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Enamel preservation during composite removal after orthodontic debonding comparing hydroabrasion with rotary instruments

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The aim of the present study was to evaluate how hydroabrasion performs during composite removal. A standardized amount of composite was bonded to 40 enamel surfaces of extracted third molars, then removed with either a tungsten carbide bur mounted on a micro-motor handpiece without irrigation, a tungsten carbide bur mounted on a micro-motor handpiece with irrigation, a tungsten carbide bur mounted on an air-rotor handpiece, or hydroabrasion. The four treatment methods were compared using the enamel-surface-index and the adhesive-remnant-index and performing a Kruskal-Wallis statistical test to detect differences between each method' scores. Hydroabrasion produced significantly less damage to the enamel surface compared to the other three methods. Hydroabrasion was the cleaning method that produced less damages to the enamel surface, at a cost of a less efficient composite removal than tungsten carbide burs on micro-motor handpiece.

Keywords: Debonding, Hydroabrasion, Tungsten carbide bur, Enamel surface index, Adhesive remnant index

INTRODUCTION

After debonding of a fixed orthodontic appliance, residuals of composite resins are present on the enamel surface. These composite residuals need to be accurately removed, because they are responsible for an increase in plaque accumulation[1)], and the retention of discolored integuments that cause alterations in tooth color[2)]. While removing those residuals, it is important to not damage the enamel surface, because the outer layer of the enamel is the most rich in fluoride[3)], and iatrogenically induced roughness of the enamel surface will result in increased accumulation of plaque and staining particles[4)].

There are different methods for removing composite residuals, like tungsten-carbide burs, Sof-Lex discs, ultrasonic tools, hand instruments, Er:YAG or CO_2 lasers, rubber or composite burs[5-8)], and many authors have studied those methods to find the one which best combines capability of removing composite residuals, respect for the enamel surface, and operating time. Tungsten carbide burs are faster and more effective than other instruments, and are considered the gold standard[9)]; however, all of these methods cause a certain amount of enamel loss and do not allow restoration of the enamel surface to its original state[9,10)].

Alternatively to rotary instruments, the technique called air-abrasion —based on the abrasive effect due to the kinetic energy of particles of aluminium oxide powder accelerated by air pressure— has been widely used for debris removal, cavity preparation, and also orthodontic composite removal[11)]. To overcome one of the limitations of air-abrasion, the spread of aluminium oxide powder over the operative field and surroundings, a new method called hydroabrasion has been developed, using a water spray to limit the diffusion of powder particles and concentrate the particle stream, a technique that is becoming popular in dental practice for several applications due to its increased comfort[12)]. The aim of the present study was to evaluate performance in composite removal efficacy and enamel surface roughness, comparing hydroabrasion to tungsten carbide burs, the actual gold standard, mounted on a micro-motor- or air-rotor handpiece, with or without irrigation. The null hypothesis was that no difference exists in terms of composite residuals and quality of enamel surface between the four methods.

MATERIALS AND METHODS

The present research protocol was approved by the Internal Review Board of the University of L'Aquila, Italy (Protocol number 25403), all patients provided informed consent and all methods were performed in accordance with the relevant guidelines and regulations. Twenty third molars extracted for therapeutic reasons were collected; to be included in the study sample, teeth were observed under 2.5× magnifying loupes and had to present an intact enamel surface and present no signs of erosion or abrasion, no surface demineralization, no decay and no traumatic damage provoked by forceps during the extraction procedure.

The teeth were disinfected with 5% sodium hypochlorite solution (Niclor 5, Ogna, Muggiò, Italy), then stored in 0.9% sodium chloride solution at room temperature until the start of the experimentation and for no more than 2 months. For each tooth, both the vestibular and lingual surface were used, to have a total of 40 different enamel surfaces to be studied.

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Enamel conditioning and adhesion procedure

Each dental enamel surface was ideally divided into two areas, one to be conditioned and prepared for adhesion of orthodontic composite, and the other to be left unmodified and to be used as a control for normal enamel surface. All the surfaces studied were coded for identification purposes, assigning a number to each mesio-vestibular, disto- vestibular, mesio-lingual, and disto-lingual surface of each tooth. An online tool (www.randomizer.org) was used to randomly assign a treatment modality to every surface, taking care that every vestibular and lingual surface had both a treatment and a control surface. The control surface was coated with a Teflon film to avoid contamination.

