Journal of Dentistry 49 (2016) 68–74

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.intl.elsevierhealth.com/journals/jden

Protective effects of resin sealant and flowable composite coatings against erosive and abrasive wear of dental hard tissues

Xiaoyi Zhao[a,b], Jie Pan[a], Hans S. Malmstrom[b], Yan-Fang Ren[b,*]

[a] Department of General Dentistry, Peking University School of Stomatology, Beijing, China
[b] Department of General Dentistry, University of Rochester Eastman Institute for Oral Health, Rochester, NY, USA

ARTICLE INFO

Article history:
Received 24 December 2015
Received in revised form 18 January 2016
Accepted 27 January 2016

Keywords:
Resin sealant
Composite resin
Dental erosion
Tooth wear

ABSTRACT

Objectives: To test the effectiveness of sealant and flowable composite coating on eroded enamel, dentin and cementum under erosive/abrasive challenges in vitro.
Methods: A total of 108 tissue sections (36 each for enamel, dentin and cementum) from third molars were assigned to three groups: Seal & Protect sealant (S&P), Tetric EvoFlow composite (TEF) and control. Erosive/abrasive lesions were created on each specimen by citric acid and brushing with toothpaste. S&P and TEF were applied to the lesions and subjected to erosive/abrasive cycling included 24 cycles of immersion in citric acid (pH 3.6) for 60 min, followed by remineralization for 120 min and brushing with toothpastes for 600 strokes at 150 g. Erosive wear of materials or dental tissues were measured with 3D scanning microscopy and data were analyzed using ANOVA.
Results: Treatments with S&P and TEF created a protective material coating of 42.7 ± 17.8 μm and 150.8 ± 9.9 μm in thickness, respectively. After 24 cycles of erosive/abrasive challenges, tissue losses were -346.9 ± 37.3 μm for enamel, -166.5 ± 26.3 μm for dentin and -164.7 ± 18.2 μm for cementum in untreated controls, as compared to material losses of -24.4 ± 3.3 μm for S&P, and -10.8 ± 4.4 μm for TEF, respectively. Both S&P and TEF were effective in protecting enamel, dentin and cementum against erosive tooth wear ($p < 0.01$). S&P exhibited faster wear than TEF ($p < 0.01$) and showed spotted peeling in a third of the specimens. TEF remained intact on all three types of dental tissues at the end of the 24 cycles of erosive/abrasive challenges.
Conclusions: A thin coating of flowable composite resin 150 μm in thickness may provide long-term protection against erosive/abrasive tooth wear. Resin sealant may provide adequate protection for dental hard tissues in short-term and may require repeated applications if long-term protection is desired.
© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Erosive tooth wear commonly presents as shallow concavities on smooth surfaces occurring coronal from the cemento-enamel junction (CEJ) [1]. Wedge-shaped lesions that require the Class V restorations may develop with progression of the cervical wear. Such lesion was found to begin on cementum apical to the CEJ, subsequently involve underlying dentin, and eventually undermine enamel following the loss of cementum and dentinal tissues at the CEJ [2]. As erosive tooth wear compromises integrity of dental hard tissues and affects the quality of life in populations of all ages [3], its effective prevention is of paramount importance for dental professionals.

A protective coating that isolates dental hard tissues from acid contact and resists toothbrush abrasion may provide protection against erosive and abrasive challenges. In experiments in vitro, resin-based materials were able to prevent enamel erosion by hydrochloric and citric acid under long-term exposures [4], and provided protection against erosive and abrasive wear of dental enamel for two years under tooth brushing abrasive challenges [5].

Despite cervical wear is one of the most common form of erosive tooth wear and may lead to the formation of wedge-shaped cervical lesions, few studies have looked into the potential of resin-based materials for prevention of cervical erosive and abrasive wear. It is well recognized that non-carious cervical wear usually begins at CEJ, where cementum, enamel and dentinal tissues meet and form a unique tissue juncture that is vulnerable to mechanical, chemical and bacterial insults when exposed to the oral environment [6,7]. Application of resin-based materials to exposed CEJ

* Corresponding author at: Department of General Dentistry, University of Rochester Eastman Institute for Oral Health, 625 Elmwood Ave, Rochester, NY 14620, USA.
E-mail address: Yanfang_ren@urmc.rochester.edu (Y.-F. Ren).

http://dx.doi.org/10.1016/j.jdent.2016.01.013
0300-5712/© 2016 Elsevier Ltd. All rights reserved.

may isolate this area from extrinsic mechanical and chemical insults and prevent the progression of cervical wear. Though resin-based materials were shown to be effective against erosive wear of dental enamel in a recent study [5], it is not known if similar protective effects could be achieved on dentin and cementum as these tissues differ greatly from enamel in structure and properties.

The resin-based materials used in previous laboratory and clinical studies were limited to the lowly filled bonding agents or sealants [4,5,8–11]. The protective effects of these materials were often described as temporary in nature, presumably due to their lack of resistance to erosive and abrasive wear [9,12]. The highly filled composite resin materials may have the potential to improve the long-term outcomes as they have demonstrated high durability under erosive and abrasive attacks [13].

The aim of this study was therefore to investigate the protective effects of different resin-based coating materials against erosive and abrasive wear of enamel, dentin and cemtentum in vitro. We tested the hypothesis that a resin composite coating is superior to a sealant coating in protecting dental hard tissues against erosive and abrasive wear.

2. Materials and methods

2.1. Sample preparations

Enamel, dentin and cementum sections, 36 pieces each, were cut from the third molar with a water-cooled low speed diamond saw (MTI Corporation, Richmond, CA). A flat surface area approximately $3 \times 3\,mm^2$ was created on each specimen using 600, 1200, 2400 and 4000 grit (Extec Corporation, Enfield, CT) carbide paper on a rotating polishing machine (Unipol-810, MTI Corporation, Richmond, CA) under constant water irrigation.

