# BIOMECHANICAL PROPERTIES AND CLINICAL USE OF A POLYETHYLENE FIBRE POST-CORE MATERIAL

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The development of fibre-reinforced composite (FRC) technology has led to substantial improvement in the flexural strength, toughness and rigidity of dental resin composites. A number of materials for this type of reinforcement such as carbon, graphite, glass, Kevlar as well as other types of fibre have been considered and appropriate techniques for their use have been investigated. The findings of these studies have shown that both strength and fracture toughness can be increased as a result of their incorporation[1]. This increased toughness has been attributed to the transfer of stress from the weak polymer matrix to the fibres that have a high tensile strength[2].

Ultra high strength polyethylene (UHSPE) fibres with higher specific strength, fracture toughness and chemical resistance than carbon, glass or Kevlar fibres were the next materials to be evaluated. It was found that the polyethylene fibres that were used initially were not satisfactory. UHSPE fibres are known to have a low melting point, high creep and, most importantly, a polyolefin backbone. An adequate interface bond between the fibres and various matrix resins is therefore difficult to achieve[3, 4]. They exhibit poor wetting properties and are difficult to bond because of low surface energies. Chemical inertness and the complete absence of polar groups on the fibres are additional factors[4].

Different surface enhancements such as plasma spraying, flame and radiation treatment were then studied to improve the properties of the material. Chemical exposure to chromic acid or sulphonic acid invariably resulted in a significant loss of fibre strength[5]. The addition of cold gas plasmas significantly improved adhesion of UHSPE fibres with epoxy matrices and higher interfacial shear strengths of plasma treated UHSPE fibres with PMMA was obtained[4,6]. In a plasma process, gas molecules are dissociated into an equal number of ions and electrons, free radicals and some neutral species under a strong electromagnetic field. The resulting species are highly energetic and can readily react with the substrate, modifying its surface[7].

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## Ribbond

A ribbon reinforcement material, Ribbond, (Ribbond Inc., Seattle WA) has been available commercially since 1992. This material is composed of pre-impregnated, silanized, plasma treated, leno-woven, ultra high molecular weight (UHMW) polyethylene fibres. Leno-weave is a special pattern of cross linked, locked-stitched threads which increase the durability, stability and shear strength of the fabric[8]. The open and lace-like architecture of the leno-woven ribbon allows it to adapt closely to the contours of the teeth and dental arch. The dense network of locked nodal intersections of the material reduces the potential for damage to the fabric architecture by preventing the fibres from shifting during manipulation and adaptation before polymerization. The material has a three dimensional structure due to the leno weave or triaxial braid (Figure 1). These features provide mechanical interlocking of the resin and composite resin at different planes, thereby enabling a wide processing window. In addition, micro-cracking is minimised during polymerization of the resin.[9]

