

## RESEARCH AND EDUCATION

# Effect of a retention groove on the shear bond strength of dentin-bonded restorations

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In the era of dental amalgam and complete crown restorations, strict preparation guidelines were followed to improve the survival of restorations.<sup>1,2</sup> As these restorations lacked adhesion, the preparation provided macromechanical retention, and the thickness provided strength. With the introduction of adhesive dentistry, these concepts changed completely.

Direct composite resin restorations in combination with an adhesive system provide excellent adhesion to tooth structure.<sup>3,4</sup> With no or minimal preparations and good esthetics, composite resins make clinically successful restorations.<sup>5-7</sup> Indirect glass ceramic restorations in combination with an adhesive cement also have good adhesive properties<sup>3,8-10</sup> and show good clinical results as inlay and onlay restorations in various applications.<sup>11,12</sup> These adhesive restorations

do not require macromechanical retention and, therefore, less sound tooth material will be sacrificed than with conventional restorations.<sup>13</sup> As a result, preparation

## ABSTRACT

**Statement of problem.** With the increasing use of minimally invasive restorations, effective adhesion becomes more important. Applying mechanical retention to a flat dentin surface might improve the adhesion of ceramic and composite resin restorations.

**Purpose.** The purpose of this in vitro study was to evaluate the effect of a groove in a flat dentin surface on the bond strength of various restorative materials.

**Material and methods.** Dentin specimens of bovine teeth were prepared with or without a groove. Identical disks were fabricated from direct composite resins (Filtek Supreme XTE [FS] and Clearfil AP-X [AP]) and indirect ceramics (Vita Mark II [VM] and IPS E.max CAD [EM]). These materials were bonded directly or cemented adhesively to the dentin specimens. Shear bond strength was tested with a universal testing machine. Finite element analysis (FEA) models of the test arrangement were made to further analyze the stress distribution.

**Results.** VM (no groove, 5.1 ±3.0 MPa; groove, 8.7 ±1.5 MPa) and EM (no groove, 11.4 ±3.7 MPa; groove, 17.7 ±5.2 MPa) showed significant effect of a groove on the shear bond strength. FS (no groove, 18.6 ±4.9 MPa; groove, 16.3 ±4.3 MPa) and AP (no groove, 25.8 ±3.8 MPa; groove, 24.2 ±7.2 MPa) showed no significant effect of a groove. For the composite resins, the retention groove increased the shear stress along the dentin-restoration interface, and debonding at the contact surface started at lower load values than for the specimens without a groove.

**Conclusions.** Application of a groove to a flat dentin surface improved the shear bond strength for ceramic restorations. For direct composite resin restorations, exhibiting a lower elastic modulus, a groove had no significant effect on the shear bond strength, while it increased the shear stress along the dentin-restoration interface for composite resin. (*J Prosthet Dent* 2016;■:■-■)

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## Clinical Implications

While a groove will improve the bond strength of ceramic restorations to dentin, the opposite is true of composite resin materials, as earlier debonding of the restoration may occur.

guidelines for composite resins and partial ceramic restorations appear to be less strict. Effective caries removal and proper height reduction for ceramics will be sufficient in most situations. Extension of the preparation for retention can be omitted as adhesion will be established. However, in some situations, the surface of the preparation is flat and provides little or no resistance. In such a situation, loading the restoration can result in unfavorable forces, parallel to the adhesive interface. This occurs, for example, in patients with severe tooth wear, where flat surfaces of exposed dentin need to be restored<sup>14</sup> and where the restoration is loaded in occlusion or articulation, enhancing the risk of debonding. These worn teeth are even more susceptible to debonding, as occlusal enamel will be lost and a large surface of dentin is exposed.<sup>14</sup> Earlier studies showed that adhesion of composite resin and glass ceramics to dentin is less effective than to enamel.<sup>15-17</sup>

To reduce the risk of early debonding, creating a retentive preparation with a resistance form or undercuts appears logical. The preparation of undercuts, slots or grooves, or surfaces perpendicular to the loads subjected along the restoration might decrease the forces transferred to the adhesive interface. However, except for studies of resin-bonded prostheses,<sup>18</sup> little is known about the benefit of resistance form to the retention of adhesive restorations. Previous laboratory research has shown that, depending on the adhesive technique, superficial grinding with a rotary instrument improves the bond strength to dentin<sup>19</sup> and that a preparation improves the performance of large cusp-replacing composite resin restorations.<sup>20</sup> However, an additional shoulder preparation led to no further improvement,<sup>20</sup> and no benefit of an additional shoulder on the fracture strength of partial ceramic restorations was found.<sup>21</sup>

This *in vitro* study evaluated how a resistance groove in a flat dentin surface affects the shear bond strength of restorations with different elastic moduli. Finite element analysis models were used for a better understanding of the results.