2.2. Creation of erosive and abrasive lesions on enamel surfaces

All 108 specimen discs were partly covered with an adhesive tape to leave a $2\,mm \times 2\,mm$ band of exposed tissue surfaces. Each sample was then placed in individual containers with 15 ml of 0.034 M citric acid (Sigma–Aldrich Co., St. Louis, MO) at pH 3.6 for 30 min at 35 °C with gentle shaking (100 rpm) on a rocking incubator to simulate sipping a drink. The specimens were then rinsed in distilled water for 30 s, followed by immersion of each sample in 20 ml of artificial saliva for 60 min. The composition of the artificial saliva (pH 7.0) was adopted from Oliveira et al. [14] and contained the following chemicals in one liter of distilled water: 0.33 g KH_2PO_4; 0.34 g Na_2HPO_4; 1.27 g KCl; 0.16 g NaSCN; 0.58 g NaCl; 0.17 g $CaCl_2$; 0.16 g NH_4Cl; 0.2 g urea; 0.03 g glucose; 0.002 g ascorbic acid. Artificial saliva was prepared freshly every day. Exposed surface of each specimen was then brushed with a toothbrushing machine (Proto-tech, Portland, OR) for 300 strokes at a frequency of 120 strokes/min under 150 g pressure using the ADA standard toothbrush with a slurry of toothpaste (Crest® Cavity Protection, Procter & Gamble, Cincinnati, OH) and artificial saliva at 1:3 ratio by weight.

After the erosive and abrasive challenging cycles, adhesive tapes were removed and the surface profiles of the enamel, dentin and cementum were evaluated with a focus-variation 3D scanning microscopy (InfiniteFocus® G4, Alicona Imaging, Grambach/Graz, Austria) to capture the 3D topography of the eroded tissue surfaces [15,16]. Cementum specimens were inspected again at x1,000 magnification to ensure that no dentin tubules were exposed and the erosion remained within the limit of cementum tissue. The images of the erosive and abrasive lesions were taken at magnifications of approximately 200 with vertical resolutions of 0.1 μm. The depth of tissue wear was measured in μm at the maximum depth of the profile in 5 locations and the average of the 5 measurements was used to represent the erosive tissue wear.

2.3. Treatment of the erosive and abrasive lesions with resin-based materials

The enamel, dentin and cementum specimens with erosive and abrasive lesions were randomly assigned to three treatment groups, with 12 specimens in each group. After randomization, the adhesive tapes were replaced on the enamel surfaces to leave only the lesions exposed. The exposed enamel, dentin and cementum lesions were treated as follows: Group 1. No treatment, as negative control. Group 2. Coating of enamel, dentin and cementum lesions with a resin-based sealant (S&P). The lesion area was rinsed with water spray and air-dried, and the resin-based sealant Seal & Protect (Dentsply DeTrey GmbH, Konstanz, Germany) was applied for 20 sec. After air-drying for 5 s to remove the solvent, the sealant was light-cured for 10 s. The sealant was reapplied for 10 s, air-dried and light-cured again for 10 s. Group 3. Coating of enamel, dentin and cementum lesions with a flowable composite (TEF). The lesions were etched with 32% phosphoric acid gel (UNI-ETCH, BISCO Inc., Schaumburg, IL) for 15 s. After rinsing with water for 15 s and gently air-drying, a resin adhesive (OptiBond Solo Plus, Kerr Corp., Orange, CA) was applied for 15 s using a light brushing motion, and air-thinned for 3 s to avoid pooling before light curing for 5 s. A flowable composite resin, Tetric EvoFlow (Ivoclar Vivadent Inc, Amherst, NY), was applied and light cured for 10 s, and polished with Sof-Lex (3 M ESPE, St. Paul, MN) polishing discs in sequences of 4 from coarse to superfine following the manufacturer's instruction.

2.4. Erosive and abrasive challenges of treated lesions

After treatments with resin-based materials, enamel, dentin and cementum specimens in the 3 study groups were once again subjected to erosive challenges by citric acid and abrasive challenges by toothbrushing. Each erosive and abrasive challenging cycle included immersion of the specimens in citric acid (pH 3.6) for 60 min, in artificial saliva for 120 min and brushing for 600 strokes with the toothpaste slurry under 150 g of pressure at 35 °C. The specimens were placed in artificial saliva overnight between treatment cycles.

A total of 24 cycles of erosive and abrasive challenges were completed and the erosive wear of the treated areas were assessed with the 3D scanning microscopy at the end of 6, 12, 18 and 24 cycles of erosive and abrasive challenges. The depth of tissue or material wear was measured in μm at the maximum depth of the profile in 5 locations and the average of the 5 measurements was used to represent the erosive wear of the lesions in the control group or the material loss of the resin coating remained on the lesion surfaces in the study groups.

2.5. Statistical analyses

Two-factor analysis of variance (ANOVA) and the post hoc Fisher's least significant difference tests were used to compare tissue and material loss among the experimental groups. The two-factor repeated measures ANOVA and post hoc paired-*t* tests were used to compare tissue and material wear with time within the same group. All statistic analyses were conducted using the StatView 5.01 software (SAS Institute, Cary, NC). Bonferroni correction was applied to account for the effect of multiple comparisons.

3. Results

3.1. Baseline erosive and abrasive lesions on enamel, dentin and cementum

Lesion depths were on average −20.7 μm (±3.5) for enamel, −12.4 μm (±3.2) for dentin and −11.3 μm (±3.1) for cementum (Fig. 1). Enamel tissue showed greater erosive and abrasive wear than dentinal and cementum tissues ($p < 0.01$) (Table 1). Fig. 1 demonstrates the difference between enamel and dentinal wear in a specimen that includes both enamel and dentin.

