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Design principles for the direct fibre-reinforced composite resin post and core system

Douglas Terry provides a model to assist in the development of the restorative equation

Restorative dentistry continually evolves with each development of a new material or technique. The use of models, in any industry, enables one to negotiate a design task by visualising the problem and then dissecting it into discrete, manageable units. Specific design principles bring us to higher levels of understanding potential problem areas in any restorative case. The purpose of this paper is to provide the clinician with a series of design principles, a model, to assist in the development of the restorative equation.

The system

A 'system' is defined as any set of components working together for the overall objective of the whole (Smith & Schuman, 1998). Selecting the proper post and core system for a specific clinical situation requires an evaluation of the various components and interfaces of the system (Blitz, 1998). The components of the direct fibre reinforced composite resin post system are the root dentine surface, intra-radicular post, core build up, luting cement and the crown (Chalifoux, 1998). The system can be analysed in four regions: at the intra-radicular surface (dentine surface), at the post-tooth interface, within the core, and intracoronally. For the successful rehabilitation of the endodontically treated tooth, it is imperative to understand the disparity and complexity of the inter-relation of these interfaces with various restorative materials (Freedman, 1996a). When evaluating the interfaces of any system, their failures provide us with design principles that can be utilised with any post-crown retained system. Therefore, the following design principles should be considered when using the direct fibre reinforced composite resin post system in the reconstruction of the tooth-restorative complex.

Maximum post retention and core stability

Dislodgement and tooth fracture are causes for failure of post and core restorations (Figures 1a to 1c). Core stability and post retention are important in preventing these failures in the restoration of endodontically treated teeth. The ideal post system should replace lost tooth structure while providing adequate retention and support to the core, allowing retention of the restoration while transferring occlusal forces during function and parafunction to prevent root fracture. The fibre reinforced composite resin post utilises the internal anatomy, surface area and irregularity, to increase the bonded interfaces which can improve the structural integrity of the remaining radicular dentine and increase the retention and resistance to displacement (Freedman, 1996a; Freedman, 1996b; Freedman et al, 1994).

Conservation of tooth structure

Traditional cast post systems and prefabricated post systems often require the removal of undercuts for a proper path of insertion and adaptation to the canal wall. This enlargement of the post-endodontic channel throughout biomechanical preparation during and after the endodontic procedure removes dentine for access to the canals. This reduction in the amount of dentine weakens the tooth (Trope, Maltz & Troustand, 1985) and can be responsible for horizontal and vertical root fracture. Improvements in composite materials and adhesive technology have resulted in a more conservative design concept. The fibre reinforced composite resin post allows preservation of the canal structure and is a method that can be utilised in the treatment of irregular canal configurations, because it does not require a converging path of

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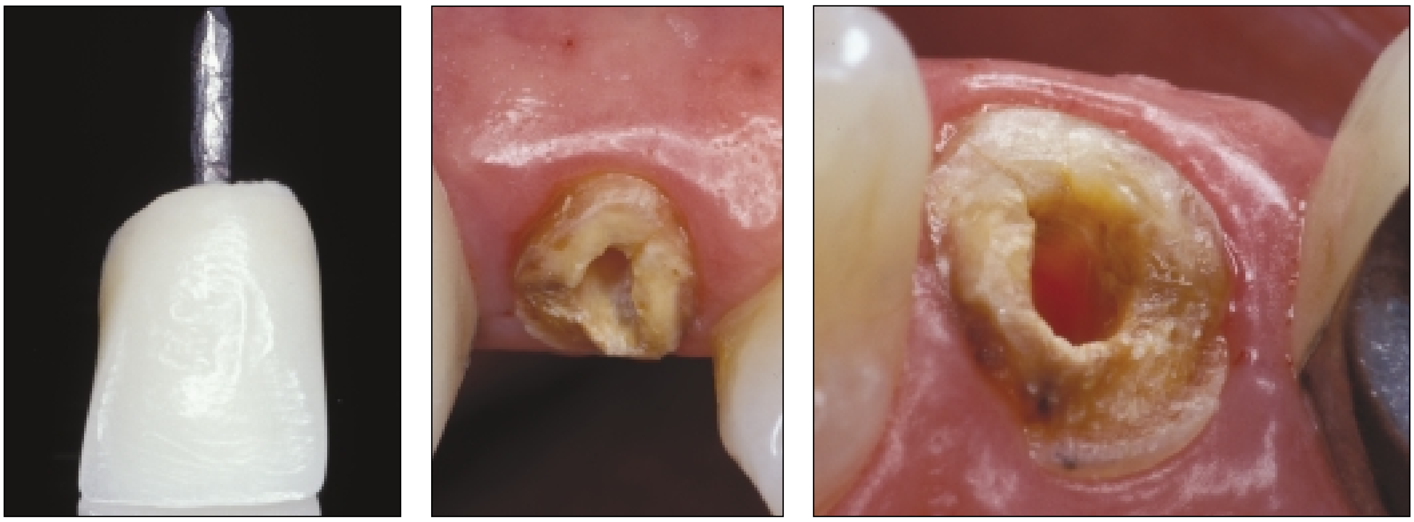


