©Operative Dentistry, 2017, **42-3,** 233-243

Clinical Technique/Case Report

Stress-reduced Direct Composites for the Restoration of Structurally Compromised Teeth: Fiber Design According to the "Wallpapering" Technique

S Deliperi • D Alleman • D Rudo

Clinical Relevance

When most of the dentinoenamel complex (DEC) is lost, the "wallpapering" of the residual cavity walls with Leno weaved ultra-high-molecular-weight polyethylene fibers may help to both emulate the crack shielding mechanism of the DEC and absorb the stress from either polymerization shrinkage or occlusal load.

SUMMARY

Purpose: The purpose of this work was to present a restoration technique based on an understanding of the biomechanical properties of the dentinoenamel complex (DEC) and the physical-mechanical properties of the resin-based composite including the stress generated from both polymerization shrinkage and occlusal forces.

Technique Summary: The DEC is a functional interphase that provides crack tip shielding; the DEC should be preserved during restorative procedures. Dentists can design the strategic placement of restorative materials into the cavity to both resist the mode of failure and mimic the performance characteristics of the intact natural tooth. The term "wallpapering" describes a concept of covering the cavity walls with overlapping closely adapted pieces of Leno weaved ultra-high-molecular-weight polyethylene (LWUHMWPE) ribbons. The key for success is that the ribbons are adapted and polymerized as closely as possible against the contours of residual tooth substrate. The resulting thin bond line between the fibers and the tooth structure creates a "bond zone" that is more resistant to failing due to the intrinsic stress and energy absorbing mechanism of the LWUHMWPE ribbons. The formation of defects

*Simone Deliperi, DDS, adjunct assistant professor, Tufts University, Comprehensive Care, Division of Operative Dentistry, Boston, USA and private practice, Cagliari-Italy. Co-director of the Alleman-Deliperi Centers for Biomimetic Dentistry, Cagliari, Sardinia. Italy

David Alleman, DDS, private practice, South Jordan, Utah. Co-director of the Alleman-Deliperi Centers for Biomimetic Dentistry; South Jordan, Utah

David Rudo, DDS, president, Ribbond INC, Seattle, Washington

*Corresponding author: Piazza Unione Sarda 39, Cagliari 09122, Italy; e-mail: info@simonedeliperi.com

DOI: 10.2341/15-289-T

and voids, from which crack propagation may start, is also reduced. The fibers' tight adaptation to tooth structure allows a dramatic decrease of the composite volume between the tooth structure and the fiber, thus protecting the residual weakened walls from both the stress from polymerization shrinkage and the occlusal load.

Conclusion: By using a similar approach, fiber-reinforced stress-reduced direct composite restorations may be performed in the restoration of structurally compromised vital and nonvital teeth.

INTRODUCTION

During a tooth's lifetime, a wide range of overload events may happen, including those from bruxism, trauma (high extrinsic loads), or during dynamic loading (intrinsic chewing strokes in a small area due to a hard foreign body such as a stone or seed). Cracks form within enamel[1] typically without causing catastrophic tooth fracture. The dentin-enamel junction (DEJ) successfully unites two very dissimilar dental materials: the hard and wear-resistant enamel cover-layer and the softer and less mineralized dentin core.[2] The DEJ, or dentinoenamel complex (DEC), is known for its unique biomechanical properties. The DEC is composed of a three-dimensional continuum of gradations of interphases that enable the harmonious transfer of stress between dentin and enamel, two materials having dissimilar elastic properties. The DEC brings these two dissimilar materials into strain harmony and allows them to function together as a tooth. The DEC provides a crack-arresting barrier to the cracks formed in enamel from traversing the enamel-dentin interface and causing catastrophic tooth fractures.[3] These cracks are found to start either at so-called "tufts" (hypocalcified fissures extending outward from the DEC) growing toward the enamel surface or at flaws close to the tooth surface.[3] Latter cracks propagate toward the DEC and are arrested there[4,5] or with limited penetration of the underlying dentin core.[6,7]

Imbeni and others[6] examined how cracks propagate in the proximity of the DEC and also quantified, using interfacial fracture mechanics, the fracture toughness of the DEC region. They reported that the DEJ toughness is approximately 5-10 times higher than enamel but approximately 75% lower than dentin. They also reported that cracks penetrating through the interface tend to reach the (optical) DEC and arrest when they enter the tougher mantle dentin adjacent to the interface. The mantle dentin is a thin material layer close to the DEC that is somewhat softer than the bulk dentin, showing decreased peritubular dentin and tubule density. They explained crack arrest by the gradually increasing toughness from enamel to mantle dentin.[6] Although there is little consensus on the mechanism of crack arrest at the DEC, research definitely agrees that the DEC is a very strong, durable, damage tolerant, and well-bonded interface that is unlikely to fail within healthy teeth despite the formation of multiple cracks within enamel during a lifetime of exposure to masticatory forces.[7-9]

Structurally compromised teeth are teeth exhibiting substantial loss of tooth structure due to previous caries, preexisting restorations, and endodontic procedures. The more structurally compromised the tooth, the lower is the proportion of the residual DEC region in the tooth and the higher is the potential of a catastrophic failure of the residual tooth structure. Cast coverage restorations[10] and large amalgam restorations[11] have been selected for the restoration of endodontically treated teeth for many years. Metal-based restorations and the residual tooth structure behave as two different entities during function because they are not bonded to the residual tooth structure. As a matter of fact, the residual tooth structure is continuously subjected to both occlusal and thermal stresses. Furthermore, the need for mechanical retention or resistance forms, such as boxes, grooves, slots, pins, and posts creates regions of great stress concentrations that dramatically weaken the residual tooth structure and increase the potential for crack formation.[12]