3.2. Coating thickness after treatment with resin-based materials

After treatments of eroded lesions, a thin coating of the materials was visible on enamel, dentin and cementum surfaces in both the S&P and TEF groups (Figs. 2–4, Table 1). There were statistically significant differences in coating thickness among enamel, dentin and cementum surfaces and between the S&P and TEF groups ($p < 0.01$). Coating thickness was greater on the enamel surface than on the dentin and cementum surfaces ($p < 0.05$), and greater in the TEF than in the S&P groups ($p < 0.01$) (Table 1).

3.3. Erosive and abrasive wear of untreated tissue surfaces

As shown in Table 1 and Figs. 2–4, further erosive and abrasive challenges caused significant tissue loss on the untreated enamel, dentin and cementum surfaces (Table 1). There were significantly more tissue loss on enamel than on dentin and cementum after erosive and abrasive challenges ($p < 0.01$). Cementum tissue was completely lost and underlying dentin exposed in 7 specimens (58.3%) after 6 cycles, in 10 (83.3%) after 12 cycles, in 11 (91.7%) after 18 cycles, and in 12 (100%) after 24 cycles of erosive and abrasive challenges.

3.4. Erosive and abrasive wear of surfaces treated with resin-based materials

There were no further tissue loss in the S&P and the TEF groups as a coating of sealant and composite resin remained on the treated enamel, dentin and cementum surfaces after 24 cycles of erosive and abrasive challenges. In comparison to the baseline coating thickness for the S&P and the TEF groups, total material loss was on average −24.4 ± 3.3 μm for the S&P and −10.8 ± 4.4 μm for the TEF groups after 24 cycles of erosive and abrasive challenges. The material loss was statistically significant higher in the S&P than in the TEF group on all tissue surfaces ($p < 0.01$) (Table 2). There were no differences in material loss among different tissue surfaces treated by the same material ($p > 0.05$).

The material coating remained intact in the TEF group on enamel, dentin and cementum surfaces after 24 cycles of erosive and abrasive challenges. In contrast, spotted and partial peeling of material coating was seen in one third of the specimens in the S&P group at the end of erosive and abrasive cycling. Such partial peeling occurred on the peripheral of the material coating only after 18 cycles of erosive and abrasive challenges in most instances (Table 3). There was no statistically significant difference in frequency of material peeling among the three types of tissue surfaces ($p > 0.05$).

4. Discussion

The findings of the present study indicate that resin-based sealant and flowable composite coatings could protect enamel, dentin and cementum against erosive and abrasive challenges from extrinsic acids and toothbrushing and have the potential to prevent erosive cervical wear. The relatively highly filled (58%) flowbale composite showed significantly better protective effects against erosive wear and was stable on all three types of dental

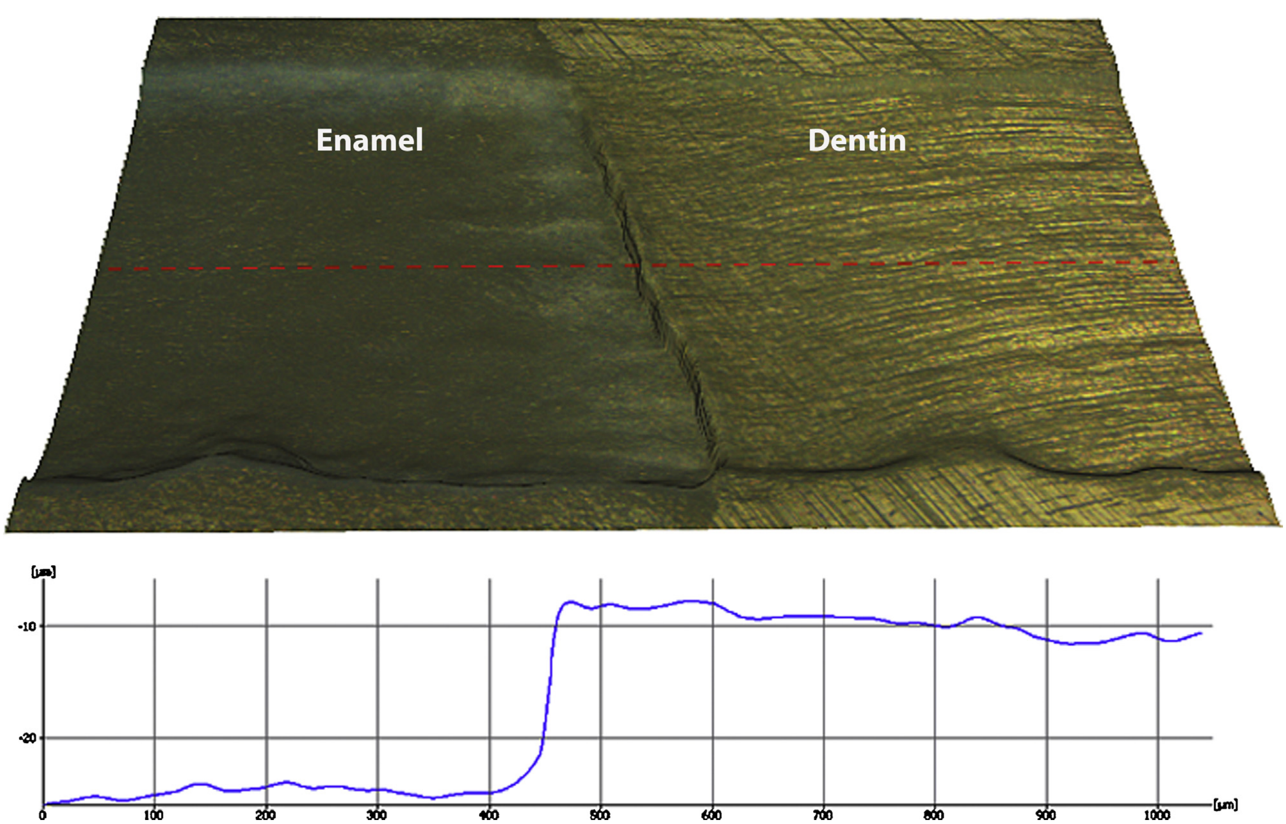

Fig. 1. Relative erosive and abrasive lesion depth on enamel and dentin.