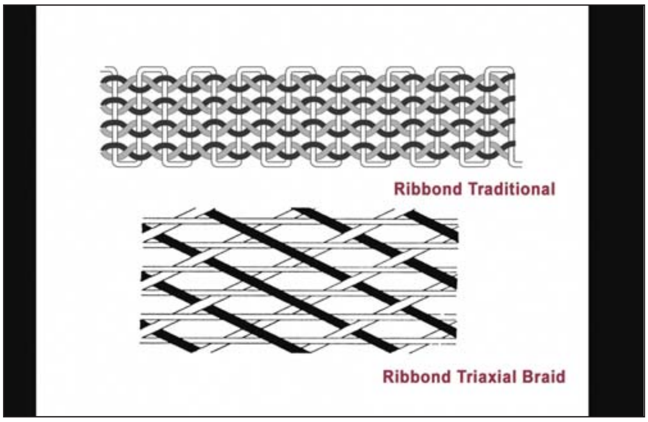


***Figure 1. Schematic representation of Ribbond Traditional and Ribbond Triaxial.***

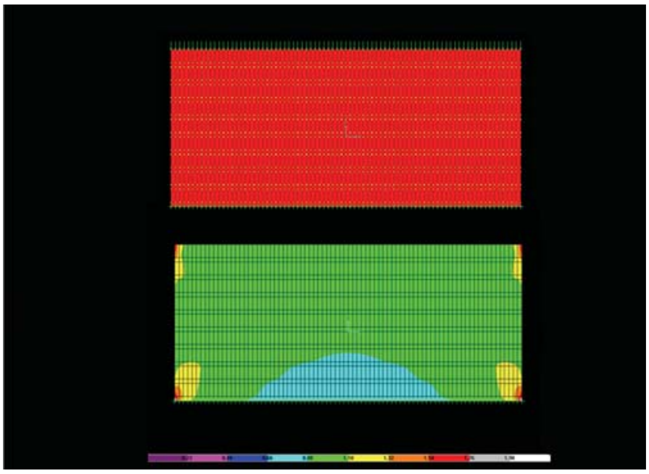

*Figure 2. Stress distribution in the model representing unidirectional fibre design. All nodes at the bottom border of the model have been constrained. Load has been applied to all the nodes at top border of the model. An increased stress is observed in the corners (red–yellow;1.1-1.75 MPa). A homogenous stress distribution is observed all around the model (green; 0.88-1.1 MPa). This stress is reduced at the bottom of the model (blue; 0.66-0.88 MPa).*

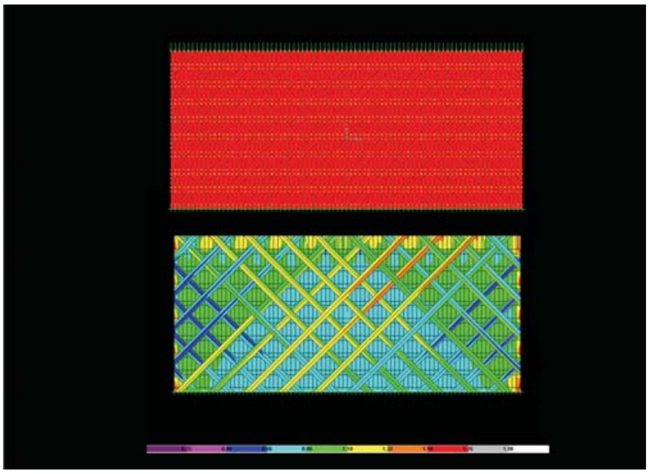

*Figure 3. Stress distribution in the model representing diagonal type fibre design (Ribbond Triaxial). The colour scale indicates that stress is reduced throughout the model when compared to Figure 2. Diagonal fibres appear to absorb stress (yellow; 1.1-1.32 MPa).*

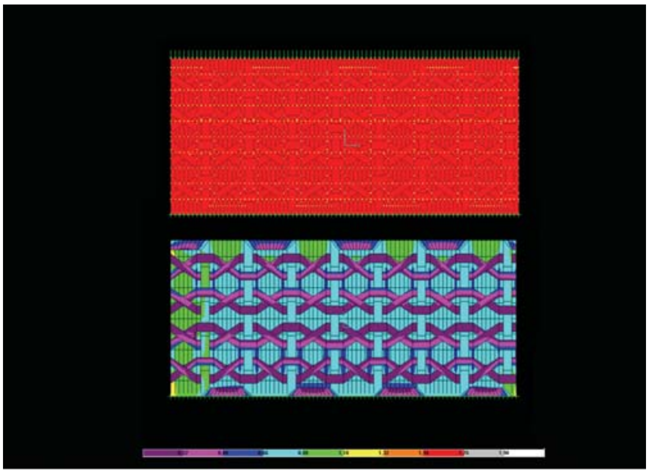

*Figure 4. Stress distribution in a model representing leno weave-type fibre design with a lock-stitch feature (Ribbond Traditional). The stress values which were obtained in Figure 2 and 3 are reduced by 30% in this model (From 1.3MPa to 0.8 MPa). The high stress areas (green) are reduced and low stress areas (blue & violet) are increased when compared to the previous two models.*

## Micro-crack minimization and the reinforcement effect of UHMW polyethylene fibre

Fibre-reinforced restorations have an acceptable success rate[1,2]. The physical properties of the materials used for these restorations are dependent on the type of composite material, the position, quantity, direction and form of the fibres, the fibre/matrix ratio, distribution of the fibres in the matrix and impregnation of the fibres with the polymer matrix[2,10-13]. Application of a fibre layer in a restorative material might increase the load bearing capacity of the restoration and could prevent crack propagation from the restoration to the tooth. Fibre reinforced composites (FRC) effectively withstand tensile stress, and woven continuous FRC's have the potential to provide more consistent properties than unidirectional fibres because of the three dimensional structure resulting from the leno weave or triaxial braid[14].