/Figures 1a to 1c: Failure from dislodgement of a post-retained system

insertion and can be used with minimal preparation since it utilises the undercuts and surface irregularities to increase the surface area for bonding. This conservation of dentine reduces the possibilities of tooth fracture during function or in the event of traumatic injury (Trabert, Caput & Abou-Raas, 1978).

INTERNAL ADAPTATION

Conventional luting cements, such as zinc oxysphosphate, only fill in the void between the restorative interfaces without attaching to either surface (Freedman, 1996a). The use of a dual-cure luting agent with the fibre-reinforced composite rein post has a physical and potentially a chemical interaction with the reinforcement material and the dentine that enhances the adhesive interfacial continuity. The use of the composite resin cements between the adhesive system and the reinforcement material ensures a more intimate contact with the dentine bonding agent because of lower viscosity and results in enhanced morphologic intraradicular adaptation (Goracci & Mori, 1996). The low modulus composite acts as an elastic buffer that compensates polymerisation shrinkage stress by flow, eliminating gap formation and reduced microleakage (Prager, 1997). If the elastic modulus is low, the composite will stretch to accommodate the inherent modulus of the tooth.

Figure 2: Cast metal post systems completely block the incidental light causing the characteristic shadow at the submarginal zone

Also, the lower viscosity resin cements may enhance the wetting capacity resulting in a more complete interfacial internal adaptation, reducing void formations which can contribute to a weakened surface and microleakage (Frankenberger et al, 1999). Therefore, the use of a resin luting cement to line and strengthen the canal walls actually reinforces the root and supports the tooth-restorative complex (Sirimai, Riis & Morgano, 1999; Lui, 1987).

OPTIMAL AESTHETICS

When aesthetics is of primary concern, the selection of appropriate restorative materials becomes an important consideration factor. The light transmission properties of traditional prefabricated or cast metallic posts are different from those of the natural dentition. The incidental light is completely blocked by the metal post, which causes the characteristic shadow at the submarginal zone (Yamamoto, 1985) (Figure 2). When using an all-ceramic restoration, the colour and opacity of the metal post may lead to discoloration and shadowing at gingiva and the cervical region of the tooth (Vichi, Ferrari & Davidson, 2000; Tamse, 1988).

The secondary optical properties (e.g. translucency, opacity, opalescence,

Figure 3: Transmission of occlusal forces through the metal core can focus on stresses at specific regions of the root causing root fracture. Note gutta percha reveals point of fracture and fistula present

Figure 4: The fibre-reinforced composite resin post system provides an adhesive integration of all interfaces

Figure 5: Failure of post-crown retained system

iridescence, and fluorescence) of composite resin allow the optical properties of light passing through the natural tooth and the restorative material to reflect, refract, absorb, and transmit according to the optical densities of the hydroxyapatite crystals, enamel rods and the dentinal tubules (Winter, 1993). Therefore, in creating optimal aesthetic harmony with the surrounding dentition, the underlying restorative material can directly influence the final restoration.

RESISTANCE TO CATASTROPHIC ROOT FAILURE

Root fracture is another reason for failure of the post and core system (Purton & Payne, 1996; Asmussen, Peutzfeldt & Heitmann, 1999). The primary goal of restoring endodontically treated teeth is to develop a design which distributes occlusal stress uniformly, while preserving the tooth structure if the restoration fails during occlusal stress or dental trauma. Traditional cast posts have a modulus as high as 10 times greater than that of natural dentine (Freedman, 1996a). This possible incompatibility can create stress concentrations in the less rigid root, resulting in post separation or failure. Additionally, the transmission of occlusal forces through the metal core can focus stresses at specific regions of the root, causing root fracture (Freedman, 1996a) (Figure 3). The fibre-reinforced composite resin post has negligible root fracture and studies indicate that dentine-bonded resin post core restorations provided significantly less resistance to failure than cemented custom cast posts and cores and that the dentine-bonded resin posts and cores fractured in every instance before the roots fractured (Bex et al, 1992).