Table 1
Lesion depths of untreated surfaces and material coating thickness (μm) of the sealant and flowable composite resin at baseline and after 6, 12, 18 and 24 cycles of erosive and abrasive challenges.

		Baseline		Cycle 6		Cycle 12		Cycle 18		Cycle 24	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control	Enamel	−20.7	3.5	−175.3	17.7	−250.9	33.6	−310.0	36.2	−367.5	39.8
	Dentin	−12.4	3.2	−68.5	8.5	−105.4	17.1	−145.2	24.5	−178.9	25.3
	Cementum	−11.3	3.1	−66.6	1.4	−102.9	18.5	−145.0	19.0	−181.4	19.4
S&P	Enamel	48.3	19.7	37.2	19.4	33.4	19.3	28.0	17.9	23.6	17.9
	Dentin	42.5	19.0	30.7	18.6	26.8	18.2	21.4	17.1	17.4	17.4
	Cementum	37.2	14.0	26.4	13.7	22.3	13.3	17.3	12.6	13.7	12.9
TEF	Enamel	159.7	7.5	156.2	6.5	153.8	7.3	151.2	7.1	148.5	7.1
	Dentin	143.5	7.7	131.9	6.8	141.1	8.1	138.1	10.3	135.4	10.9
	Cementum	142.5	8.2	131.3	8.2	140.3	8.9	138.1	9.6	136.0	10.5

S&P = Seal & Protect sealant; TEF = Tetric EvoFlow composite resin.

hard tissues as compared to the lightly filled (5%) sealant. A thin coating of the flowable composite, approximately 150 μm in thickness, provided adequate protection against 24 cycles of 600 strokes brushing and 60 min of citric acid erosion. The sealant created a thinner coating of less than 50 μm in thickness on dental hard tissue surfaces and may provide protection for at least 12 cycles of erosive and abrasive challenges.

The erosive and abrasive cycling model used in the present study intended to simulate long-term outcomes of coating treatments of eroded enamel, dentin and cementum surfaces. Assuming that each tooth may be subjected to two minutes of erosive challenges from extrinsic acids and 20 strokes of brushing per day [17], a total of 60 min of erosion in pH3.6 citric acid and 600 strokes of brushing represents one month of cumulative erosive and abrasive challenges. Twenty-four cycles therefore included 1,440 min of erosion and 14,400 brushing strokes, representing erosive and abrasive challenges in a two-year period. Citric acid (0.034 M, pH 3.6) was used to simulate the erosive attacks caused by most commercial orange juices [18]. Considering the remineralizing effect of saliva, eroded tissues were exposed to a remineralizing solution of artificial saliva containing 1.5 mmol/L calcium and 4.8 mmol/L phosphate for 2 h before the abrasive challenges and for at least 16 h overnight between each cycle. At the end of the experiments, about 11 μm of the material was lost in the flowable composite resin group, representing only 7% of the 150 μm total coating layer. The composite resin coating remained intact on enamel, dentin and cementum tissue surfaces. These findings indicate a thin coating of flowable composite resin may have the potential to provide long-term protection against erosive wear in the cervical area. In contrast, about 25 μm of the material was lost in the resin sealant group, representing more than 50% of the sealant coating layer. More importantly, partial peeling of sealant coating occurred in 3% of the specimens after 6 and 12 cycles but 25% of the specimens after 18 cycles of erosive and abrasive challenges, which suggests that the sealant coating becomes unstable with time and may require repeated applications if long-term protections are desired. These findings are in overall agreement with previous studies that showed the Seal &