The successful design of any structure requires in-depth analysis to predict and accommodate the stresses that will develop under anticipated applied loads[15]. The Finite Element Stress Analysis Technique allows the stress values throughout the structure under consideration to be measured accurately. Finite element analysis of FRC models have indicated that reinforcement with leno-weave polyethylene fibre (Ribbond Traditional) designed with a lock-stitch feature reduces stress values when compared with the unidirectional or diagonal (Ribbond Triaxial) type fibre designs under loading.[16] (Figure 2-4). Fibre design has a significant effect on both stress value and stress distribution and should therefore be taken into consideration when placing fibre reinforced restorations.

When models are evaluated under laboratory conditions, structural failure of fibre reinforced materials generally occurs as a result of fibre fracture, matrix fracture or fibre-matrix interfacial bond fracture[17]. In a typical application, the load is transferred from one fibre to another via the interface and matrix. When a fibre breaks, a strong interface is needed for the redistribution of loads from the broken fibre to the surrounding fibres in the matrix[4]. If the fibre is unconstrained

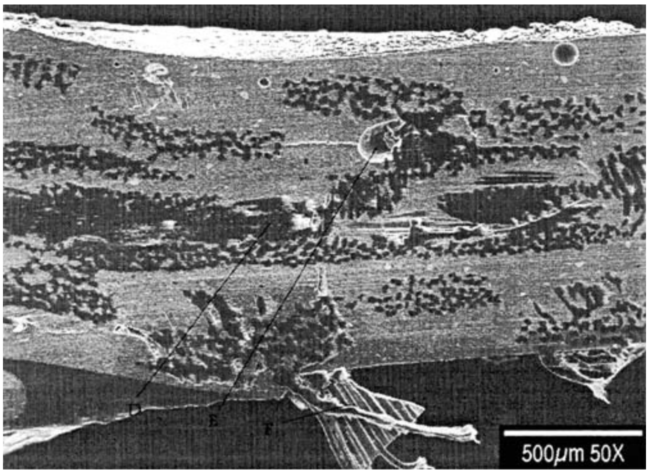


*Figure 5. SEM image of composite resin reinforced with polyethylene fibre. fibre and horizontal crack in resin stopping at fibre (arrows) (With permission of Brendan F. Grufferty) [66].*