## MATERIAL AND METHODS

Shear bond strength tests were performed on 2 ceramic and 2 composite resin materials, bonded to a flat bovine dentin surface with or without an additional groove. Materials used in this study are summarized in [Table 1](#).

Cleaned bovine teeth stored in 0.5% chloramine at 4°C were used. All specimens were wet polished with 400-grit abrasive paper (Ecomet polisher; Buehler LTD), and, in half of the specimens, a groove was prepared with a diamond rotary instrument (FG 110/014; Komet Dental) at a speed of 18 000 rpm. The dimensions of the grooves were 5.0 mm long, 1.0 mm wide, and 0.6 mm deep. The composite resins Clearfil AP-X (AP) and Filtek Supreme XTE (FS) were bonded with Clearfil SE bond according to the manufacturer's instruction. A rubber mold (4.0-mm diameter, 2.5-mm height) was clamped to the treated surfaces and filled with the composite resin. The composite resin was photopolymerized for 20 seconds (Astralis10; Ivoclar Vivadent AG), the mold was removed, and the different specimens (n=8) were stored in water at 37°C for 24 hours.

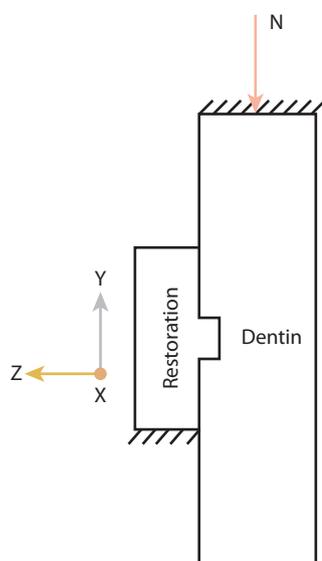
Cylinders of IPS E.max CAD (EM) and VITA Mark II (VM) were drilled from computer-aided design/computer-aided manufacturing (CAD/CAM) blocks under water cooling with a diamond-coated, hollow cylinder drill with an inner diameter of 4.0 mm. The cylinders, still attached to the block, were wet cut with a diamond-coated saw (Isomet 1000; Buehler LTD), preparing flat disks (diameter=4.0 mm; height=2.5 mm). In half of the specimens, a protrusion 4.0 mm long, 1.0 wide, and 0.5 mm high was prepared under water cooling with a diamond rotary instrument (FG 110/014; Komet Dental). Disks made of EM were crystallized in a porcelain furnace (Progamat P100; Ivoclar Vivadent AG) according to the manufacturer's instructions. The ceramic disks were pretreated to provide the optimal bond strength when luting them to dentin with a dual polymerizing composite resin cement.<sup>9</sup> Therefore, all ceramic specimens were etched for 20 seconds with 9% hydrofluoric acid (Ultradent Porcelain Etch; Ultradent Products Inc), rinsed with water, and dried. A chemical bond was established by silanating the etched microretentive surfaces with Clearfil porcelain bond activator mixed with Clearfil SE bond primer, according to the manufacturer's instructions. The bovine dentin was pretreated by applying a mixture of Panavia F2.0 ED primer II A and B for 30 seconds. The ceramic disks were then cemented to the dentin with a composite resin cement, Panavia F2.0. After excess cement had been removed, the specimens were photopolymerized for 20 seconds. This was followed by application of an oxygen-inhibiting gel (Panavia F2.0 Oxyguard II; Kuraray Medical Inc) on the margins for 5 minutes before the gel was rinsed off with water. This allowed the cement to polymerize chemically without oxygen inhibition. After cementation, the 4 different groups of specimens (n=8) were stored at 37°C at 100% humidity for 24 hours.