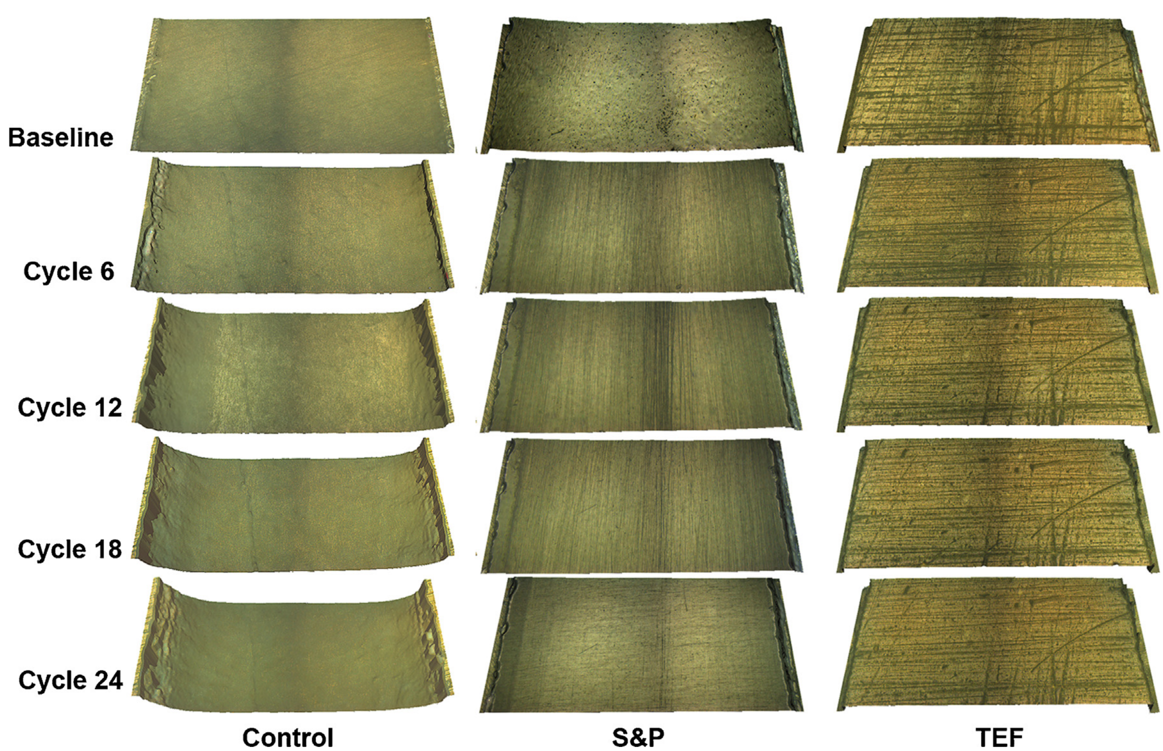

Fig. 2. Enamel tissue loss of untreated lesion (Control) and material loss of sealant (S&P) and flowable composite (TEF) after 6, 12, 18 and 24 cycles of erosive and abrasive challenges.

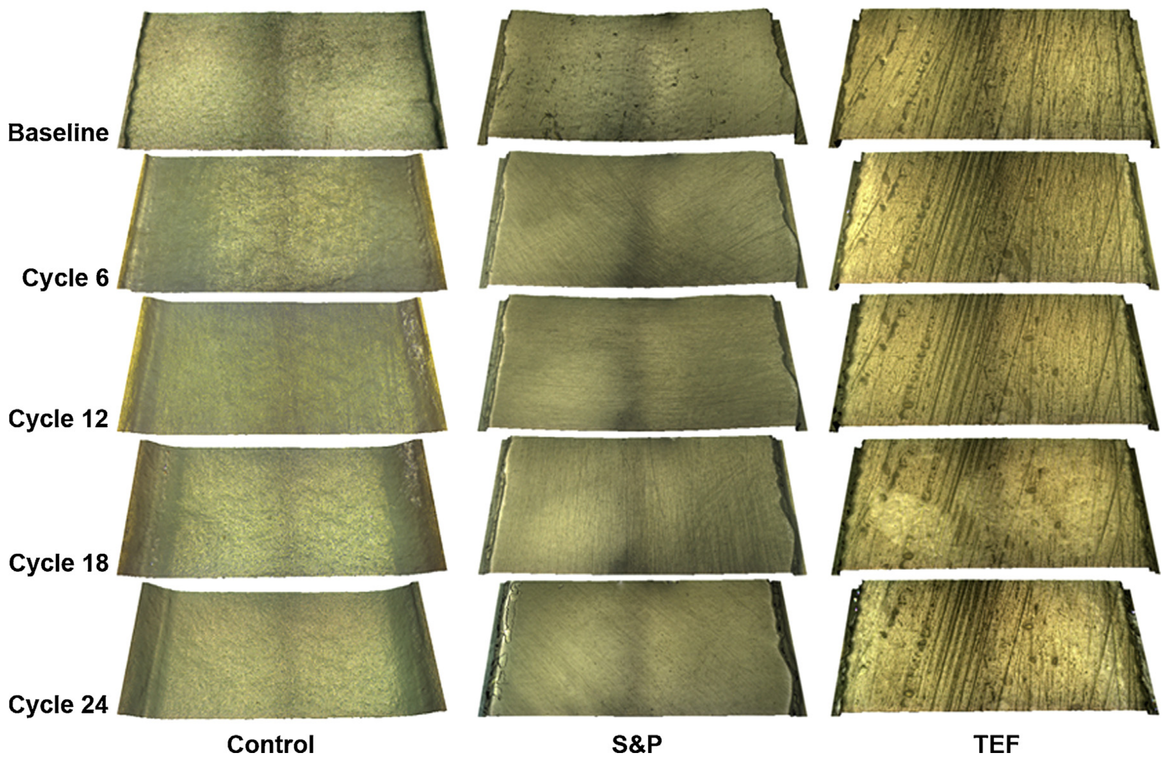

Fig. 3. Dentinal tissue loss of untreated lesion (Control) and material loss of sealant (S&P) and flowable composite (TEF) after 6, 12, 18 and 24 cycles of erosive and abrasive challenges.