An area with a dimension of approximately 5×3 mm was etched with 37% orthophosphoric acid gel (DentoEtch, Itena, Paris, France) for 30 s, then rinsed with water for 30 s and accurately dried with compressed air. A thin layer of adhesive primer (Transbond XT Light Cure Adhesive Primer, 3M Unitek, Monrovia, CA, USA) was coated above the etched surface; the excess was gently removed with compressed air, then light-cured for 10 s.

To have a standardized amount of orthodontic composite for removal a silicone mould (Mini-Mold small wire bonder, G&H Orthodontics, Franklin, IN, USA) was used to apply the composite (Transbond Plus, 3M Unitek) onto the enamel. After removing the excess with a dental explorer, the composite was light-cured for 40 s. This method was preferred over the conventional bonding of a bracket and its subsequent removal, because debonding a bracket results in an uneven composite surface, therefore each enamel surface would have had a different amount of composite to be removed, possibly biasing the study results.

Composite removal

The so-prepared composite layers were then removed following four different methodologies:

- Tungsten carbide (WC) bur with eight blades, 1.6 mm diameter and a working-surface length of 4.7 mm (Komet Dental, Lemgo, Germany) mounted on a micro-motor low-speed handpiece, used without irrigation and with a continuous flow of compressed air to avoid overheating and to remove the powder produced during mechanical removal of composite to assure visibility;
- WC bur with eight blades, 1.6 mm diameter and a working-surface length of 4.7 mm (Komet Dental) mounted on a micro-motor low-speed handpiece, used with continuous irrigation;
- WC bur with eight blades, 1.6 mm diameter and a working-surface length of 4.7 mm (Komet Dental) mounted on an air-rotor high-speed handpiece, used with continuous irrigation;
- Hydroabrasion (PrepStart H2O, Danville, CA, USA) at an air pressure of 3 bar, the flow of aluminium oxide powder (with a particle's diameter of 27 μ) set at a minimum, and the water flow opened by two turns and four graduation marks; the nozzle of the handpiece was oriented parallel to the enamel surface, at a distance of nearly 5 mm; to avoid accidental damage, the intact 'control' enamel surface was isolated with three layers of masking tape during this procedure.

Each instrument was used under the same conditions of lighting and positioning by the same operator (EB), until complete removal of composite residual was achieved under naked eye observation.

Sample preparation and outcome assessment

After composite removal, the samples were dehydrated through immersion in ascending alcoholic solutions: in 25% ethanol and 75% distilled water for 2 h, then in 50% ethanol solution for 2 h, then in 75% ethanol solution for 24 h, then immersed in pure ethanol for 2 h. At this point, the teeth were first observed through a stereo microscope (S8 APO, Leica Microsystems, Wetzlar, Germany) for a preliminary assessment (Fig. 1), then thoroughly evaluated with a scanning electron microscope (SEM; XL30 CP, Philips Electron Optics, Eindhoven, the Netherlands) equipped with an energy dispersive spectroscope (EDS; INCA Energy 250, Oxford Instruments, Abingdon, UK) under back scattering electron (BSE) modality at different magnifications (60×, 125×, 250×, 500×, and 1,000×). The BSE modality gives images where contrast is derived from the composition of the observed material; in addition, the EDS device was used to specifically evaluate the elemental composition of the dental surfaces to discriminate between adhesive and composite remnants. The specimens were not coated with any conductive material, to avoid biased results of the elemental composition analysis. Then BSE images at 500× were associated to the observed elemental composition, allowing to discriminate between primer, composite, and enamel based on the contrast of the images. The SEM images at 250× and 60× magnification of both the treated and control enamel area of each of the 40 dental surfaces were used to assess the presence of adhesive or composite residuals and the quality of the surface after use of each of the four instruments. The quality of the enamel surface was assessed on 60× and

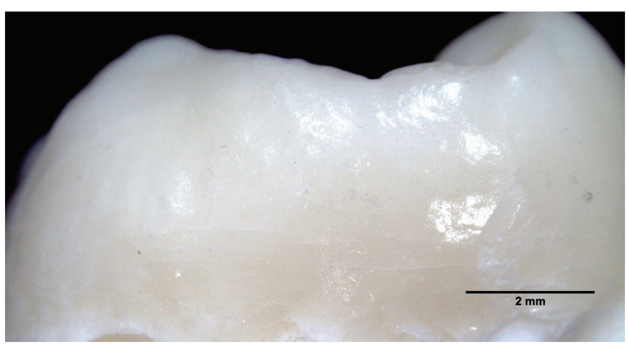

Fig. 1 Dental surface after composite removal observed with a stereo microscope.