Also of concern in the structural design is the ability to retrieve the direct fibre-reinforced composite resin post. This material is easy to cut intraorally with a diamond, and to remove from the canal for retreatment unlike ceramic post systems (Asmussen, Peutzfeldt & Heitmann, 1999).

LACK OF CORROSIVENESS

The combination of noble and non-noble alloys in the oral environment may result in electrochemical reactions such as corrosion of metals. This can result in destruction and breakdown of these materials and also cause interaction between the biological host environment and the released corrosion products (Arvidson, 1978). Traditional pre-fabricated posts are made of metal alloys, and root fracture has been attributed to corrosion products resulting from possible galvanic activity between the amalgam core and stainless steel or brass in posts (Purton & Payne, 1996; Smith & Shuman, 1998). Another structural design benefit that adds to the applicability of the fibre-reinforced composite resin system is the corrosion resistance and the compatibility of the restorative materials.

ANTIROTATION

Posts can be subjected to rotational forces from occlusion. Rotational forces can be resisted by slotting the most coronal internal position of the post channel or preparing rounded indentations adjacent to the post space.

When considering the core build up, the preparation design influences the stability of the crown by preventing crown rotation. The anti-rotational feature of the post and core complex requires the placement of a 2mm ferrule around the circumference of the preparation on sound tooth structure (Christensen, 1993; Christensen, 1996; Christensen, 1998; Paul & Schärer, 1997). Clinical studies have demonstrated and confirmed the importance of this coronal tooth ‘collar’ on the mechanical resistance of the endodontically restored tooth complex (Dietschi, Romelli & Goretti, 1997; Rosen & Partida-Rivera, 1986; Barkhordar, Radke & Abbasi, 1989; Hemmings, King & Setchell, 1991).

MODULUS OF ELASTICITY SIMILAR TO ROOT DENTINE

The elastic modulus defines the relative stiffness of the restorative material within the elastic range (Combe et al, 1999). It also has been described as the ratio of uniaxial stress to strain in a structure or restorative material at small strain levels (Watts, 1994). The ideal restorative design for a post system requires the modulus of elasticity of the system to be similar to that of the dentine (King & Setchell, 1990). As has previously been indicated, the traditional metal posts have a high modulus of elasticity (Assif et al, 1989), whereas the fibre-reinforced post system has a modulus similar to that of the dentine. Natural hard tissue has a range of elastic moduli values and the addition of restorative material with different moduli value can affect the total stiffness of the tooth- restorative complex and

Figure 6: Removal of gutta percha with a Gates-Glidden drill

Figure 7: The preparation was etch for 15 seconds with 37.5% phosphoric acid semi-gel (Gel-Etchant, Kerr/Sybron, Orange, CA)

result in a generation of interfacial stresses. This interfacial stress resulting from the discrepancy in modulus mismatch may result in thermal, mechanical, or shrinkage strain in the restorative material (Combe et al, 1999; Watts, 1994). The fibre-reinforced composite resin post system has several advantages that can be afforded to the complex mechanism between polymerisation shrinkage and adhesion. Since the elastic modulus of the adhesive and resin cement is low, the composite will stretch to accommodate the inherent modulus of the tooth. Therefore, the internal layer may absorb polymerisation shrinkage stress of the resin composite by elastic elongation (Lindberg, van Dijken & Horstedt, 2000; Van Meerbeek et al, 1998). These factors which diminish and distribute the stresses to the remaining dentinal structures reduce the likelihood of post separation or root fracture, therefore improving the clinical success rate of the restorative complex (Freedman, 1996a).

FLEXURAL AND TENSILE STRENGTHS SIMILAR TO ROOT STRUCTURE

Both the design and restorative material affect the resistance to fracture of endodontically treated teeth restored with post and core systems (Akkayan & Gulmez, 2002; Sorenson & Martinoff, 1984). An outstanding characteristic of a post system is to have biomechanical properties similar to those of the host dental tissue (Akkayan & Gulmez, 2002; Tjan, Grant & Dunn, 1991). Metal posts are isotropic, meaning they have an homogenous structure that has properties that are the same in all directions measured (i.e. conductivity, speed of transmission of light, etc). Whereas, the fibre-reinforced composite is anisotropic, meaning it has properties that vary according to the direction in which they are measured. The mechanical properties of fibre-reinforced composite materials depend on the load direction and the structure of the materials. The fatigue behaviour of the anisotropic fibre-reinforced composites is also very different than the homogenous material. In a homogenous material under fatigue loading, a crack once initiated, often propagates quickly, thus leading to sudden failure of the material. The microstructure of anisotropic materials influences the fatigue behaviour and the damage processes in composite materials are complex, consisting of matrix cracking, delamination, interface debonding, fibre bending or breakage, or a combination of these events (Torbjörner et al, 1996).