Over the last two decades, new restorative protocols have been proposed to properly use modern adhesive systems and preserve the remaining sound tooth structure.[4,13-15] The goal of these procedures, utilizing either direct or indirect composite restorations, is to maximize the bond and minimize the stress in an attempt to mimic the functional and optical characteristics of the intact natural tooth.[16]

When clinicians select a composite resin restorative material, they need to keep in mind that composite resin is a rigid material; it does not lack of strength or stiffness but lacks of toughness.[17] Toughness is defined as the resistance of a material to the rapid propagation of cracks. Toughness is an inherent property of the material and can be used to predict structural performance.[17]

Figure 1. *Preoperative view of tooth #19 showing an incongruous tooth-colored restoration.*

Leno weaved ultra-high-molecular-weight polyethylene (LWUHMWPE) fibers are plasma-treated fibers. LWUHMWPE fiber reinforcement ribbon systems have been introduced in the attempt to increase composite resin toughness, thus increasing both durability and damage tolerance.[17,18] These bondable reinforcement fibers can be closely adapted to the residual tooth structure without requiring additional preparation. The woven fibers have several advantages. The structure of the fiber based on multidirectional yarns and locked nodal intersections creates a great multitude of load paths that redistribute the occlusal forces throughout a greater region of dental restorative composite.[19-21] The higher modulus of elasticity and lower flexural modulus of polyethylene fiber have a modifying effect on the interfacial stresses developed along the cavity walls.[22] Sengun and others[23] reported a fail-safe mechanism for fiber-reinforced restorations compared with restorations without LWUHMWPE fibers. Because fractures generally occur above the cementoenamel junction (CEJ), the remaining tooth structure is restorable, and catastrophic failures are avoided.

If clinicians can understand the mode of failure of both the composite resin and the weakened residual tooth structure, the strategic fiber insertion against the cavity walls may contribute to avoid failure through a stress distributing and energy absorbing mechanism.

This paper introduces a clinical protocol for the restoration of structurally compromised devitalized teeth using the "wallpapering" of the residual cavity walls with LWUHMWPE fibers to mimic the crack shielding mechanism of the DEC.

CASE PRESENTATION AND CLINICAL TECHNIQUE

A 35-year-old female patient presented with an existing fractured composite resin restoration in a lower molar tooth (#19). The patient's tooth was restored with a direct composite resin and prefabricated carbon fiber posts eight years earlier (Figure 1). The patient reported that failure of both the distal marginal ridge and the disto-lingual cusp occurred two years following the restoration placement.

When a stress-reduced direct composite (SRDC) protocol is selected, six steps need to be followed[24]:

1. Analysis of the occlusion and opposing dentition
2. Cavity preparation and caries removal end points
3. Analysis of residual tooth structure
4. Preparation of the dental substrate to achieve a reliable bond to enamel and dentin
5. Control of polymerization stresses by using appropriate layering and curing techniques, and wallpapering of dentin walls with LWUHMWPE fibers
6. Occlusal force equilibration

Step 1: Analysis of the Occlusion

Analysis of occlusion is required to intercept either areas of occlusal overload or lack of centric stops. A composite mockup may be performed to establish and test a temporary occlusion; it also allows for the determination of the three-dimensional location of fibers within the restorations. It is important that the fibers are not damaged or exposed to the oral cavity by later occlusal adjustments. Preoperative occlusal analysis showed concentration of the occlusal load on the residual facial cusp of tooth #19 and in the distal area close to the fractured marginal ridge (Figure 2). Because of the unbalanced occlusion, a fracture of the remaining wall can occur under mastication due to concentration of the load on the weakened facial cusps. After completing the analysis of occlusion and presenting a treatment plan to the patient for both a direct and indirect restoration, a fiber-reinforced (FR)-SRDC restoration was selected for the restoration of tooth #19.

Step 2: Cavity Preparation and Caries Removal End Points

A rubber dam was placed, and the existing restoration was removed using # 2 and #4 round burs (Brasseler, Savannah, GA, USA). The cavity was prepared in a very conservative manner, removing just the decayed dental tissue and trying to preserve the remaining sound tooth structure according to the basic guidelines for direct adhesive preparations. A caries indicator (Sable Seek, Ultradent Products,

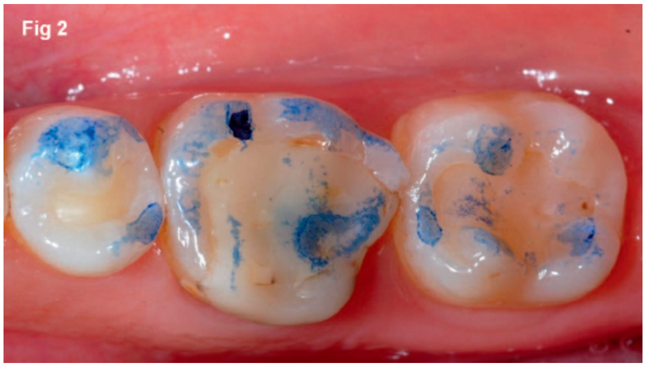

Figure 2. *Before starting anesthesia, occlusion was checked and centric stops were recorded.*