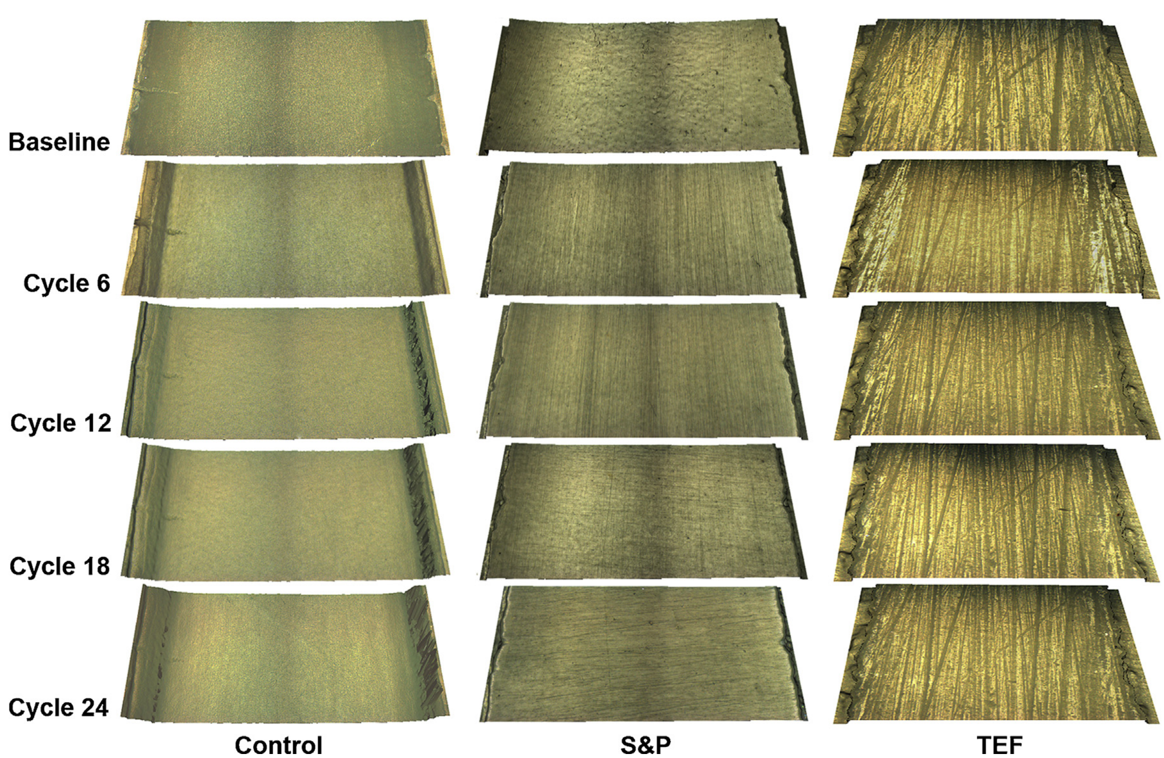

Fig. 4. Cementum tissue loss of untreated lesion (Control) and material loss of sealant (S&P) and flowable composite (TEF) after 6, 12, 18 and 24 cycles of erosive and abrasive challenges.

Table 2
Tissue wear and material loss (μm) after 6, 12, 18 and 24 cycles of erosive and abrasive challenges.[a]

		Cycle 6		Cycle 12		Cycle 18		Cycle 24	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control	Enamel	−154.6 a	16.0	−230.2 e	31.4	−289.3 k	34.0	−346.9 r	37.3
	Dentin	−56.1 b	9.8	−92.9 f	17.9	−132.8 m	25.4	−166.5 s	26.3
	Cementum	−55.3 b	8.8	−91.6 f	16.0	−130.0 m	17.7	−164.7 s	18.2
S&P	Enamel	−11.1 c	2.5	−15.0 g	2.8	−20.4 n	3.3	−24.7 t	3.6
	Dentin	−11.8 c	2.4	−15.6 g	2.6	−21.1 n	3.1	−25.1 t	3.4
	Cementum	−10.7 c	2.2	−14.9 g	1.9	−19.9 n	2.8	−23.5 t	3.0
TEF	Enamel	−3.6 d	1.4	−5.9 h	2.1	−8.6 p	2.7	−11.3 u	3.5
	Dentin	−2.9 d	2.0	−5.3 h	2.2	−8.4 p	5.0	−11.0 u	5.7
	Cementum	−3.7 d	1.9	−5.8 h	2.5	−8.0 p	3.1	−10.2 u	4.0

[a] Different letters in the same row (Two-Factor Repeated Measures ANOVA and *post hoc* paired-t test) and the same column (Two-Factor ANOVA and *post hoc* Fisher's LSD test) denotes statistically significant differences at $p < 0.01$. S&P = Seal & Protect sealant; TEF = Tetric EvoFlow composite resin.

Protect resin sealant could provide temporary protections against erosive and abrasive wear [9–11], and partial peeling of material may occur after an extended period of erosive and abrasive challenges [5].

Though its durability is inferior to that of a flowable composite resin, Seal & Protect sealants may still be an useful product against erosive tooth wear due to its ease of application in clinical settings [8]. Seal & Protect is promoted as a self-adhering sealant for dentin but there is evidence that it adheres to enamel as well and protect enamel surface against erosive and abrasive challenges [5]. As it does not require etching, it may be acceptable to apply the sealant coating periodically to exposed cervical area after each prophylactic teeth cleaning. Another way to extend the longevity of the protective coating is to apply multiple coats of the sealant. It has been shown that a coating about 169 μm thick could be created if five coats of the sealant were applied instead of the two as suggested by the manufacturer, and the sealant coating remained intact on the cervical surface after 19 months and effectively prevented the progression of cervical wear in 24 patients [19]. The findings of the present study provide further evidence that this type of sealant coating is useful for application in the cervical area as it could provide protection to all three types of dental hard tissues around the CEJ.

The flowable composite used in the present study, Tetric EvoFlow, contains a much higher amount of fillers (58%) than the sealant, which is likely the reason for its improved resistance to erosive and abrasive challenges. In comparison to dental hard tissues, composite resin is significantly more resistant to erosion by acidic beverages and abrasion by toothbrushing. Yu et al. [13] reported that, after six daily cycles of erosion by citric acid (pH 2.3) for one minute, remineralization in artificial saliva for 30 min and abrasion by toothbrushing under 250 g pressure for 100 strokes, tissue loss was 36.74 μm for dental enamel as compared to material loss of only 0.56 μm for Tetric EvoFlow, signifying a 60-folds difference between enamel and flowable composite in their ability to resist erosive and abrasive challenges. We used a mild acid (pH 3.6), a long remineralization time (120 min after erosion and overnight between cycles) and 150 g brushing load for the erosive and abrasive cycling, and found that tissue loss for enamel was 30 times higher than material loss for Tetric EvoFlow (Table 2). The fact that dental hard tissues wore significantly faster than composite restoration surfaces under erosive and abrasive conditions has important clinical implications. It on one hand substantiates the clinical observation that composite restorations often stand proud of the adjacent tooth surfaces due to erosive wear and helps with differential diagnosis of dental erosion [20]. On the other hand, it indicates that dental hard tissues covered by the composite materials will be protected against erosion and abrasion, and supports the use of composite material coating as a preventive measure for erosive tooth wear.