The reinforcement material used for the fibre-reinforced composite resin post consists of polyethylene woven fibres that are treated with cold-gas plasma. These reinforcement fibres enhance the mechanical properties of the tooth-restorative complex by increasing flexural and tensile strengths (Miller, 2000). Various manufacturers use several types of weaves and these can influence strength, stability, and durability. The leno weave of Ribbond reportedly resists shifting and sliding under tension more than a plain weave, minimising crack propagation by reducing the coalescence of micro-cracks within the resin matrix into cracks that could lead to failure of the restorative complex. This composite reinforcement fibre network provides an efficient transfer of stress within the internal framework by absorbing the stresses that are applied to the restorative complex and redirecting those forces along the long axis of the remaining root structure, thereby minimising the risk of root fracture (Freedman, 1996a; Freedman, 1996b; Duret, Reynaud & Duret, 1990).

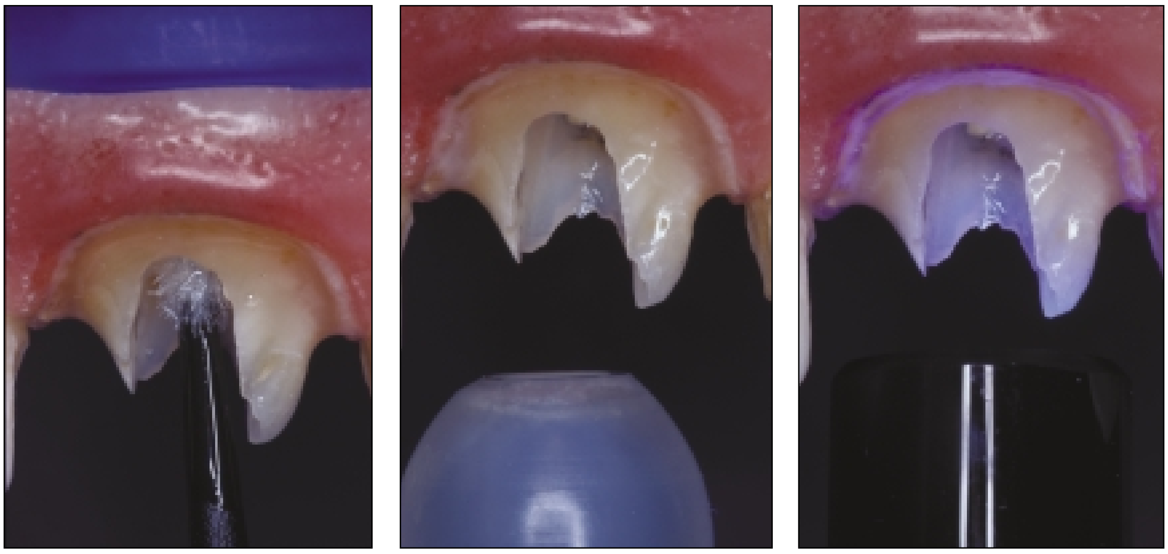
UNINTERRUPTED BONDING AT ALL INTERFACES

As has been mentioned in the previous discussion on internal adaptation, conventional luting cements, such as zinc oxysphosphate, only fill in the void between the restorative interfaces without attaching to either surface (Freedman, 1996a). The fibre-reinforced composite resin post system provides an uninterrupted bonding at all interfaces, resulting in increased resistance to fatigue and fracture, enhanced retention and a reduction in microleakage and bacterial infiltration. This adhesive integration between the five components of the direct fibre-reinforced composite resin system (the root dentine surface, luting cement, intra-radicular post, core build up, and the crown) provides a structural integrity for intraradicular rehabilitation (Freedman, 1996a; Freedman et al, 1994) (Figure 4).

The following restorative sequence illustrates the use of these design principles in the fabrication of the direct fibre-reinforced composite resin post for the rehabilitation of the intraradicular anatomy of the post-endodontic channel on a maxillary right central incisor (Figure 5).

RESTORATIVE MATERIAL SELECTION

The insight offered by the integration of the design principles with restorative materials and adhesive techniques has altered post design preparation and resulted in the introduction of a simplified ‘one- visit’ post and core restorative option. This method of post fabrication utilises a bondable



Figures 8a to 8c: The single component adhesive agent (Optibond Solo Plus, Kerr/Sybron, Orange, CA) was applied in a continuous motion for 20 seconds, air thinned for 5 seconds, and light cured for 20 seconds

reinforcement fibre (Ribbond, Seattle, WA; Construct, Orange, CA) as the post material , a fourth generation bonding agent (Optibond, Kerr, Orange, CA) a dual-cure hybrid composite (Nexus II, Kerr/Sybron, Orange, CA) as the luting agent and a dual-cure hybrid composite (CoreRestore2, Kerr/Sybron, Orange, CA) as the core build-up.