The shear bond strength of all specimens was determined in a universal testing machine (Model 6022; Instron) with a load cell of 1 kN at a crosshead speed of

**Table 1.** Composition of materials used

Code	Product	Composition
FS	Filtek Supreme XTE, 3M ESPE	Nanocomposite, filler load 62% vol. Non-agglomerated/non-aggregated 15-20nm zirconia nanofiller, Bis-GMA, UDMA, TEGDMA, Bis-EMA
AP	Clearfil APX, Kuraray Medical Inc	Conventional hybrid, filler load 70% vol. Barium glass filler 3 $\mu\text{m}$ , Bis-GMA, TEGDMA, silica, pyrogenic $\text{SiO}_2$
VM	VITA Mark II, VITA Zahnfabrik	30% vol.wt. feldspathic crystalline
EM	IPS e.max CAD	$\text{LiO}_2$ , $\text{K}_2\text{O}$ , $\text{MgO}$ , $\text{Al}_2\text{O}_3$ , $\text{P}_2\text{O}_5$
	Clearfil SE bond primer, Kuraray Medical Inc	MDP, HEMA, hydrophilic dimethacrylate, photo-initiator, water
	Clearfil SE bond, Kuraray Medical Inc	MDP, HEMA, Bis-GMA, hydrophobic dimethacrylate, photoinitiators, silanated colloidal silica
	Panavia F2.0 ED Primer II liquid A, Kuraray Medical Inc	HEMA, MDP, 5-NMSA, water, accelerator
	Panavia F2.0 ED primer II, liquid Kuraray Medical Inc B	5-NMSA, accelerator, water, sodium benzene sulfonate
	Clearfil porcelain bond activator, Kuraray Medical Inc	Hydrophobic dimethacrylate, $\gamma$ -MPS
	Panavia F2.0 paste A, Kuraray Medical Inc	Hydrophobic aromatic dimethacrylate, hydrophobic aliphatic dimethacrylate, sodium aromatic sulfonate (TPBSS, <i>N,N</i> -diethanol- <i>p</i> -toluidine, surface-treated (functionalized) sodium fluoride, silanated barium glass
	Panavia F2.0 paste B, Kuraray Medical Inc	MDP, hydrophobic aromatic dimethacrylate, hydrophobic aliphatic dimethacrylate, hydrophilic dimethacrylate, silanated silica, photoinitiator, dibenzoylperoxide

5-NMSA, *N*-methacryloyloxy-5-aminosalicylic acid; Bis-EMA, ethoxylated bis-phenol-A-dimethacrylate; Bis-GMA, bis-phenyl glycidylmethacrylate; EBPADMA, ethoxylated bis-phenol-A-dimethacrylate;  $\gamma$ -MPS,  $\gamma$ -methacryloyloxy propyltrimethoxy silane; HEMA, 2-hydroxyethyl dimethacrylate; MDP, 10-methacryloyloxydecyl dihydrogenic phosphate; PMMA, poly(methyl methacrylate); TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

**Figure 1.** Schematic representation of experimental arrangement and FEA model. FEA, finite element analysis.

1 mm/minute. The results at the load of failure by debonding were recorded in newtons. After testing, the surfaces of the dentin and the debonded ceramic and composite resin disks were examined using scanning electronic microscopy (SEM, model XL20; Philips). The failures were classified as adhesive, cohesive composite resin/ ceramic, cohesive dentin, or mixed failures.

The statistical differences of the shear bond strength of the groove versus no-groove and between the materials was analyzed with a 1-way ANOVA with a post hoc least significant difference test ( $\alpha=.05$ ) with software (PASW v20.0; SPSS, IBM Corp).