South Jordan, UT, USA) was applied to the dentin; stained nonmineralized and denatured dental tissues were removed with a spoon excavator to an ideal caries removal end point that creates a highly bondable peripheral seal zone.[25] Residual enamel sharp angles and unsupported prisms were smoothed using the Standard Distal (SD) and Standard Ball (SB) partially diamond-tipped ultrasonic tips (EMS, Nyon, Switzerland); the SB instrument was also used to smooth sharp angles located within the dentin. No bevels were placed on either the occlusal or the gingival margins. The main goals of step 2 were to avoid the formation of any sharp line angle on either the prepared enamel or dentin and to preserve the peripheral rim.

Step 3: Analysis of Residual Tooth Structure

Once the preparation was complete, it was determined that both the lingual cusps were missing, the lingual cavosurface margins were located below the gingival level on dentin-cementum, and a very thin area of enamel was preserved on the distal gingival margins (Figure 3). However, the thickness of the residual facial walls greater than 2 mm and the preservation of the entire mesial marginal ridge were considered sufficient to support an FR-SRDC restoration.

Figure 3. *Cavity preparation was completed using partially diamond tipped ultrasonic tips.*

Step 4: Preparation of the Dental Substrate to Achieve a Reliable Bond to Enamel and Dentin

A circular matrix (OmniMatrix, Ultradent Products) was placed around tooth #19, and lingual and interproximal matrix adaptation was secured by only tightening it; good adaptation to the gingival margin was achieved without using any dental wedge and burnishing the most gingival area of the metal matrix (Figure 4). The tooth was etched for 15 seconds using a 35% phosphoric acid (UltraEtch, Ultradent Products) (Figure 5). The etchant was removed, and the cavity was rinsed with water spray for 30 seconds, being careful to maintain a moist surface. The cavity was disinfected with a 2% chlorexidine antibacterial solution (Cavity Cleanser, Bisco, Schaumburg, IL, USA) (Figure 6).[26] A three-step etch and rinse 40% filled ethanol-based adhesive system (All Bond 3, Bisco) was placed in the preparation; both the primer and the coating resin were gently air thinned and light cured for 20 seconds using an LED curing light (Valo, Ultradent Products) (Figure 7).

Step 5: Control of Polymerization Stresses: Step 5a: Buildup of the Skeleton

The missing peripheral tooth structure was built up via 2-mm wedge-shaped composite increments. Vit-l-escence microhybrid composite resin (Ultradent Products) was used to restore the teeth. Stratification was initiated using multiple 1- to 1.5-mm triangular-shaped (wedge-shaped) increments; apico-occlusal placed layers of A4 shade were used to reconstruct the cervical third of both the lingual and distal surfaces (Figures 8 and 9). At this point, the circular matrix was replaced with a sectional matrix to achieve a more predictable contact point with the second molar tooth.[24] Both the proximal surface and the external shell of the lingual cusp buildups were completed using the Pearl Smoke (PS) enamel shade.

Step 5b: Wallpapering of Dentin Walls With LWUHMWPE Fibers or Ribbond Fibers

Preparation to the wallpapering includes the selection of the correct length and width of the fibers to properly fit into the cavity. A dental probe (Hu-

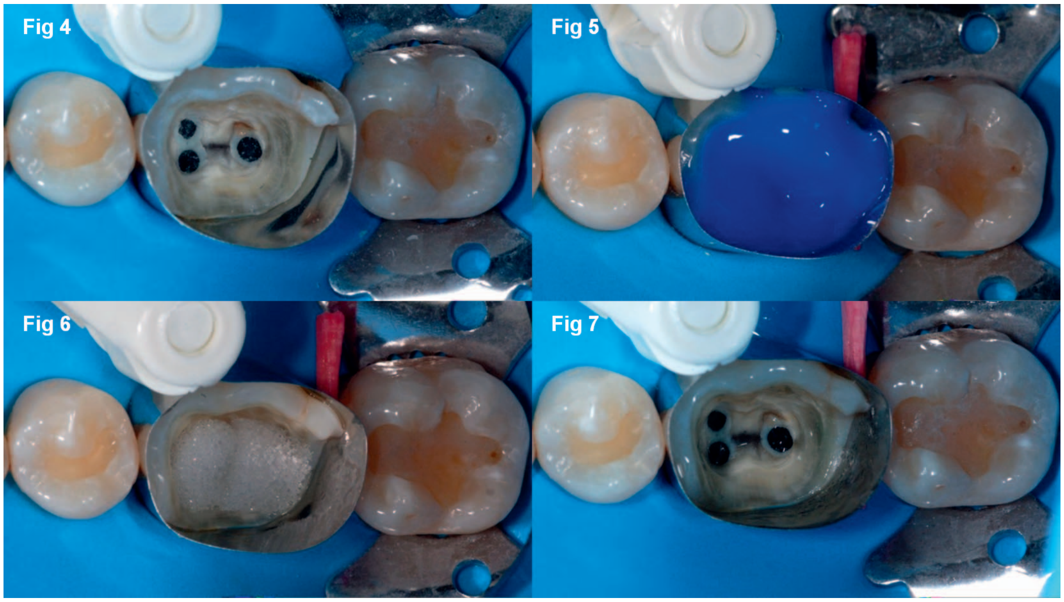

Figure 4. *A circular matrix was placed.*
Figure 5. *Etching was performed using 35% phosphoric acid.*
Figure 6. *A 2% digluconate chlorexidine solution was applied on dentin for 30 seconds.*
Figure 7. *An ethanol-based primer was applied on both enamel and dentin followed by the application of a hydrophobic resin coating.*