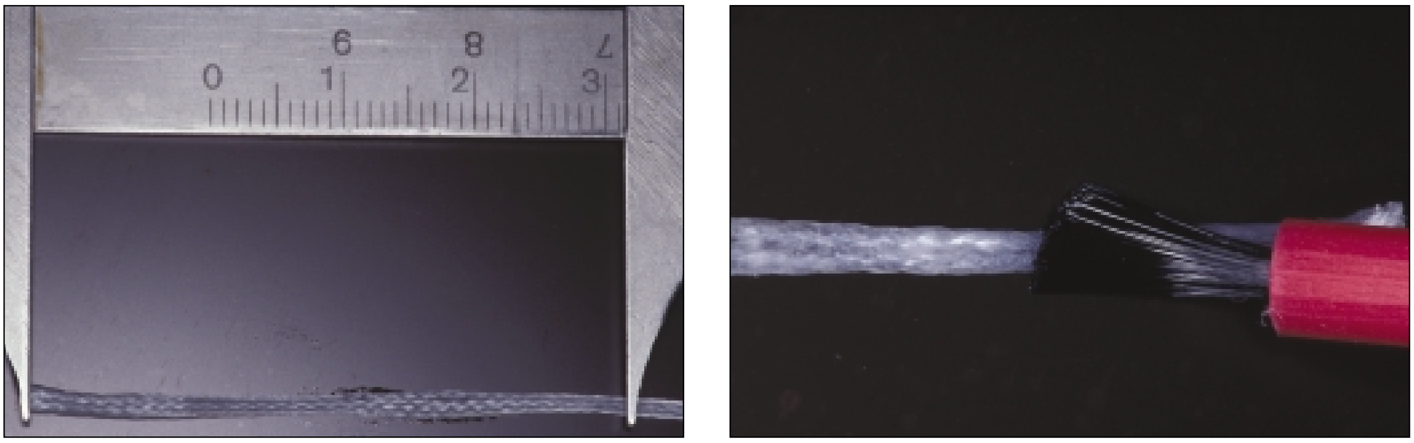
The reinforcement material used for the post consists of polyethylene woven fibres that are treated with cold -gas plasma. This treatment creates a lower contact angle with the wetting resin and provides a greater bonded surface area to enhance the adhesion to any synthetic restorative material (Hornbrook & Hastings, 1995). These reinforcement fibres enhance the mechanical properties of the tooth-restorative complex by increasing flexural and tensile strengths (Miller, 2000; Rudo & Karbahari, 1999). The cross-linked lock stitch Leno weave reportedly minimises crack propagation by reducing the coalescence of micro-cracks within the resin matrix into cracks that could lead to failure of the restorative complex. This fibre network also provides an efficient transfer of stress within the internal fibre framework by absorbing the stresses that are applied to the restorative complex and redirecting those forces along the long axis of the remaining root structure (Freedman, 1996a; Freedman, 1996b; Duret, Reynaud & Duret, 1990).