**Table 2.** Material properties used in FEA

Material	Elastic Modulus (GPa)	Poisson Ratio
Dentin	17.5 <sup>25</sup>	0.3
Filtek Supreme XTE	10.3 <sup>26</sup>	0.3
Clearfil APX	15.3 <sup>a</sup>	0.3
Vita Mark II	63.0 <sup>a</sup>	0.3
IPS e.max CAD	95.0 <sup>a</sup>	0.3

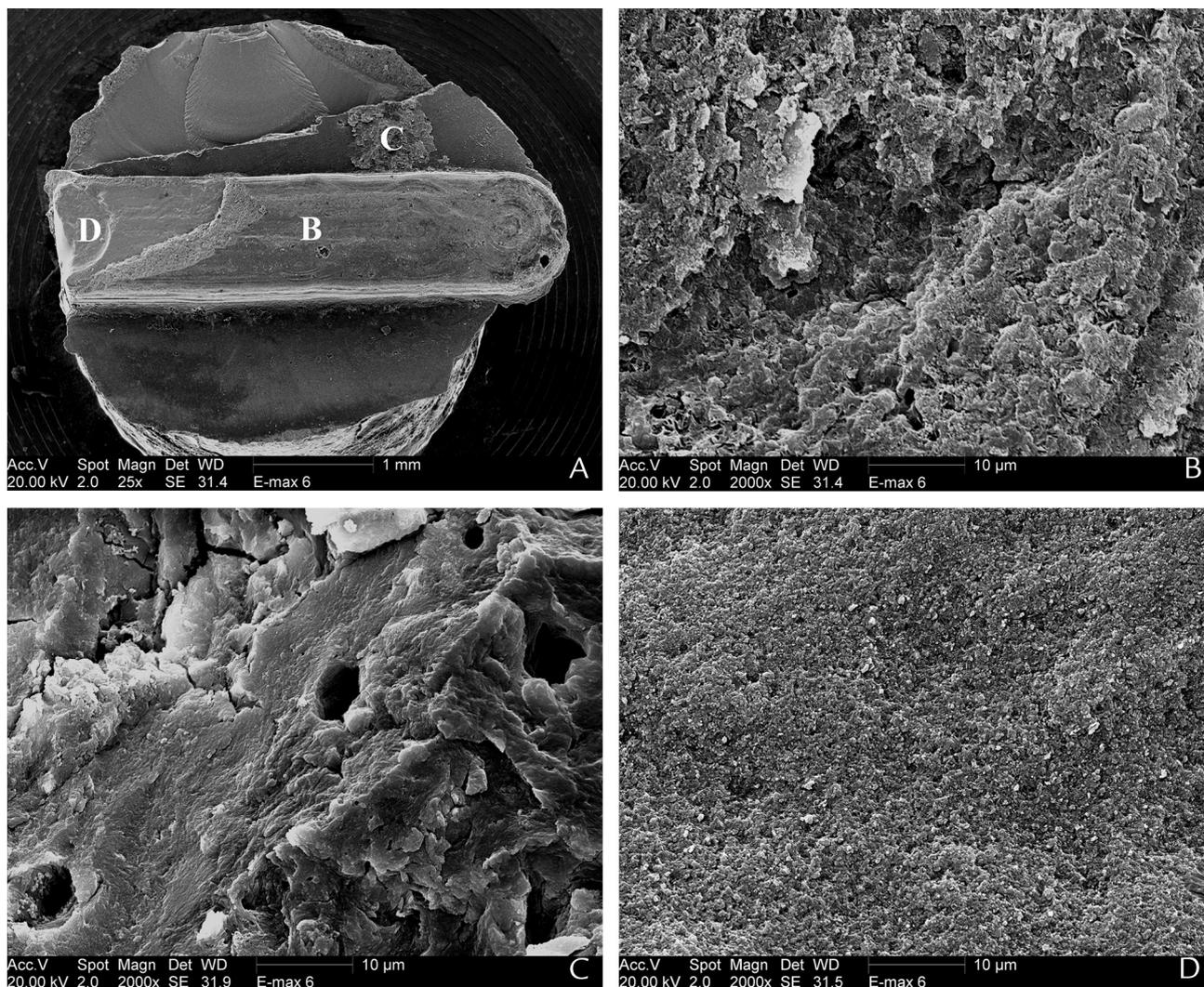
<sup>a</sup>According to manufacturer information.