Table 1 Enamel surface index according to Zachrisson and Årtun

Score 0	Perfect surface with no scratches and intact perikymata
Score 1	Satisfactory surface with fine scratches and some perikymata
Score 2	Acceptable surface with several and some deeper scratches, no perikymata
Score 3	Imperfect surface with several distinct deep and coarse scratches, no perikymata
Score 4	Unacceptable surface with coarse scratches and deply marked appearance

Table 2 Adhesive remnant index according to Årtun and Bergland

Score 0	No adhesive residuals left on the enamel surface
Score 1	Less than 50% of adhesive left on the enamel surface
Score 2	More than 50% of adhesive left on the enamel surface
Score 3	Less than 50% of adhesive and composite left on the enamel surface
Score 4	More than 50% of adhesive and composite left on the enamel surface

250× images through the enamel surface index (ESI) as proposed by Zachrisson and Årthun[13], assigning scores from 0 to 4 (Table 1) to each treated surface. Such magnifications were chosen to have both a wide view on the treated surface, and a closer view of the details of the enamel surface. The presence of adhesive/composite residuals was evaluated on 60× images with the adhesive remnant index (ARI) as proposed by Årtun and Bergland[14], assigning scores from 0 to 4 (Table 2) to each treated surface. Such magnification was chosen to have a wide view on the entire treated surface. The scores were calculated by one operator (MT) who was blinded regarding the method used for composite removal on each surface.

Error of the method

Both ARI and ESI scores were evaluated twice for every dental surface by the same operator (MT), at a 1-week interval. Intra-rater agreement was calculated using Cohen's weighted kappa.

Statistical analysis

A Kruskal-Wallis test was used to evaluate if any difference was present between the four composite removal methods regarding the ARI and ESI scores. *Post hoc* analysis was performed using a Mann-Whitney *U*-test. The type I error was set as 0.05 for all tests.

RESULTS

The EDS device was first used to analyze a 3 mm diameter disc of polymerized primer and a disc of polymerized composite, thus recording a spectrum mainly composed of carbon and oxygen for the primer, and of silicium and aluminium for the composite (Fig. 2).

Intra-rater agreement as calculated with Cohen's kappa with square weights was 99.4% for ARI scores (kappa=0.95; p<0.001) and 98.3% for ESI scores

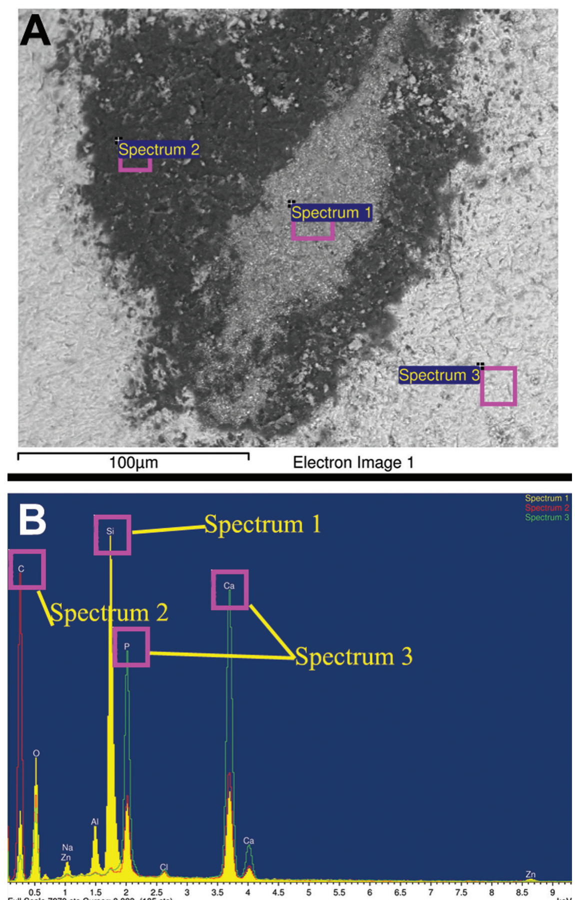

Fig. 2 Energy dispersive spectroscopy (EDS) of composite (Spectrum 1), adhesive (Spectrum 2) and enamel (Spectrum 3).
(A) The three materials as they appear under BSE imaging modality. (B) The elemental composition of composite (yellow), adhesive (red) and enamel (green).

(kappa=0.94; p<0.001).