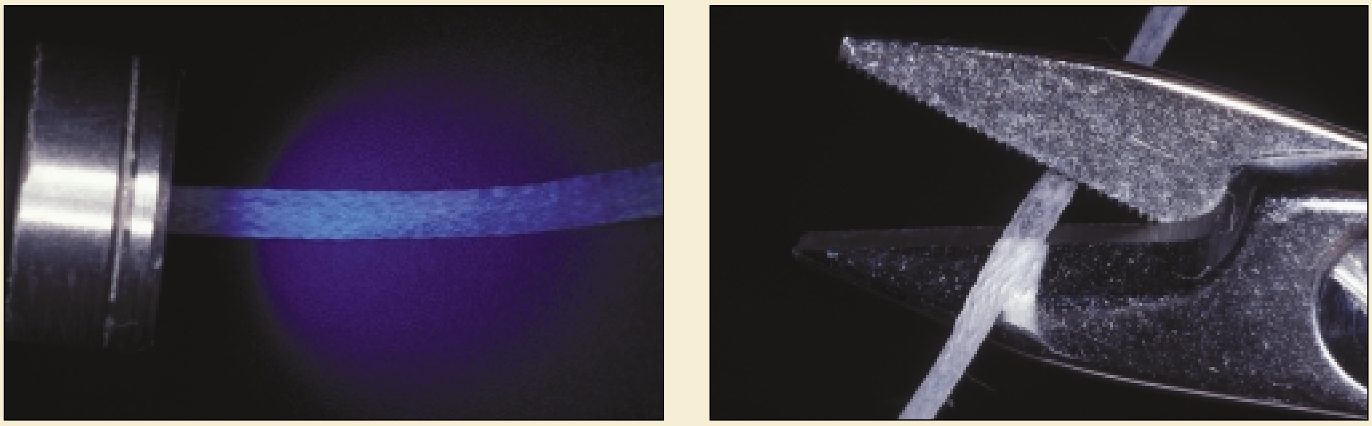
RESTORATIVE SEQUENCE

After placement of the rubber dam to isolate the area, and upon the completion of endodontic therapy, the gutta-percha and any root canal sealer adhering to the walls of the canal is removed with a heated instrument, or a #3 Gates-Glidden drill (Figure 6) (Torbjörner et al, 1996). The depth of the post space is prepared to approximately the height of the final coronal preparation. It is not necessary to eliminate undercuts as in the conventional preparation, because the additional surface area enhances adhesion. The remaining tooth structure is acid-conditioned with a 37.5% gel etchant for 15-30 seconds and the post channel is rinsed thoroughly. (Figure 7) For a hydrophilic adhesive, the dentine substrate should remain moist, and any excess moisture in the post space is removed with endodontic paper points. The adhesive is applied in a continuous motion reapplying every five seconds for 20 seconds with a micro applicator, and using saturated endodontic paper points to facilitate placement of the resin to the base of the post space and to remove any excess (Figures 8a to 8c). The adhesive (e.g., OptiBond, Kerr) is gently air dried for five seconds and light-cured for 20 seconds. If the post space preparation is deeper than 4mm, a dual-cure adhesive is recommended.

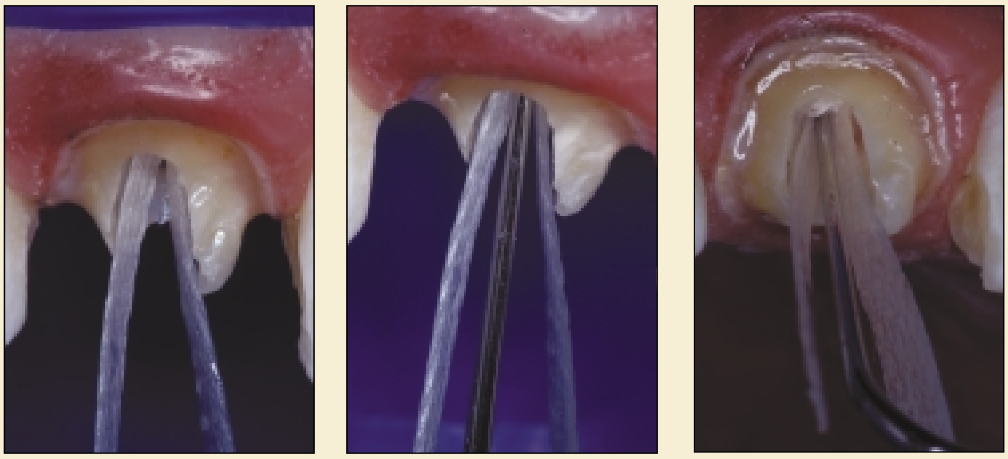
The reinforcement fibre is supplied in various widths including 1mm, 2mm, 3mm, 4mm and 9mm, depending on the manufacturer. The most frequently used is the 2mm width; however a 3mm width may be used in a larger post space. The appropriate length of

Figures 9a & 9b: The appropriate length of the fibre is measured and coated with an unfilled light-cured resin-bonded adhesive





Figures 10a & 10b: The resin is polymerised for 20 seconds and cut with a supplied shear



Figures 11a to 11c: A rehearsal of the placement of the fibre in the post channel

the fibre is determined by folding the material once in the canal and folding back on each end, which is approximately six times the height of the anticipated preparation. The plasma-coated fibre ribbon is measured and coated with an unfilled light-cured resin bonding adhesive or a composite sealant and the excess is removed with a lint-free 2x2 gauze. (Figures 9a & 9b) The resin is light-cured for 20 seconds and the fibre is cut with a supplied shear (Figures 10a & 10b). A special cotton glove should be worn while handling the ribbon until the resin has been applied and polymerised. The plasma coating on the fibre should not be contaminated with oils from the fingers or compounds from the latex or vinyl gloves because this can disturb the plasma coating and decrease the bond strength (Duret, Reynaud & Duret, 1990). Recently, a new polyethylene braid has been introduced, (Construct, Kerr) which is impregnated with resin and can be handled by fingers without the use of gloves.