Friedy, Chicago, IL, USA) was used to measure the mesio-distal distance and the pulp chamber-coronal length of the cavity. Two 4-mm-wide by 11-mm-long Ribbond fiber pieces (Ribbond THM, Ribbond Inc, Seattle, WA, USA) were wetted with an unfilled resin first (Ribbond Wetting resin, Ribbond Inc).[12,27] After removing the excess resin, fibers were covered with a very thin layer of tacky flowable composite, Ribbond Securing Composite (Ribbond Inc); fibers were C-shaped prior to insertion into the cavity. The first Ribbond fiber was bonded immediately against the lingual wall and cured for 20 seconds (Figure 10). The same procedure was also completed for the second polyethylene fiber which was placed on the facial wall and cured for 20 seconds. The Ribbond pieces overlapped one another at the proximal surfaces, with each piece stopping at an imaginary DEJ line on the top and folding down onto the axial-pulpal floor line angle on the bottom at both the facial, lingual and proximal walls (Figure 11). Being bondable reinforcement fibers, they could be closely adapted to the residual tooth structure. The fibers' tight adaptation to tooth structure was the key to decreasing the composite volume between the tooth structure and the fiber; thus, stress from polymerization shrinkage could be prevented on the residual weakened walls. In cases of visible cracks, structural weakness of the pulp chamber floor, or patients with parafunction, another piece of Ribbond may be prepared in the same manner and bonded closely against the pulpal floor. In a similar clinical scenario, one more piece of Ribbond may be placed

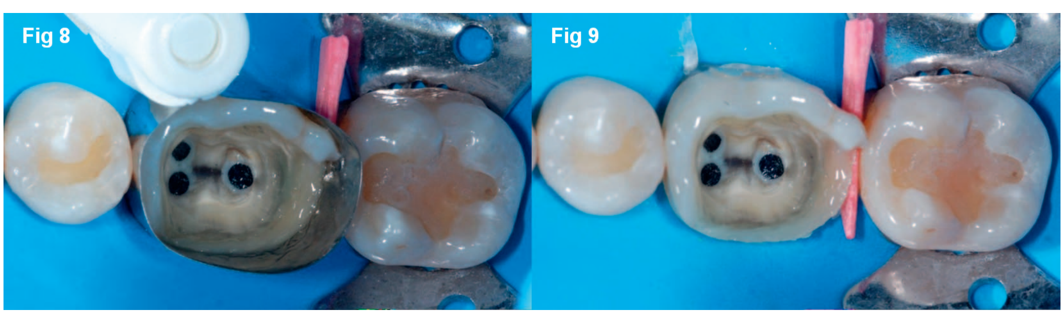

Figure 8. *Multiple 1- to 1.5-mm triangular-shaped (wedge-shaped) increments were used to reconstruct the cervical third of both the lingual and distal surfaces.*
Figure 9. *The circular matrix was replaced with a sectional matrix and the peripheral enamel skeleton was built up first using wedge-shaped increments.*

Figure 10. *The first C-shaped polyethylene fiber is bonded immediately against the lingual wall and cured for 20 seconds.*
Figure 11. *The same procedure is also completed for the second C-shaped polyethylene fiber, which is placed as close as possible to the contour of the facial wall.*

1.5 mm below the occlusal surface to assure an additional distributing and energy absorbing mechanism.

Step 5c: Dentin and Occlusal Surface Buildup

Stress reduction during the early polymerization of the dentin bonding system (the first 3-30 minutes) was very important.[13,28] By the time the skeleton buildup and fiber application were completed, time had been given for the bond to dentin to mature before it was connected to the next layers of composite resins.[16] Stratification of dentin was started by placing a 1- to 1.5-mm even layer of A3.5 flowable composite (PermaFlo, Ultradent Products) on the dentin floor, which was followed by the application of dentin wedge-shaped increments strategically placed to only two bonded surfaces, decreasing the cavity configuration or C-factor ratio (Figures 12 and 13). The C-factor is defined as the ratio between bonded and unbonded cavity surfaces; increasing this ratio also increases the stress from polymerization shrinkage.[29] Due to the stress absorbing effect of the Ribbond fibers,[22] 2-mm-thick dentin layers of composite resin can be placed into contact with the Ribbond fibers. For the same reason, single increments of PS enamel shade were applied to one cusp at a time; each cusp was cured separately, achieving the final primary and secondary occlusal morphology (Figure 14). To reduce stress from polymerization shrinkage, the authors utilized a previously described polymerization technique, based on a combination of pulse (enamel) and progressive (dentin) curing technique through the tooth.[16] The pulse curing protocol was adopted for the proximal and occlusal enamel buildup polymerization; it was accomplished by using a very short curing time (one or two seconds) per each increment. The progressive curing technique was used for the polymerization of the dentin increments; it was performed by placing the light tip in contact with