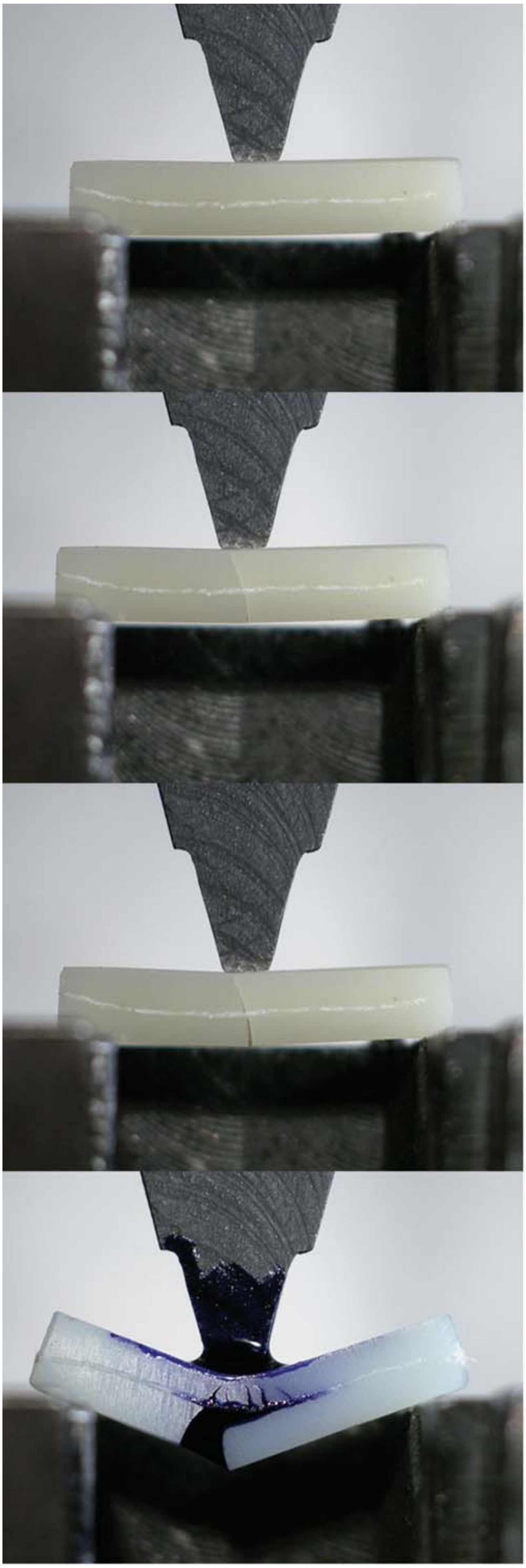

***Figure 6. Failure of a Ribbond reinforced composite resin block under loading: a) A compressive load applied to the central of the resin block using a universal testing machine at a cross speed of 0.5mm/min; b) The crack hits the plane of the fibre reinforcement and a vertical crack is shown causing debonding along the fibre-resin interface towards the right; c) The crack continues to grow along the horizontal plane; d) The top half starts to crack as well but the thickness of the material prevents rupture.***

and is not obstructed along its length, a crack will traverse the entire length of the material resulting in substantial weakening. If the circumferential crack reaches a weak segment of the fibre, the fibre will break and disconnect (Figure 5)[18]. The use of transverse fibres such as those found in a leno-weave or triaxial braid limits the extension of this process between two sets of fibres.

When a composite sample without fibre reinforcement is placed in a flexure, cracks appear on the tensile face and, due to the brittleness of the material, rapidly propagate causing failure. When a fibrous ribbon is placed in the composite resin, the fibres serve as crack stoppers and toughening agents and they provide a set of interfaces that prevent rapid crack growth. Minor cracks that do occur are constrained within areas subtended by interwoven fibres which then restrict their growth to small dimensions. Once the crack reaches the plane of the fibrous reinforcement, its forward path is blunted and it propagates along the weaker interface causing it to change direction (Figure 6). The use of UHMW reinforcement polyethylene fibres in polymethyl methacrylate-based provisional restorations prevents major crack propagation and this therefore becomes an effective method for the reinforcement of interim restorations[19].

## Polymerization shrinkage reducing effect of UHMW polyethylene fibre

During the restoration of teeth, there can be appreciable loss of tooth structure including anatomic features such as cusps, ridges and the arched roof of a pulp chamber. As this loss could weaken the tooth, preservation of tooth structure is important for protection under occlusal loading. Unlike amalgam, bonded composite restorations usually strengthen the tooth. However, polymerization shrinkage remains a problem in extensive direct restoration with composites[20]. Modifications that would reduce or eliminate the interfacial stress concentration within the composite restoration may increase the bond strength by increasing the force required to create and propagate a crack through the interfacial composite/adhesive bonding resin complex. The layer of collagen fibrils densely packed with resin may act as an inherent elastic buffering mechanism to compensate for the polymerization contraction of the restorative resin[21]. The hybrid layer provides a stress modifying effect under composite or ceramic restorations[22]. Although the application of a low modulus intermediate resin between the bonding agent and the composite resin might relieve contraction stresses and improve marginal integrity[23,24], flowable composites are unable to produce gap-free resin margins in Black Class II slot cavities[25].