We found that enamel tissue loss was almost twice as high as dentin and cementum loss in the untreated control group under the erosive and abrasive conditions used in the present study (Table 2). Comparisons with previous findings are difficult as experimental conditions such as erosive agents, pH values, dentifrices, toothbrushes, brushing force, and especially the reminineralization intervals, vary greatly among the studies comparing erosive wear of different dental tissues [21–24]. In general, enamel tissue loss was found to be higher than dentin loss under erosion alone [21,25,26], but dentin tissue loss was higher than enamel loss under a combination of erosion and abrasion [27–30]. For example, enamel loss was reported to be three times higher than dentin loss per cycle (6.7 μm vs 2.0 μm on average) under an erosive cycling protocol that included 10 min of citric acid (pH 2.3) erosion and one hour of remineralization at 37 °C [25]. In contrast, dentin loss was nearly three times higher than enamel loss per cycle (1.03 μm vs 0.35 μm on average) under an erosive and abrasive cycling protocol that included 10 min of citric acid (pH 3.2) erosion, two hours of remineralization and 200 strokes of brushing abrasion under a load of 2 N at 23.8 °C [30]. The fact that the dentin tissue showed less wears than enamel in the present study is likely related to a lower brushing load (150 g), an extended remineralization interval and the long-term nature of the study design. Enamel and dentin tissues have distinct differences after an erosive attack. As an organic matrix or subsurface demineralization is absent after mineral loss, eroded enamel surfaces are not conducive to remineralization in oral environment. In contrast, an organic matrix rich in collagen is exposed on dentin surfaces during erosion, which may act as a buffering membrane preventing further acid penetration and as a scaffold for dentin

Table 3
Number and proportions of specimens with partial peeling of material coating on eroded enamel, dentin and cementum surfaces in the S&P group.[*]

	Enamel (n = 12)		Dentin (n = 12)		Cementum (n = 12)		Total(N = 36)	
	#	%	#	%	#	%	#	%
Cycle 6	0	0	1	8.3	0	0	1	2.8
Cycle 12	0	0	1	8.3	0	0	1	2.8
Cycle 18	3	25.0	4	33.3	2	16.7	9	25.0
Cycle 24	4	33.3	5	41.7	3	25.0	12	33.3

[*] Fisher's exact contingency table test, $p > 0.05$.

remineralization [31,32]. This organic matrix and a demineralized layer underneath may be removed by strong abrasive forces if no remineralization occurs. In the present study, the eroded dental tissues were placed in a remineralizing solution containing 1.5 mmol/L calcium and 4.8 mmol/L phosphate ions. It is probable that the eroded dentin surfaces were partially hardened after they were placed in remineralizing solution for 2 h after erosion and for more than 16 h over night between cycles simulating 24 months of erosive and abrasive challenges. As the brushing force of 150 g was lower than that in most previous studies, it might not be heavy enough to remove the organic matrix on the eroded dentin surfaces and cause tissue loss [33].

Erosive wear of cementum surfaces were nearly identical to that of dentin. In fact, cementum was completely removed and underlying dentin exposed in more than half of the specimens after 6 cycles and in all specimens after 24 cycles of erosive and abrasive challenges. Cementum is therefore very vulnerable to erosive wear once gingival recession occurs and CEJ exposes to the oral environment.

In summary, this study demonstrated that a thin coating (150 μm) of flowable composite resin could provide adequate protection against erosive and abrasive wear of enamel, dentin and cementum for at least a period equivalent to 24 months. A coating of sealant provided adequate protection for enamel, dentin and cementum for a shorter period and may require repeated applications if long-term protection is desired. The sealant wore at a faster pace than the flowable composite resin and may lose surface integrity after a period equivalent to 12 months of erosive and abrasive challenges. A brushing force of 150 g appeared to be inadequate to cause accelerated wear of eroded dentin surfaces. These findings suggest that coating of exposed cervical area with a thin coating of flowable composite may provide long-term protection against erosive wear and has the potential to prevent the formation of wedge-shaped lesions.

Acknowledgment

This study was self-funded by the authors' institutions and the authors received no financial support from commercial or industrial entities.