Figure 3 reports the images of the tooth surfaces under BSE modality at 250× magnification, used to evaluate the ESI score; the intact enamel with appreciable perikymata is indicated with outlined arrows, while the treated surfaces, with different aspects, are indicated by solid black arrows (Fig. 3). Figure 4 reports the images at 60× magnification under BSE modality, used to evaluate the ARI score; the normal enamel and the residuals of adhesive or composite resin are indicated with different arrows, referring to the data obtained from the EDS analysis (Fig. 2). Frequencies of ESI and ARI scores are reported in Tables 3 and 4. The Kruskal-Wallis test for ESI scores showed a highly statistically significant difference (Table 5): the *post hoc* analysis showed that hydroabrasion produced significantly less damage to the enamel surface than the other three methods. In addition, there was no difference between WC burs on a low-speed handpiece with and without irrigation, but both methods produced significantly less damage than a WC bur on a high-speed handpiece (Table 6, Fig. 3).

Regarding the ARI scores, the Kruskal-Wallis test detected a highly statistically significant difference (Table 5): the *post hoc* analysis revealed that WC burs on a low-speed handpiece with and without irrigation produced less residual adhesive than hydroabrasion (p=0.007 and p=0.001, respectively) or a WC bur

Table 3 Frequencies of ESI scores for each method

Score	Hydroabrasion		WC bur on low-speed without irrigation		WC bur on low-speed with irrigation		WC bur on high-speed	
	n	%	*n*	%	*n*	%	*n*	%
0	0	0	0	0	0	0	0	0
1	9	90	4	40	4	40	0	0
2	1	10	4	40	5	50	0	0
3	0	0	2	20	1	10	3	30
4	0	0	0	0	0	0	7	70
Total	10	100	10	100	10	100	10	100

ESI, Enamel Surface Index according to Zachrisson and Årtun; WC, Tungsten carbide bur.

Table 4 Frequencies of ARI scores for each method

Score	Hydroabrasion		WC bur on low-speed without irrigation		WC bur on low-speed with irrigation		WC bur on high-speed	
	n	%	*n*	%	*n*	%	*n*	%
0	0	0	0	0	2	20	0	0
1	2	20	9	90	6	60	2	20
2	0	0	1	10	0	0	0	0
3	7	70	0	0	2	20	8	80
4	1	10	0	0	0	0	0	0
Total	10	100	10	100	10	100	10	100

ARI, Adhesive Remnant Index according to Årtun and Bergland; WC, Tungsten carbide bur.

Table 5 Kruskal-Wallis test for comparison of indexes scores between the 4 groups (n=10 for each group)

Index	Chi-Square	df	p
ESI	26.42	3	<0.001
ARI	18.39	3	<0.001

ESI, Enamel Surface Index according to Zachrisson and Årtun; ARI, Adhesive Remnant Index according to Årtun and Bergland.

Table 6 *Post-hoc* comparison of ESI scores between each group (n=10 for each group)

Method (I)	Method (J)	Mann-Whitney U	Z	p
Hydroabrasion	WC bur on low-speed without irrigation	24.0	−2.33*	0.020
	WC bur on low-speed with irrigation	24.5	−2.30*	0.021
	WC bur on high-speed	0.0	−4.01**	<0.001
WC bur on low-speed without irrigation	WC bur on low-speed with irrigation	47.0	−0.25	0.805
	WC bur on high-speed	3.0	−3.69**	<0.001
WC bur on low-speed with irrigation	WC bur on high-speed	1.5	−3.81**	<0.001

*statistically significant with p<0.05; **statistically significant with p<0.01; ESI, Enamel Surface Index according to Zachrisson and Årtun; WC, Tungsten carbide bur.