Before placing the adhesive or resin cement, a rehearsal of the placement of the fibre in the post channel is recommended (Figures 11a to 11c). The fibre is transported to the base of the post space with a modified Luk's gutta percha condenser, which has a V-shaped groove across the end.

A dual-cure composite or resin cement (Nexus 2, Kerr/Sybron, Orange, CA) is injected into the post channel with a needle tube syringe (Centrix, Shelton, Connecticut) (Figure 12). The resin material should flow easily and the working time should be as long as possible. It is important to place the tip at the base of the post space and the resin material is injected as the syringe tip is slowly removed. This technique reduces the possibility of entrapping air bubbles and ensures optimal adaptation of the resin material to the

Figure 12: A dual cure composite or resin cement is injected into the post channel with a needle tube syringe

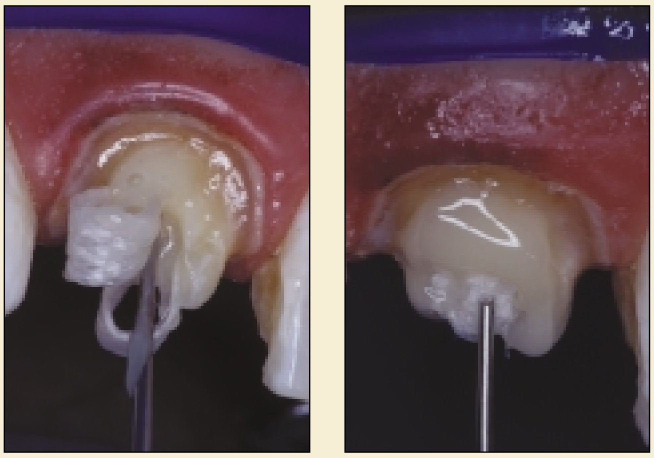


Figure 13a & 13b: The fibre is immediately inserted into the posthole and the folded ends are arranged into the desired shape of the core

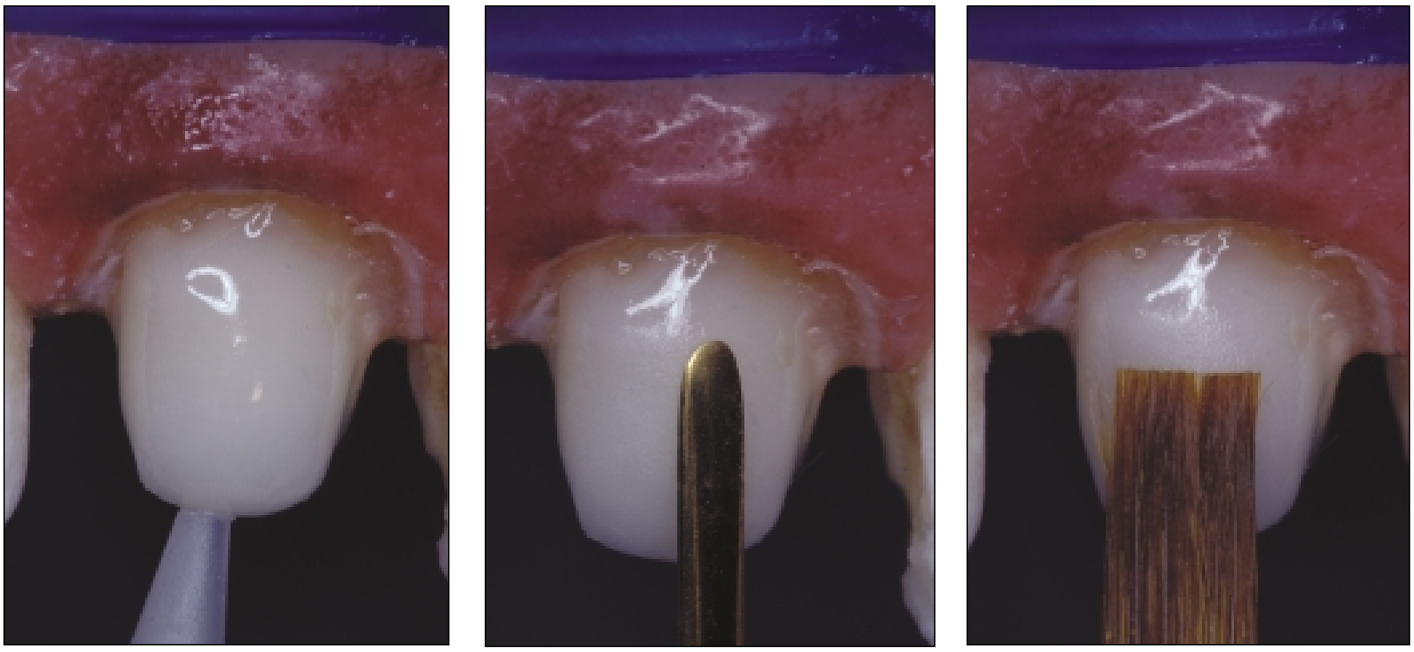


Figure 14a to 14c: A dual-cure or light-cured composite is injected with a over the coronal fibres, sculpted and smoothed to an ideal coronal preparation dimension