The elastic modulus of UHMWPE fibre was previously shown to be 1397 MPa. However, in clinical conditions UHMWPE fibre Ribbond is used in combination with flowable resin and an adhesive resin, resulting in the elastic modulus increasing to 23.6 GPa[26]. The higher modulus of elasticity and lower flexural modulus of the polyethylene fibre are believed to have a modifying effect on the interfacial stresses developed along the etched enamel/resin boundary[27]. Embedding a LWUHM polyethylene fibre into a bed of flowable resin under an extensive composite restoration increases both the fracture strength in root filled molars with MOD cavities[28] and the microtensile bond strength to dentin[29], but decreases microleakage in cavities with a high c-factor[30]. LWUHM polyethylene fibre's dense concentration of fixed nodal intersections assists in maintaining the integrity of the fabric enabling the stresses in the bulk of the material to be transferred more effectively due to well defined load paths from one area to another.

## Clinical use of LWUHM polyethylene fibre

Ribbond is a colourless and pliable material which adapts readily to tooth morphology and dental arch contour. Its translucency allows aesthetic restoration and it can be cured with light-cured composites. Three different forms of UHMW Polyethylene fibre Ribbond are commercially available: Original Ribbond, Ribbond THM and Ribbond Triaxial. Both Original Ribbond and Ribbond THM consist of cold plasma treated polyethylene fibres but the latter differ in shape and thickness. During applications in which the final fibre breaking strength is of primary concern, Original Ribbond is recommended. Its 0.35 mm thickness can be increased with the addition of filled composite over the fibre during the creation of direct adhesive restorations which do not require tooth preparation. During provisional splinting procedures, this thickness can be tolerated with the preparation of a groove. However in temporary splinting cases, this could cause an occlusion problem especially on the palatal surfaces of the upper incisor teeth. Ribbond-THM was consequently developed with a higher concentration of thinner (0.18mm diameter) fibres. It was designed for use with applications in which thinness, adaptability, smoothness and a higher modulus were the primary concerns. The primary indications for Ribbond THM are the same as for Original Ribbond, i.e. periodontal splinting[31], conservative treatment of cracked tooth syndrome[32], the creation of fixed partial dentures[33,34], trauma stabilization, orthodontic fixed lingual retainers or space maintainers[35] as well as directly bonded endodontic posts and cores[36] Its composition utlizes pre-impregnated, silanized, plasma treated polyethylene fibres.

Ribbond Triaxial was developed subsequently. Its structure is a hybrid of unidirectional and braided fibres forming a double layered triaxial ribbon and consists of cold plasma treated polyethylene fibres. This material provides greater multidirectional fracture toughness and a greater modulus of elasticity than the other Ribbond products[37]. Where fracture toughness is the primary concern, Ribbond-Triaxial is indicated. However the thickness of the material requires tooth preparation in order to conserve tooth contour.

## The use of Ribbond as a post-core material

Early post techniques were quick, inexpensive and simple[38]. These posts were usually cast in a precious alloy or prefabricated in stainless steel, titanium or precious alloy. However, they did not take into account the individual shape of the root canal and, as a result, their adaptation was not ideal[39]. A post core system should include components of differing rigidity. Because the more rigid component is able to resist forces without distortion, stress would be transferred to the less rigid substrate. The difference between the elastic modulus of dentin and that of the post material may therefore be a source of stress to the root structures.

Fibre reinforced composite root canal posts with an elastic modulus close to that of dentin were introduced in the 1990's[40,41]. They were found to reduce the incidence of root fracture[42,] and, in the case of endodontic retreatment, they could be removed from the root canal with ease and predictability without compromising core retention[43]. Glass fibre-supported resin dowel systems comprising unidirectional glass fibres in a resin matrix were introduced in 1992[44]. These materials were able to distribute stress over a broad surface area thus increasing the load threshold at which the dowel began to show evidence of microfracture[45].

***Figure 7. Ribbond composite laminate post core build-up adapts accurately to the root morphology. (Photo: Ribbond Inc. Seattle WA).***

*Figure 8. A fractured right central incisor requiring a post restoration. A rubber dam is applied for the isolation of the tooth preparation.*