Figure 12. *Dentin stratification was performed by using wedge-shaped increments of composite dentin shades.*
Figure 13. *A brown composite tint was placed at the end of dentin stratification.*
Figure 14. *Restoration was completed with the application of PS enamel shade to each cusp to develop cusp ridges and supplemental morphology.*

Table 1: *Recommended Photocuring Times and Intensities for Proximal and Occlusal Enamel and Dentin*

Buildup location	Polymerization technique	Intensity (mW/cm^2)	Time (s)
Proximal enamel	Pulse (P)	800	2 (P) + 20[a]
Dentin	Progressive (Pr)	800	20[a]
Occlusal enamel	Pulse (P)	800	1 (P) + 20[a]

[a] *"Curing through": 20 seconds per each surface (lingual, facial, and occlusal surface).*

the external cavity walls to start the polymerization through the wall (indirect polymerization) at a lower intensity (Table 1). Areas of undercuts in the cavity are very common when adopting an ultra-conservative preparation protocol. A progressive curing protocol assured composite resin polymerization in hidden areas of the cavity and reduced stress. Final polymerization was then provided at a higher intensity and extended curing time. Initial occlusal and proximal adjustment of the restoration was performed using #7404 and #7902 carbide burs (Brasseler). The patient was recalled after 48 hours to complete the occlusal adjustment and perform the final polishing.

Step 6: Occlusal Force Equilibration

Occlusion was verified, avoiding excessive load on the residual facial cusp and creating a centric stop in the composite restoration at the distal area of the tooth-restoration complex. The centric stops located on the tooth structure and composite resin are of the same intensity; they do not differ from the ones on the adjacent teeth (Figure 15). A "verticalization" of occlusion is adopted to avoid overloading of either the restored or residual cusps during both centric and eccentric movements. Centric stops are preferably located at the center of the tooth to assure a prevalence of axial loads on the tooth restoration complex and avoid excessive lateral forces.

Figure 15. *Occlusal view of the final restorations after occlusion checking.*

Figure 16 shows a schematic representation of the wallpapering technique.

DISCUSSION

Endodontically treated teeth have been restored using indirect porcelain-bonded restorations and indirect/semidirect resin-bonded composite restorations.[13,30]

The stress generated from polymerization shrinkage and the lack of adequate protocols have discouraged many clinicians from selecting a direct technique for the restoration of structurally compromised vital and devitalized teeth for many years. However, SRDC restorations have been proposed as a valid alternative to indirect resin-bonded composite restorations.[4] Spreafico and others[15] reported no difference in the clinical performance of semidirect and direct class II composite resin restorations after a 3.5-year evaluation period. Deliperi and Bardwell[31] reported no failure for class II direct cusp-replacing resin-bonded composite restorations after two years of clinical service using both a bonding preservation and stress-reducing protocol. When adopting the same restorative protocol, they also reported equal results for large-size three-surface SRDC restorations over a two-year period.[32] These clinical studies were performed on vital teeth with thickness of the residual cavity walls greater than 2 mm.

Lately, increasing attention has been focused on the proper utilization of LWUHMWPE fibers (Ribbond Inc) for the direct restoration of structurally compromised endodontically treated teeth.[12,27,33] Although only a few clinical case reports and a pilot study have been published in the literature, fiber-reinforced restorations performed very well in different laboratory tests.[5-9,22] LWUHMWPE Ribbond fibers increase the flexural strength and fracture toughness of composite resin restorations. Due to the fiber design based on a dense network of locked nodal intersections, they also serve as a crack stopping mechanism; the locked stitch interwoven fibers prevent rapid crack growth and change the direction that ultimately dissipates the strain. Belli and others[5] reported that the placement of LWUHMWPE Ribbond fibers against the dentin walls increased the fracture strength and decreased the cusp movement under loading of root filled molars with Mesial Occlusal Distal (MOD)

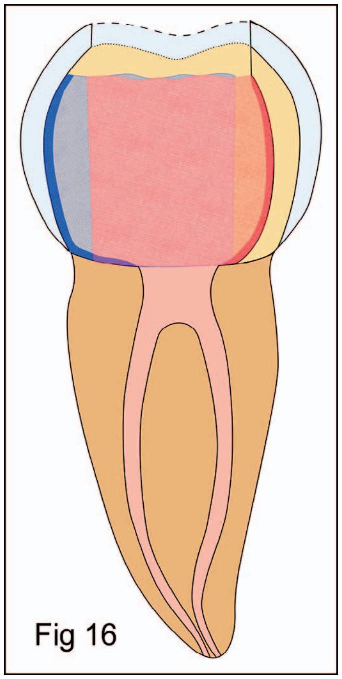

Figure 16. *Schematic representation of the fiber laydown protocol showing the wallpapering of both the facial and lingual surface; fibers stop at an imaginary DEJ line in the coronal area and fold down onto the axial-pulpal floor at the cervical area.*

cavities.[34] In a study published in 2006, Belli and others described that Ribbond increased the microtensile bond strength and lowered the C-factor effect.[35]

The former laboratory studies were performed placing the composite into the cavity without following a stress-reducing protocol; both the maturation of the bond[36,37] and the strategic layering/curing protocol may further reduce stress concentration on the residual cavity walls.[4,24] In the first three to five minutes following the polymerization of the adhesive system, early bond strength to enamel was reported to be twice as strong as the early bond strength to dentin[38]; this trend changes dramatically after a five-minute period as the late bond strength to dentin may be even higher than the one to enamel.[39]