posthole preparation. The fibre is immediately inserted into the posthole with the modified Luk's gutta percha condenser and the fibre is folded over so that the ends are pointing back into the post channel and between the emerging ends of the fibre. The folded ends are arranged into the desired shape of the core and light-cured for 60 seconds (Figure 13a & 13b).

A dual-cure or light-cured composite (CoreRestore 2, Kerr/Sybron, Orange, CA) is applied freehand or injected with a needle tube syringe over the coronal fibres to an ideal coronal preparation dimension (Figures 14a to 14c). In the preparation and finishing of the fibre-reinforced resin core (Figures 15a & 15b), a 2mm circumferential ferrule is placed on sound tooth structure, which enhances the mechanical retention and resistance of the endodontically restored tooth complex (Christensen, 1998; Christensen, 1993; Paul & Schärer, 1997; Christensen, 1996). The entire preparation is lightly lubricated with glycerine before the final impression is taken. The final postoperative view reflects the results of meticulous utilisation of design principles for the successful rehabilitation of the intraradicular space (Figure 16).

CONCLUSION

Preparing for a restorative procedure using newly developed materials and techniques requires more than a rudimentary understanding of them. A model or series of design principles guides the clinician to a higher level of understanding of the proper adaptation and the potential problem areas. These fundamental design principles provide a framework or model by which one can ensure a successful restoration, giving detailed comprehension to what may seem an otherwise overwhelming incomprehensible situation.

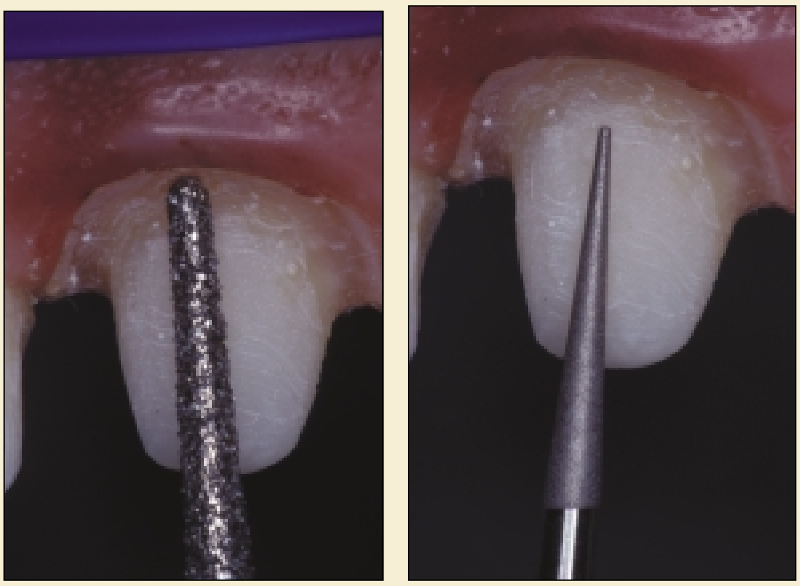


Figure 15a & 15b: Preparation and finishing of the fibre-reinforced resin core

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Figure 16: A circumferential ferrule 1-2mm is placed on sound tooth structure, which enhances the mechanical retention and resistance

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Q1
The fibre-reinforced composite resin post uses what to increase the bonded interfaces?
a) Internal anatomy
b) Surface area
c) Irregularity
d) All of the above

Q2
Traditional cast posts have a modulus how many times greater than dentine?
a) 10
b) 20
c) 30
d) 40

Q3
The internal layer may absorb polymerisation shrinkage stress of the resin composite by:
a) Elastic elongation
b) Photo polymerisation
c) Chemical polymerisation
d) Microscopic interweave pattern

Q4
The fibre-reinforced composite is:
a) Brittle
b) Dense
c) Anisotropic
d) Isotropic

Q5
In a homogenous material under fatigue loading, a crack when initiated often:
a) Propagates quickly
b) Is self-limiting
c) Propagates 90º to the surface
d) Propagates 45º to the surface