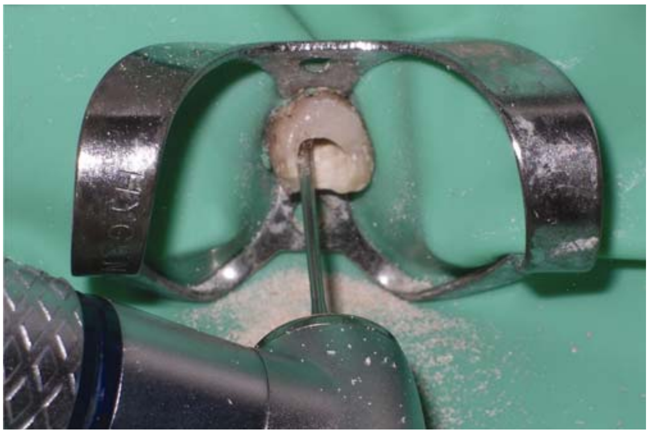

*Figure 9. Removal of the gutta percha using a Gates Glidden drill after determining the working length for the post.*

Ribbond is used in combination with composite resin (Ribbond Composite Laminate Endo Post and Cores). The physical properties of this material allow the conservative fabrication of aesthetic dowels and core foundations. As a result, what is produced is an aesthetic post core system that adapts to the root morphology individually (Figure 7). It must be noted that most root fractures occur years after post placement. Minimal cracking occurs in the laminate resin post structure due to the inherent crack-stopping property of fibre-resin interfaces[46]. The relative flexibility of the fibre composite laminate post has been reported to minimize microcrack propagation in the root[47,48].

It has been shown that posts change dentin stress substantially under compression in vertical loading[49]. Eskitascioglu et al (2002)[26], evaluated the relationship of rigidity of post core systems to stress distribution using the finite element stress analysis method (FEM). Minimal stress values were recorded within the LWUHM polyethylene fibre post system when compared to the cast post system. The LWUHM polyethylene fibre post system transferred stress to the cervical 1/3 of the tooth and to the supporting bone structure while stress accumulation within the cast post system occurred in the apical 1/3 of the root and within the post. Polyethylene woven fibre and composite resin without a prefabricated post resulted in significantly fewer vertical root fractures when compared to conventional post and core systems. However the mean failure load coincided with the values at the lowest level[50]. Fibre reinforced dowels are reported to reduce the risk of tooth fracture and display higher survival rates than teeth restored with zirconia dowels[51]. They have also been shown to have reduced coronal leakage when compared to stainless steel or zirconia dowel systems[52].

## Post restoration technique with Ribbond THM

All carious dentin must be removed. A periodontal procedure is usually indicated when the cervical margin of the restoration is below the gingival tissue. In such cases, placement of rubber dam may be difficult and an opal dam will be helpful to avoid gingival contamination. Orthodontic extrusion of the root is an alternative treatment option.

Following isolation of the tooth, (Figure 8), gutta percha should be removed from the root canal with rotary instruments and with heated instruments or solvents[53-55] until the desired length for the post is achieved (Figure 9), At least 4 to 5 mm of gutta percha should be left in situ in order to preserve the apical seal[56].

Previously the length of the post was a critical factor due to a lack of adhesive properties of the post systems[57]. Developments in adhesive dentistry now allow more conservative post space preparation as adhesive luting cements prevent adhesive failure and adhesive post systems prevent cohesive failure.

In a recent FEM study, the effect of the post length of a prefabricated glass fibre system on stress distribution was evaluated under incisal loading. The findings indicated that the post length should not be shorter than the clinical crown as this would cause an increase in stress accumulation at the cervical region. On the other hand, the post length does not need to extend beyond 2/3 of the root because as the post

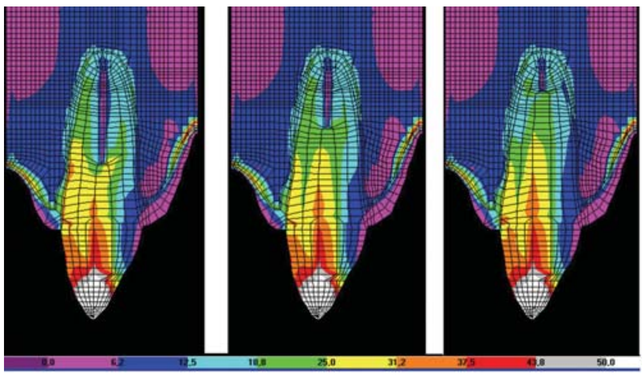

*Figure 10. FEM analysis of a model restored with glass fibre post system. a) When the post is shorter than the clinical crown, more stress accumulated on cervical 1/3 of the tooth and the buccal bone b) When the post length designed equal or longer than clinical crown, same mathematical values are observed. c) As the post length increases, stress moves through the apical area .*