Combining composite stratification with wedge-shaped increments and polymerization with a low-intensity approach is also mandatory to reduce stress in the restoration. Multiple wedge-shaped increments are placed trying to contact no more than two bonded cavity walls; the technique allows the decrease of stress from polymerization shrinkage by reducing the composite mass (per increment) and transforming the high C-factor configuration into multiple low C-factor configurations.[4,24] The application of small increments allows the clinician to influence the C-factor at a micro level (micro C-factor) by maximizing the unbonded free surfaces each time a single composite increment is placed. In addition to this sophisticated stratification technique, a combination of progressive and pulse curing polymerization is used on dentin and enamel, respectively, to further decrease the stress from polymerization shrinkage.[4] By adopting a similar soft-start curing protocol, physical and mechanical properties of composite resin may also be improved; more time is available for composite flow into the direction of the cavity walls, resulting in stress release during polymerization shrinkage and increased crosslinking. The quality of the polymer network, which is not equivalent to the degree of conversion, is influenced by the modified curing scheme. A research study[40] corroborated previous findings[41,42] supporting that polymerization protocols based on low intensity and increased curing time result in longer polymer chain formation; conversely, frequency of crosslinking increases using higher intensity and short curing times, which leads to multiple short polymer chains formation and reduced degree of cure.

The literature suggests that cracking along the DEC occurs very rarely.[5-9] The DEC seems to be a very well- and strongly bonded interface that provides crack tip shielding. Preserving the DEC during cavity preparation as much as possible is the first rule each restorative dentist should follow.

Interestingly, Bechtle and others[9] reported that crack arrest occurs only if cracks approach the DEC from the enamel side. If cracks are induced from the dentin side, samples fractured after elastic and some amount of plastic deformation. This in vitro finding does have clinical significance.

During occlusal loading, vertical loading creates lateral forces against the cavity walls (the Poisson effect); the lateral forces create a tensile force across the pulpal floor that may be responsible for the initiation of a crack on the residual cavity walls. Due to the composite resin's intrinsic lack of toughness, a catastrophic failure may occur if structurally compromised teeth are restored with a resin bonded composite only.[34,43,44] The wallpapering of the residual cavity walls with the Ribbond polyethylene fibers is intended to diminish the possibility of a failure while preserving the residual sound tooth structure. When a failure occurs, it happens in a safe mode due to the energy absorbing mechanism and stress distribution effect of the fibers; the damage on the tooth-restoration complex is minimal and can be easily repaired because it occurs above the CEJ.[23] The intrinsic characteristic of the fiber network and the correct fiber insertion into the cavity walls may help clinicians to push the envelope with direct restorations; if a stress-reduced approach is adopted, direct restorations may be extended to structurally compromised vital and devitalized teeth without requiring cusp coverage of residual weak walls. However, the thinner the remaining cavity walls, the higher the risk for a catastrophic failure of the tooth to occur. Structurally compromised teeth with residual cavity walls thinner than 2 mm lack of the major portion of the DEC on both the occlusal, proximal, and lateral walls. The lack of the functional shielding mechanism of the DEC and the composite resin's intrinsic lack of toughness are two of the reasons that pushed clinicians to cover the residual weak cusps with bonded onlay restorations.[13,14] By adapting the LWUHMWPE Ribbond ribbons as closely as possible against the internal contours of the residual tooth substrate, it is possible to both replicate and reinforce the crack shielding mechanism of the DEC. The Leno weaved Ribbond provides multiple load paths that distribute the stresses over a greater region. Because of this greater stress distribution effect, stress from either polymerization shrinkage or occlusal load can be better controlled, and thin cavity walls can be preserved. Like the DEC, which enables the dentin and enamel to function in strain harmony together, the Ribbond liner bonded immediately against the cavity walls, which enabled the tooth substrate and the restorative composite to also function in strain harmony.

Bechtle and others[9] also tested notched rectangular-shaped enamel-dentin bending bars with the dentin side under tension. They observed that crack propagation occurred simultaneously within dentin and enamel; the two cracks may either coalesce or stay separate at the DEC. In the latter case, they reported that the DEC formed an unbroken ligament between cracks, which kept the two fractured parts together (DEC bridging).

The ideal cavity preparation for resin bonded composite is a "saucer-shaped" configuration[45]; however, this is not always possible. A notched dentin sample represents an in vitro tool to replicate a very common clinical scenario. The areas of the cavity prepared for mechanical retention or resistance form (boxes, grooves, slots) do have acute internal line angles. These regions of greatly increased stress intensities challenge the crack tip shielding mechanism of the DEC. The use of ultrasonic tips definitely helps to smooth the sharp line angles; however, covering these areas with Ribbond fibers is recommended to avoid stress concentration on these areas and avoid the formation of cracks either on the pulpal floor and axial walls.

Cavity preparation, material design, and occlusal equilibration represent different stages of the restorative procedure to achieve stress reduction and assure the longevity of the tooth-restoration complex.