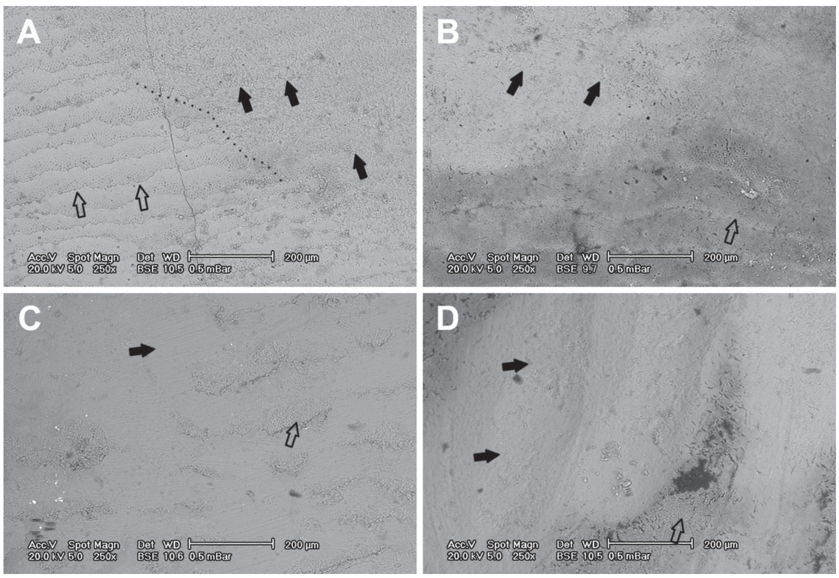

Fig. 3 Enamel surface under BSE imaging modality at 250× magnification for ESI score evaluation.
(A) Composite removed with hydroabrasion: the dotted line divides the treated area from the intact enamel, outlined arrows indicate the intact enamel with clearly defined perikymata, while solid arrows indicate the dotted surface treated with hydroabrasion, with perikymata still appreciable. (B) Composite removed with a tungsten carbide bur on a low-speed handpiece with no irrigation: the outlined arrow indicates the perikymata of untouched enamel, while solid arrows indicate the fine scratches produced by the bur. (C) Composite removed with a tungsten carbide bur on a low-speed handpiece with irrigation: the solid arrow indicates the fine scratches produced by the bur, while the outlined arrow indicates the intact perikymata. (D) Composite removed with a tungsten carbide bur on a high-speed handpiece: the solid arrows indicate a deep sulcus in the enamel excavated by the bur, while the outlined arrow indicates an area of intact enamel with remnants of adhesive and composite.

on a high-speed handpiece (p=0.007 and p=0.001, respectively). There was no significant difference in the presence of adhesive residuals between the use of hydroabrasion and a WC bur on a high-speed handpiece, or between the use of WC burs on a low-speed handpiece with and without irrigation (Table 7, Fig. 4). Therefore, the null hypothesis was rejected.

Table 7 *Post-hoc* comparison of ARI scores between each group (n=10 for each group)

Method (I)	Method (J)	Mann-Whitney U	Z	p
Hydroabrasion	WC bur on low-speed without irrigation	11.0	−3.31**	0.001
	WC bur on low-speed with irrigation	17.0	−2.71**	0.007
	WC bur on high-speed	46.0	−0.4	0.689
WC bur on low-speed without irrigation	WC bur on low-speed with irrigation	47.0	−0.3	0.765
	WC bur on high-speed	11.0	−3.36**	0.001
WC bur on low-speed with irrigation	WC bur on high-speed	18.0	−2.68**	0.007

**statistically significant with p<0.01; ARI, Adhesive Remnant Index according to Årtun and Bergland; WC, Tungsten carbide bur.

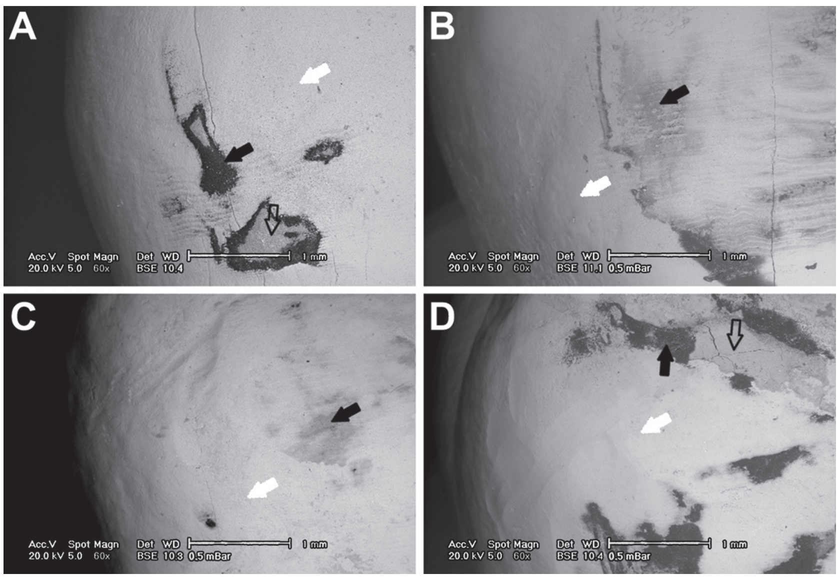

Fig. 4 Enamel surface under BSE imaging modality at 60× magnification for ARI score evaluation.
Solid white arrows indicate clean enamel without residuals, solid black arrows indicate residuals of adhesive, and outlined arrows indicate residuals of composite resin. (A) Composite removed with hydroabrasion. (B) Composite removed with a tungsten carbide bur on a low-speed handpiece with no irrigation. (C) Composite removed with a tungsten carbide bur on a low-speed handpiece with irrigation. (D) Composite removed with a tungsten carbide bur on a high-speed handpiece.