**Table 3.** Shear bond strength comparison

Material	Mean ( $\pm$ SD) Shear Bond Strength (MPa) No Groove	Mean ( $\pm$ SD) Shear Bond Strength (MPa) With Groove
Filtek Supreme XTE	18.6 ( $\pm$ 4.9) <sup>1,a</sup>	16.3 ( $\pm$ 4.3) <sup>1,a</sup>
Clearfil APX	25.8 ( $\pm$ 3.8) <sup>1,b</sup>	24.2 ( $\pm$ 7.2) <sup>1,b</sup>
Vita Mark II	5.1 ( $\pm$ 3.0) <sup>1,c</sup>	8.7 ( $\pm$ 1.5) <sup>2,c</sup>
IPS e.max CAD	11.4 ( $\pm$ 3.7) <sup>1,d</sup>	17.7 ( $\pm$ 5.2) <sup>2,a</sup>

<sup>1,2</sup>Values with the same superscript numbers indicate no significant difference within rows. <sup>a,b,c,d</sup>Values with the same superscript letters indicate no significant differences within columns.

Three-dimensional finite element analysis (FEA) models of the test arrangement for the composite resin and ceramic restoration material were created. A model was made where the adhesion between the restoration material and the dentin was strong enough to resist the shear stresses in the interface restoration material/dentin (Fig. 1). The model was composed of 18 651 to 25 133 parabolic tetrahedron solid elements. The mechanical properties of the materials used are summarized in Table 2. A standardized load of 100 N was applied at the node in the middle of the top of the dentin disk. The nodes at the top of the dentin disk were fixed in the X-direction, and the nodes at the bottom of the restoration material disk were fixed in the X- and Y-directions



**Figure 2.** Scanning electron microscopy of ceramic fractures. A,  $\times 25$  magnification of complete specimen. B,  $\times 2000$  magnification showing cement. C, Magnification  $\times 2000$  showing dentin. D, Magnification  $\times 2000$  showing ceramic.

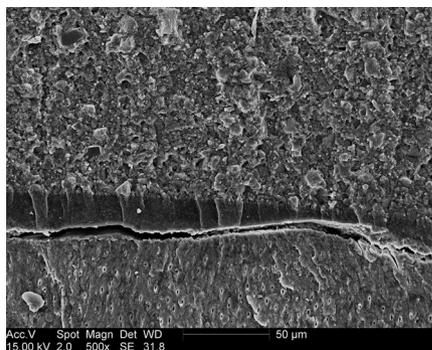
(Fig. 1). The nodes at the lateral surface of the dentin disk were allowed to slide along the surface only. The FEA was carried out using software (FEMAP v10.1.1; Siemens PLM), and analysis was carried out with appropriate software (NX Nastran; Siemens PLM).

## RESULTS

The mean shear bond strength and results of the statistical analysis are summarized in Table 3. The shear bond strength of VM ( $P=.028$ ) and EM ( $P\leq.001$ ) significantly increased in the presence of a retention groove. The shear bond strength of both composite resin materials was significantly higher than that for the ceramic materials, regardless of the presence or absence of a groove ( $P\leq.001$ ), except for FS with and without groove compared to EM with groove. Clearfil AP-X demonstrated a significantly higher shear bond strength than

Filtek Supreme ( $P\leq.001$ ). The type of failure as determined by SEM is shown in Figures 2 and 3 and Table 4. The specimens restored with composite resins without a groove failed adhesively or cohesively in the dentin. The specimens restored with these materials with a groove showed various types of failures. The specimens restored with ceramics always failed adhesively and sometimes were mixed cohesive failures. It was especially the ceramic specimens with a groove that showed a mixture of adhesive and cohesive failures in the ceramic. Only EM also failed cohesively sometimes in dentin.

The maximum tensile stress (solid maximum principal stress) in the dentin and the restoration and the shear stress (solid Y normal stress) along the adhesive interface in the dentin layer at a load of 100 N are shown in Table 5. This table shows the influence of the groove on the distribution of stresses for the different restorative materials. The shear stress concentration in the adhesive



**Figure 3.** Scanning electron microscopy image of Filtek Supreme XTE specimen after shear bond strength test at  $\times 500$  magnification, showing composite resin above and dentin below.

interface in the dentin layer increased for FS and AP specimens in the presence of a retention groove, whereas this stress decreased for VM and EM under the same conditions. Figure 4 shows the shear stress in the dentin layer for the FS and EM specimens with and without a groove. The positive and negative values, indicating the direction of the stresses, are equally important. The highest stresses in the interface of the FS restoration were found in the lower half of the specimen and increased in the presence of a groove. In contrast, the highest stresses at the interface of the EM restoration were found in the upper half of the specimen and decreased in the presence of a groove.