CONCLUSION

The SRDC protocol allows clinicians to not only create minimally invasive preparations but preserve the remaining sound tooth tissues in structurally compromised teeth. Avoiding the creation of sharp angles during cavity preparation minimizes the increase in stress intensities in both the remaining tooth structure and the restorative composite; allowing some time for dentin bond maturation and designing the strategic placement of restorative materials into the cavity to both resist cracks and mimic the performance characteristics of the intact natural tooth are the fundamentals to complete stress-reduced direct composite resin restorations in structurally compromised teeth.[46]

Long-term clinical studies are required to confirm the superiority of this protocol over traditional restorative strategies.

Acknowledgements

The authors thank Ribbond, Bisco, and Ultradent for donation of the materials mentioned in this paper.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Sardinia Dental Teaching Center.

Conflict of Interest

David Rudo is President of Ribbond, Inc. The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 20 June 2016)

REFERENCES

1. Chai H, Lee JJW, Constantino P, Lucas PW, & Lawn B (2009) Remarkable resilience of teeth *Proceeding of the National Academy of Sciences of the United States of America* **106(18)** 7289-7293.

2. Bazos P, & Magne P (2011) Bio-emulation: biomimetically emulating nature utilizing a histo-anatomic approach; structural analysis *European Journal of Esthetic Dentistry* **6(1)** 8-19.

3. Lee JJW, Kwon JY, Chai H, Lucas PW, Thompson VP, & Lawn BR (2009) Fracture modes in human teeth *Journal of Dental Research* **88(3)** 224-228.

4. Deliperi S, & Bardwell DN (2002) An alternative method to reduce polymerization shrinkage in direct posterior composite restorations *Journal of American Dental Association* **133(10)** 1387-1398.

5. Xu HHK, Smith DT, Jahanmir S, Romberg E, Kelly JR, Thompson VP, Rekow ED (1998) Indentation damage and mechanical properties of human enamel and dentin *Journal of Dental Research* **77(3)** 472-480.

6. Imbeni V, Kruzic JJ, Marshall GW, Marshall SJ, & Ritchie RO (2005) The dentin–enamel junction and the fracture of human teeth *Nature Materials* **4(3)** 229-232.

7. Tesch W, Eidelmann N, Roschger P, Goldenberg F, Klaushofer K, & Fratzl P (2001) Graded microstructure and mechanical properties of human crown dentin *Calcified Tissue International* **69(3)** 147-157.

8. Zaslansky P, Friesem AA, & Weiner S (2006) Structure and mechanical properties of the soft zone separating bulk dentin and enamel in crowns of human teeth: Insight into tooth function *Journal of Structural Biology* **153(2)** 188-199.

9. Bechtle S, Fett T, Rizzi G, Habelitz S, Klocke A, & Schneider GA (2010) Crack arrest within teeth at the dentinoenamel junction caused by elastic modulus mismatch. *Biomaterials* **31(14)** 4238-4247.

10. Goerig AC, & Mueninghoff LA (1983) Management of the endodontically treated tooth. Part II: Technique *Journal of Prosthetic Dentistry* **49(4)** 491-733.

11. Smales RJ, & Hawthorne WS (1997) Long term survival of extensive amalgams and posterior crowns *Journal of Dentistry* **25(3-4)** 225-737.

12. Deliperi S, Bardwell DN, & Coiana C (2005) Reconstruction of devital teeth using direct fiber-reinforced composite resins: A case report *Journal of Adhesive Dentistry* **7(2)** 165-171.

13. Magne P. (2006) Chapter 3, Semi-direct Techniques, in: *Esthetic and Biomimetic Restorative Dentistry: Manual for Posterior Esthetic Restorations* . University of Southern California, Division of Primary Oral Health Care, School of Dentistry. pp. 44-59.

14. Rocca GT, & Krejci I (2013). Crown and post-free adhesive restorations for endodontically treated posterior teeth: From direct composite to endocrowns *European Journal of Esthetic Dentistry* **8(2)** 156-179.

15. Spreafico RC, Krejci I, & Dietschi D (2005). Clinical performance and marginal adaptation of class II direct and semidirect composite restorations over 3.5 years in vivo. *Journal of Dentistry* **33(6)** 499-507.

16. Deliperi S, & Alleman D (2009) Stress-reducing protocol for direct composite restorations in minimally inasive cavity preparations *Practical Procedure Aesthetic Dentistry* **21** E1-E6.

17. Rudo DN, & Karbhari VM (1999) Physical behaviors of fiber reinforcement as applied to tooth stabilization *Dental Clinics of North America* **43(1)** 7-35.

18. Karbhari VM, & Wang Q (2007) Influence of triaxial braid denier on ribbon-based fiber reinforced dental composites *Dental Materials* **23(8)** 969-976

19. Belli S, & Eskitascioglu G (2008) Biomechanical properties and clinical use of a polyethylene fiber post-core material in fiber posts and endodontically treated teeth. In: Ferrari M, Breschi L, Grandini S (eds) *A Compendium of Scientific and Clinical Perspectives*, 1st Ed Modern Dentistry Media, Wendywood, South Africa, 39-49.

20. Eraslan Ö, Eraslan O, Eskitaşcıoğlu G, & Belli S (2011) Conservative restoration of severely damaged endodontically treated premolar teeth: A FEM study. *Clinical Oral Investigation* **15(3)** 403-408.

21. Eskitascioglu G, Belli S, & Kalkan M (2002) Evaluation of two post-core systems using two different methods (fracture strength test and a finite elemental stress analysis study) *Journal of Endodontics* **28(9)** 629-633.