References

[1] C. Ganss, A. Lussi, Diagnosis of erosive tooth wear, Monogr. Oral Sci. 25 (2014) 22–31.
[2] L.A. Litonjua, S. Andreana, P.J. Bush, T.S. Tobias, R.E. Cohen, Wedged cervical lesions produced by toothbrushing, Am. J. Dent. 17 (4) (2004) 237–240.
[3] A.-K. Johansson, R. Omar, G.E. Carlsson, A. Johansson, Dental Erosion and Its Growing importance in clinical practice: from past to present, Int. J. Dent. 2012 (2012) 632907.
[4] F.J. Wegehaupt, T.T. Taubock, B. Sener, T. Attin, Long-term protective effect of surface sealants against erosive wear by intrinsic and extrinsic acids, J. Dent. 40 (5) (2012) 416–422.
[5] H.M. Korbmacher-Steiner, A.F. Schilling, L.G. Huck, B. Kahl-Nieke, M. Amling, Laboratory evaluation of toothbrush/toothpaste abrasion resistance after smooth enamel surface sealing, Clin. Oral Invest. 17 (3) (2013) 765–774.
[6] K. Arambawatta, R. Peiris, D. Nanayakkara, Morphology of the cemento-enamel junction in premolar teeth, J. Oral Sci. 51 (4) (2009) 623–627.
[7] K. Satheesh, S.R. MacNeill, J.W. Rapley, C.M. Cobb, The CEJ: a biofilm and calculus trap, Compend. Contin. Educ. Dent. 32 (2:30) (2011) 32–37 quiz 38, 40.
[8] G. Sundaram, R. Wilson, T.F. Watson, D. Bartlett, Clinical measurement of palatal tooth wear following coating by a resin sealing system, Oper. Dent. 32 (6) (2007) 539–543.
[9] D. Bartlett, G. Sundaram, R. Moazzez, Trial of protective effect of fissure sealants, in vivo, on the palatal surfaces of anterior teeth, in patients suffering from erosion, J. Dent. 39 (1) (2011) 26–29.
[10] A. Azzopardi, D.W. Bartlett, T.F. Watson, M. Sherriff, The surface effects of erosion and abrasion on dentine with and without a protective layer, Br. Dent. J. 196 (6) (2004) 351–354 discussion 39.
[11] A. Azzopardi, D.W. Bartlett, T.F. Watson, M. Sherriff, The measurement and prevention of erosion and abrasion, J. Dent. 29 (6) (2001) 395–400.
[12] E. Yetkiner, F.J. Wegehaupt, R. Attin, A. Wiegand, T. Attin, Stability of two resin combinations used as sealants against toothbrush abrasion and acid challenge in vitro, Acta Odontol. Scand. 72 (8) (2014) 825–830.
[13] H. Yu, F.J. Wegehaupt, A. Wiegand, M. Roos, T. Attin, W. Buchalla, Erosion and abrasion of tooth-colored restorative materials and human enamel, J. Dent. 37 (12) (2009) 913–922.
[14] G. de Oliveira, A. Boteon, F. Ionta, M. Moretto, H. Honorio, L. Wang, et al., In vitro effects of resin infiltration on enamel erosion inhibition, Oper. Dent. (2015).
[15] Y.-F. Ren, X. Liu, N. Fadel, H. Malmstrom, V. Barnes, T. Xu, Preventive effects of dentifrice containing 5000 ppm fluoride against dental erosion in situ, J. Dent. 39 (10) (2011) 672–678.
[16] Y.-F. Ren, Q. Zhao, H. Malmstrom, V. Barnes, T. Xu, Assessing fluoride treatment and resistance of dental enamel to soft drink erosion in vitro: applications of focus variation 3D scanning microscopy and stylus profilometry, J. Dent. 37 (3) (2009) 167–176.
[17] A. Wiegand, T. Attin, Design of erosion/abrasion studies–insights and rational concepts, Caries Res. 45 (Suppl. 1) (2011) 53–59.
[18] E. Rakhmatullina, A. Bossen, C. Hoschele, X. Wang, B. Beyeler, C. Meier, et al., Application of the specular and diffuse reflection analysis for in vitro diagnostics of dental erosion: correlation with enamel softening, roughness, and calcium release, J. Biomed. Opt. 16 (10) (2011) 107002.
[19] A. Baysan, E. Lynch, Treatment of cervical sensitivity with a root sealant, Am. J. Dent. 16 (2) (2003) 135–138.
[20] T.S. Carvalho, P. Colon, C. Ganss, M.C. Huysmans, A. Lussi, N. Schlueter, et al., Consensus report of the European Federation of Conservative Dentistry: erosive tooth wear—diagnosis and management, Clin. Oral Invest. 19 (7) (2015) 1557–1561.
[21] C. Ganss, J. Klimek, N. Schwarz, A comparative profilometric in vitro study of the susceptibility of polished and natural human enamel and dentine surfaces to erosive demineralization, Arch. Oral Biol. 45 (10) (2000) 897–902.
[22] S. Hooper, N.X. West, M.J. Pickles, A. Joiner, R.G. Newcombe, M. Addy, Investigation of erosion and abrasion on enamel and dentine: a model in situ using toothpastes of different abrasivity, J. Clin. Periodontol. 30 (9) (2003) 802–808.
[23] N.X. West, J.A. Hughes, M. Addy, Erosion of dentine and enamel in vitro by dietary acids: the effect of temperature, acid character, concentration and exposure time, J. Oral Rehabil. 27 (10) (2000) 875–880.
[24] N.X. West, J.A. Hughes, M. Addy, The effect of pH on the erosion of dentine and enamel by dietary acids in vitro, J. Oral Rehabil. 28 (9) (2001) 860–864.
[25] N. Schlueter, C. Ganss, U. Mueller, J. Klimek, Effect of titanium tetrafluoride and sodium fluoride on erosion progression in enamel and dentine in vitro, Caries Res. 41 (2) (2007) 141–145.
[26] N. Schlueter, J. Klimek, C. Ganss, Efficacy of tin-containing solutions on erosive mineral loss in enamel and dentine in situ, Clin. Oral Invest. 15 (3) (2011) 361–367.
[27] A. Wiegand, B. Hiestand, B. Sener, A.C. Magalhaes, M. Roos, T. Attin, Effect of TiF4, ZrF4, HfF4 and AmF on erosion and erosion/abrasion of enamel and dentin in situ, Arch. Oral Biol. 55 (3) (2010) 223–228.
[28] L.P. Comar, A. Cardosocde, S. Charone, L.T. Grizzo, M.A. Buzalaf, A.C. Magalhaes, TiF4 and NaF varnishes as anti-erosive agents on enamel and dentin erosion progression in vitro, J. Appl. Oral Sci. 23 (1) (2015) 14–18.
[29] A.T. Hara, D.T. Zero, Analysis of the erosive potential of calcium-containing acidic beverages, Eur. J. Oral Sci. 116 (1) (2008) 60–65.
[30] S. Ranjitkar, J.M. Rodriguez, J.A. Kaidonis, L.C. Richards, G.C. Townsend, D.W. Bartlett, The effect of casein phosphopeptide–amorphous calcium phosphate on erosive enamel and dentine wear by toothbrush abrasion, J. Dent. 37 (4) (2009) 250–254.
[31] C. Ganss, J. Klimek, U. Schaffer, T. Spall, Effectiveness of two fluoridation measures on erosion progression in human enamel and dentine in vitro, Caries Res. 35 (5) (2001) 325–330.
[32] C. Ganss, A. Lussi, N. Schlueter, The histological features and physical properties of eroded dental hard tissues, Monogr. Oral Sci. 25 (2014) 99–107.
[33] C. Ganss, M. Hardt, D. Blazek, J. Klimek, N. Schlueter, Effects of toothbrushing force on the mineral content and demineralized organic matrix of eroded dentine, Eur. J. Oral Sci. 117 (3) (2009) 255–260.