*Figure 11. The prepared post space is treated with A&B Primer and A&B Bond (Liner Bond 2V , Kuraray, Japan).*

*Figure 12. Panavia F dual cure resin cement (Kuraray, Japan) is introduced into the root canal with a lentulo.*

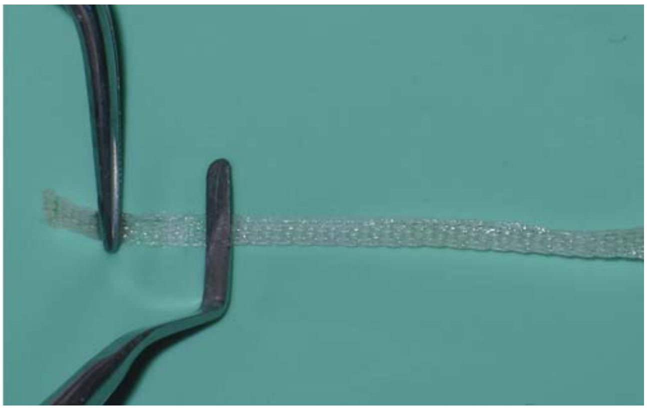

*Figure 13. Two pieces of Ribbond fibre are cut after determining the desired length, and moistened with a dual cure adhesive system. The adhesive excess is removed with a hand instrument moved in the direction of the fibres.*

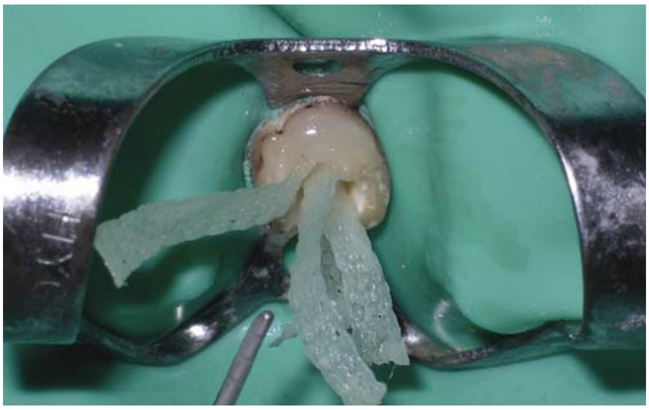

*Figure 14. Ribbond is condensed tightly into the canal space with an endodontic plugger.*

*Figure 15. A second piece of Ribbond is then condensed into the canal space perpendicular to the first piece.*

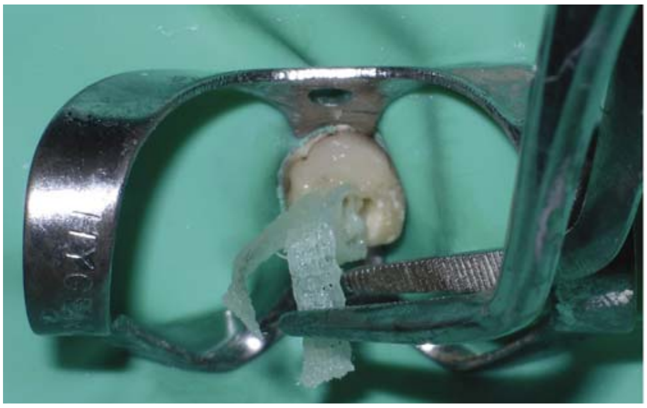

*Figure 16. The excess resin is removed and the free ends of the fibres are twisted and condensed into the canal.*

length increases, so stress moves through the apical area[58] (Figure 10). Preservation of radicular dentin is also an important factor. Teeth restored with larger diameter posts are reported to have the least resistance to fracture with a decrease in the width of the remaining dentin[59].