## DISCUSSION

This study showed no effect of a retention groove in a flat dentin surface on the shear bond strength of composite resin materials. For ceramics, the presence of a retention groove significantly reduced the shear stress at the interface of the dentin layer, resulting in an improved shear bond strength. Composite resins showed a higher shear bond strength than ceramics, regardless of the presence of a retention groove.

According to FEA analysis, the maximum stresses in the ceramics were less than in the composite resins. This is because ceramics have a much higher elastic modulus, and subsequently, the load is better distributed over the bonded area. Moreover, it is logical that the bond strength of materials with a high elastic modulus perform better than materials with a lower elastic modulus, where high local peak stress may occur. However, in addition to the stress distribution, the intrinsic bond strength between the material and dentin also determines the observed shear bond strength. For the specimens without a groove, the experimental results showed that despite the fewer shear stresses and more favorable elastic modulus of the ceramics, the bond strength between dentin and both composite resins was significantly higher. This would mean that the bond strength of the

**Table 4.** Classification of % of failures

Group	Adhesive	Cohesive Composite Resin/Ceramic	Cohesive Dentin	Mixed	
Filtek Supreme XTE	No groove	75	-	25	-
	Groove	25	37	25	13
Clearfil APX	No groove	13	-	87	-
	Groove	25	25	13	37
Vita Mark II	No groove	100	-	-	-
	Groove	-	-	-	100
IPS e.max CAD	No groove	94	-	-	6
	Groove	22	-	-	88

**Table 5.** Maximum tensile stress in restoration and dentin and maximum shear stress at interface in dentin at a load of 100 N

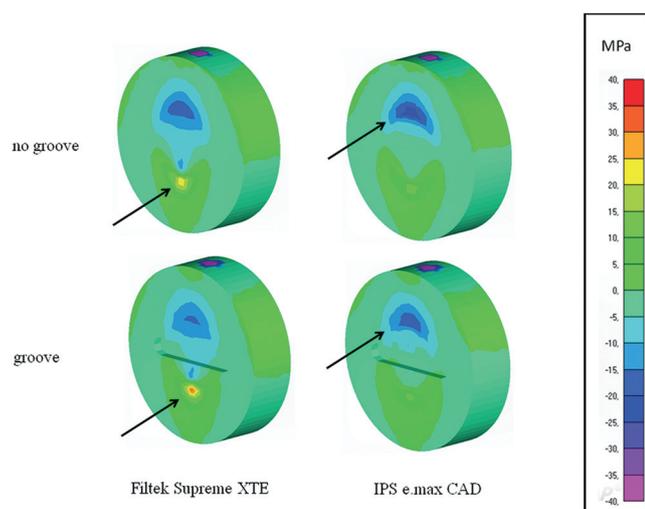
In Restoration $\sigma_t$ (MPa)	Material	In Dentin	
		$\sigma_t$ (MPa)	$\sigma_y$ (MPa)
Without groove			
42.5	Filtek Supreme XTE	46.0	25.5
39.0	Clearfil AP-X	41.5	22.5
27.5	Vita Blocks Mark II	26.0	22.5
26.0	IPS e.max CAD	23.0	24.0
With groove			
24.0	Filtek Supreme XTE	39.5	32.5
22.5	Clearfil AP-X	35.0	29.0
17.5	Vita Blocks Mark II	19.5	18.0
16.5	IPS e.max CAD	16.0	18.5

$\sigma_t$ , solid major principal stress;  $\sigma_y$ , solid Y normal stress.

cement is much weaker than the direct adhesive system of the composite resins.

The material with the highest shear bond strength was the conventional hybrid composite resin Clearfil AP-X, followed by the nanocomposite resin Filtek Supreme XTE. Both of these materials were bonded to dentin by a 2-step self-etching primer system. The superior shear bond strength of the direct composite resin restorations to dentin over indirect ceramic restorations was also expressed by a lower number of adhesive fractures and a higher number of cohesive fractures in dentin for FS and AP specimens without a groove (Table 4). These findings were confirmed in an earlier laboratory study by Sarr et al.<sup>3</sup> The AP specimen, particularly, appeared to fail earlier cohesively in the dentin than in the adhesive layer itself. The different behavior between AP and FS can also be explained by the difference in the modulus of elasticity. The higher elastic modulus of AP results in less deformation and more distribution of stresses to the dentin.

