In combination, these risks and limitations can rapidly lead to breakdown and failure. The selected post and core technique must be conservative, morphologic, retentive, aesthetic, and resist radicular failure. Bonded, aesthetic systems have thus far had inspiring short-term outcomes (Figures 15 through 17). In addressing risk, canal morphology should assume a significant role in treatment considerations. Although large maxillary anterior teeth with sufficient radicular and coronal structure could support any of the aesthetic systems discussed herein, the reinforcement and structural requirements of narrow or structurally weakened teeth — as well as the technical manageability and conformability of the bondable system — must always be addressed. Since contemporary post designs and endodontic procedures alter radicular structure, the technology of adhesive science now offers new and creative solutions to a host of complex challenges.

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