## Fibre selection and length determination

The choice of fibre is dependent on the width of the root canal (Ribbond THM, Size 2,3 or 4 mm, Ribbond Inc., Seattle WA). The length of the post space is measured using a periodontal probe. This measurement is doubled, estimated core length added and the necessary length of fibre decided. Two pieces of fibre should be cut with the special scissors

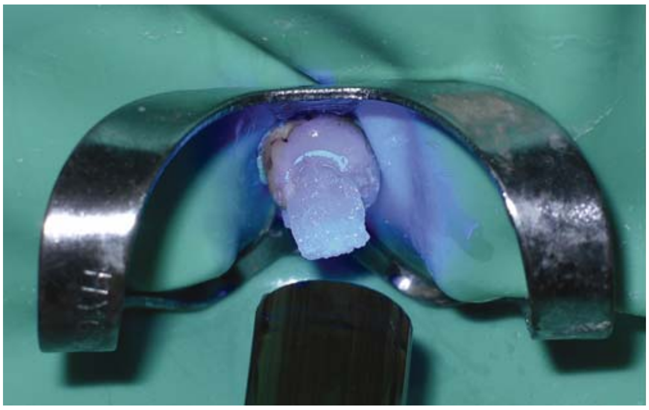

*Figure 17. The entire fibre resin post is cured for 20 seconds with a visible light curing unit.*

*Figure 18. The core is completed with a hybrid composite resin using a technique of light-cured small progressive increments.*

*Figure 19. Conservative preprosthetic rebuilding of the crown.*

which are part of the set (Ribbond Starter Kit, Ribbond Inc, Seattle WA), then coated with a dual-cure adhesive resin and set aside in a light-protected container.

## Preparation of the root surface

The internal surface of the root canal is treated with a dual cure adhesive resin (Liner Bond 2V, Kuraray, Japan) to control polymerization in the deepest parts of the root canal (Figure 11). Liner Bond 2V is a light-cure self-etch adhesive system when only Bond A is used. However it becomes a dual-curable adhesive system when Bond A and B are used together. A dual-cure resin cement (Panavia F, Kuraray, Japan) is later injected into the root canal space (Figure 12).

## Preparation of the resin coated Ribbond and post creation

Excess adhesive on the Ribbond pieces is gently removed with a hand instrument moving in the direction of the fibres (Figure 13). A piece of reinforcement fibre coated with adhesive is then wrapped and condensed tightly into the canal space with an endodontic plugger (Figure 14). A second piece is then condensed into the canal space at right angles to the first piece (Figure 15). The excess resin is removed and the free ends of the fibres are twisted and condensed into the canal (Figure 16). The entire fibre resin post is then cured for 20 seconds (Figure 17). The core is completed using a hybrid composite resin (Figure 18) following the technique of small progressive increments. All these increments are fully light-cured (Figure 19).

Impregnation of the fibres with resin before application is an important step for a successful restoration with UHMW polyethylene fibre Ribbond. Each fibre should come into contact with the resin. However, residual monomer may induce problems. These can be avoided by using pre-impregnated fibres. It is difficult to save UHMW polyethylene fibre after impregnation in the clinical situation. It is therefore advisable to wet the fibre shortly before restoration and to remove the excess resin over the fibre surfaces with a hand instrument in the direction of the fibre.

There are many factors influencing the clinical success of an adhesive post core system. The luting cement is one of these factors and it is particularly important when used in large quantities, especially in those cases where the canals are irregular and/or very wide compared to the pre-fabricated posts. A resin luting agent may create polymerization shrinkage stresses within the dowel space[60]. It has been shown that C factors in dowel spaces may be as high as 200[61]. These stresses may also cause a leakage problem when used with prefabricated fibre or zirconia dowel systems[52]. In these cases, the resin supported Ribbond post core system has an advantage because of its polymerization shrinkage reducing effect.

The bonding surface is also an important factor for the success of an adhesive post-core system. During root canal treatment, many irrigation solutions, disinfectants or gutta-percha solvents are used, and these could alter the chemical composition of the dentin surface. Such contamination of the mineral contents of dentin could affect its interaction with materials used for restoration[62,65]. Hopefully new techniques will be developed to reverse the detrimental effects of these solvents on resin-dentin bond strength.

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