The glass ceramic restorations were adhesively cemented with a composite resin cement in combination with a self-etching primer. Although the bond strength of ceramics to dentin is also claimed to be better by using an etch and rinse cementation system,<sup>8</sup> most studies have recommended this self-etching system for bonding to dentin.<sup>3,10</sup> The significant lower shear bond strength



**Figure 4.** Shear stress (Solid Y normal stress) in contact surface of dentin layer for Filtek Supreme XTE and IPS e.max CAD with load of 100 N, with dentin and restoration attached.

values of ceramics compared with composite resins could be explained by the more favorable configuration value when a direct technique is performed that will reduce the polymerization stress.<sup>22</sup> Adhesive cementation will result in a higher shrinkage stress in the cement as the polymerization shrinkage can be less compensated by flow in the cement. The resilience in the ceramic will be nearly absent, and all the stress will concentrate in the relatively thin layer of cement.<sup>23</sup> Another explanation might be the strength of the cement itself, which will be lower than that of the composite resins because the cement has a lower filler load.

The increase in shear bond strength of both of the ceramics, created by applying a retention groove, is partially explained by the reduced shear stress but also by the mechanical resistance due to the groove. This implies a momentum where the shear bond strength of the cement was exceeded and the specimen was only held in place by the retention groove. Consequently, more cohesive fractures occurred in the ceramic restorations with a groove, leading to more mixed failures as observed in the experimental tests (Table 4).

Although a laboratory study by Clausen et al<sup>21</sup> failed to demonstrate an effect of a retentive preparation on the fracture strength of a ceramic restoration, the life span of the restoration might be improved by reducing the risk of early debonding. Because the shear bond strength of ceramics cemented on dentin can be a problem in the long term,<sup>15,16</sup> improving the preparation form by adding macromechanical support with minimal tissue removal might be valuable.

An interesting outcome of the finite element analysis was the location of the highest shear stress at the interface. As seen in Figure 4, the highest stresses in the composite resin restoration were found at a different

location from the ceramic restoration, independent of the presence of a groove. This might be explained by the differences in elastic moduli, as a stiffer material like EM will deform less when a force is applied, while the more flexible FS will demonstrate more deformation. This implies that for composite resins, the location of a resistance form will influence the shear bond strength. The shorter the distance between the loading point and the groove, the higher the concentration of stress will be, producing a lower adhesive surface shear bond strength.

The effect of a resistance form on the bonding of a composite resin restoration was demonstrated in an earlier laboratory study by Kuijs et al.<sup>20</sup> That study showed an effect caused by the retention of an amalgam preparation that was positive compared with a smooth surface when restoring a fractured premolar cusp with Clearfil AP-X. This improvement in shear bond strength can be explained by the mechanical resistance caused by the presence of flat surfaces perpendicular to the load that hold the restoration in place. Although this seems like an advantage, with the knowledge of current finite element analysis, it can be assumed that the shear stress at the restorative interface was increased by the preparation form, compared with the smooth surface. This implies that although the restoration is kept in place longer, earlier debonding occurs along the restoration interface, leading to clinical risks like dental caries and discoloration. Additional laboratory studies are recommended for a better understanding of this subject.

Despite all efforts to mimic a clinical situation, a laboratory shear bond strength test cannot fully represent all intraoral conditions.<sup>24</sup> Other factors including fracture resistance, fatigue loading, and degradation by water sorption will affect the long-term bond strength of a restoration.

## CONCLUSIONS

Within the limitations of this in vitro study, the preparation of a retention or resistance groove in an otherwise flat dentin surface has no positive effect on the shear bond strength of direct resin composite resin restorations. A retention groove does have a positive effect on the shear bond strength of ceramic restorations because of their higher elastic modulus. Nevertheless, the shear bond strength of composite resin restorations without a groove still exceeds that of ceramic restorations with a groove.

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