22. Meiers JC, Kazemi RB, Donadio M (2003) The influence of fiber reinforcement of composites on shear bond strengths to enamel *Journal of Prosthetic Dentistry* **89(4)** 388-393.

23. Sengun A, Cobankara FK, & Orucoglu H (2008) Effect of a new restoration technique on fracture resistance of endodontically treated teeth *Dental Traumatology* **24(2)** 214-219.

24. Deliperi S (2012) Functional and aesthetic guidelines for stress-reduced direct posterior composite restorations *Operative Dentistry* **37(4)** 425-431.

25. Alleman DS, & Magne P (2012) A systematic approach to deep caries removal end points: The peripheral seal concept in adhesive dentistry. *Quintessence International* **43(3)** 197-208.

26. Carrilho MR, Geraldeli S, Tay F, de Goes MF, Carvalho RM, Tjäderhane L, Reis AF, Hebling J, Mazzoni A, Breschi L, & Pashley D (2007) In vivo preservation of the hybrid layer by chlorhexidine *Journal of Dental Research* **86(6)** 529-533.

27. Deliperi S (2008) Direct fiber-reinforced composite restoration in an endodontically-treated molar: A three-year case report *Operative Dentistry* **33(2)** 209-214.

28. Magne P (2006) Composite resins and bonded porcelain: The postamalgam era? *Journal of the California Dental Association* **34(2)** 135-144.

29. Feilzer AJ, de Gee AJ, & Davidson CL (1987) Setting stress in composite resin in relation to configuration of the restoration *Journal of Dental Research* **66(11)** 1636-1639.

30. Rocca GT, & Krejci I (2013) Crown and post-free adhesive restorations for endodontically treated posterior teeth: From direct composite to endocrowns *European Journal of Esthetic Dentistry* **8(2)** 156-179.

31. Deliperi S, & Bardwell DN (2006) Clinical evaluation of direct cuspal coverage with posterior composite resin restorations *Journal of Esthetic & Restorative Dentistry* **18(5)** 256-265.

32. Deliperi S, Bardwell DN, & Alleman D (2012) Clinical evaluation of stress-reducing direct composite restorations in structurally compromised molars: A 2-year report *Operative Dentistry* **37(2)** 109-116.

33. Deliperi S, & Bardwell DN (2009) Reconstruction of nonvital teeth using direct fiber-reinforced composite resin: A pilot clinical study *Journal of Adhesive Dentistry* **11(1)** 71-78.

34. Akman S, Akman M, Eskitascioglu G, & Belli S (2011) Influence of several fibre-reinforced composite restoration techniques on cusp movement and fracture strength of molar teeth *International Endodontic Journal* **44(5)** 407-415.

35. Belli S, Dönmez N, & Eskitaşcioğlu G (2006) The effect of c-factor and flowable resin or fiber use at the interface on microtensile bond strength to dentin *Journal of Adhesive Dentistry* **8(4)** 247-253.

36. Dietschi D, & Spreafico R (1997) Tooth preparation. In: Dietschi D, Spreafico R (eds) *Adhesive Metal-Free Restorations* Quintessence Publishing Co., Berlin, Germany, 79-99.

37. Irie M, Suzuki K, & Watts DC (2002) Marginal gap formation of light-activated restorative materials: Effects of immediate setting shrinkage and bond strength *Dental Materials* **18(3)** 203-210.

38. Dietschi D, Monasevic M, Krejci I, & Davidson C (2002) Marginal and internal adaptation of class II restorations after immediate or delayed composite placement. *Journal of Dentistry* **30(5-6)** 259-269.

39. Van Meerbeek B, De Munck J, Mattar D, Van Landuyt K, & Lambrechts P (2003) Microtensile bond strengths of an etch&rinse and self-etch adhesive to enamel and dentin as a function of surface treatment *Operative Dentistry* **28(5)** 647-660.

40. Peutzfeldt A, & Asmussen E (2005) Resin composite properties and energy density of light cure *Journal of Dental Research* **84(7)** 659-662.

41. Miyazaki M, Yoshida Y, Moore K, & Onose H (1996) Effect of light exposure on fracture toughness and flexural strength of light-cured composites *Dental Materials* **12(6)** 328-332.

42. Sakaguchi RL, & Berge HX (1998) Reduced light energy density decreases post gel contraction while maintaining degree of conversion *Journal of Dentistry* **26(8)** 695-700.

43. Belli S, Erdemir A, Ozcopur M, & Eskitascioglu G (2005) The effect of fibre insertion on fracture resistance of root filled molar teeth with MOD preparations restored with composite *International Endodontic Journal* **38(2)** 73-80.

44. Belli S, Erdemir A, & Yildirim C (2006) Reinforcement effect of polyethylene fibre in root-filled teeth: Comparison of two restoration techniques. *International Endodontic Journal* **39(2)** 136-142.

45. Nordbo H, Leirskar J, & von der Fehr FR (1993) Saucer-shaped cavity preparation for composite resin restorations in class II carious lesions: Three-year results *Journal of Prosthetic Dentistry* **69(2)** 155-159.

46. Alleman DS, & Deliperi S (2013) Adhesive dentistry: 2013 and into the future *Compendium of Continuing Education in Dentistry* **34(9)** 698-699.