DISCUSSION

According to the literature, there is no instrument or technique that can allow the removal of composite residuals from the dental surface without any damage to the enamel[9]. This was confirmed also by the results of the present study, since no surface earned an ESI score of 0 (*i.e.* perfect enamel surface). Initial damage to the enamel surface is produced during routine phosphoric acid etching, where 5 to 50 µm of prismatic and interprismatic enamel can be lost[15]. Then, rotary instruments cause an amount of enamel abrasion that is dependent on the hardness of the bur's material or size and the composition of abrasive particles, the rotational speed and the pressure exerted against the dental surface[16]. The latter factor makes this procedure operator-dependent. Besides that, the results of the present study confirmed that rotational speed is an important factor, because when the WC bur was mounted on a low-speed handpiece, less damage was produced than with the high-speed handpiece, which showed the worst performance (Table 6); this was in accordance with previous studies[7]. In addition, using only a blow of compressed air as a cooling method resulted in less damage to the enamel surface, compared to the same bur and a low-speed handpiece used with water irrigation; this result can probably be explained by the better visibility that allows clear distinction between the composite and the enamel surface. Air-cooling is a reliable method, since some authors have demonstrated that the thermotransduction properties of enamel and dentin result in only 10% of the temperature increase at the surface to be transmitted to the pulp; therefore, no significant heat damage can be caused to the pulp[17]. On the other hand, hydroabrasion was the most conservative method among the four tested. Compared to the rotary instruments tested, 90% of the surfaces studied presented a satisfactory surface with appreciable perikymata without scratches, and this result was statistically significant. The enamel characteristics after treatment with hydroabrasion were very similar to those achieved after acid etching, with a dotted appearance. Composite removal with hydroabrasion was, as well as that with rotary instruments, an operator-dependent procedure: orienting the nozzle parallel to the occlusal surface is crucial to obtain such conservative results, while pointing the spray perpendicular to the enamel surface can produce significant damage to the tooth structure. Hydroabrasion was never used as a method for composite removal after orthodontic debonding. Some authors studied the effect of intraoral sandblasting on the enamel surface for such a procedure, observing a behavior that was similar to that of WC burs on a low-speed handpiece[18]. However, these results are not comparable to those of the present study, because hydroabrasion has a different technology, and intraoral sandblasting was used perpendicular to the enamel surface, which can have an important effect on the outcomes. No surface polishing after composite removal was performed during the present study, and this was intended to assess the damage directly produced to the enamel by the instrument tested during composite removal. Quantifying the amount of substance loss is difficult, and all measurement methods present some limits when defining a reference point for depth measurements[9]. Using the perikymata as a reference, Zachrisson and Årthun calculated an amount of 5–10 μm of enamel lost[13], but Fjeld and Øgaard reported that perikymata can be present even at greater depths[15]. Other authors reported that an enamel layer measuring from 22.8 to 50.5 μm can be lost using a WC bur[19].

Regarding the assessment of the amount of adhesive or composite remnants, the best performance was achieved using WC burs on a low-speed handpiece with or without irrigation, with no significant difference between the two (Table 7). On the other hand, both hydroabrasion and a WC bur on a high-speed handpiece left significantly more residuals than a WC bur on a low-speed handpiece. In particular, when hydroabrasion was used, the perikymata were interspersed with bands of adhesive (Fig. 4A): less abrasion of the enamel surface was also accompanied by an almost complete removal of composite (outlined arrows, spectrum 1 of ESD analysis, Fig. 2), but incomplete removal of adhesive (solid black arrows, spectrum 2 of ESD analysis, Fig. 2). This result could have been easily anticipated, since it is not possible to completely remove adhesive remnants without damaging the enamel, because during enamel conditioning and bonding procedures, resin tags that infiltrate the enamel by up to 50 μm are produced[15]. Thus, to completely remove the resin, this layer of enamel should be abraded as well. It is necessary to underline that, during the present study, the removal of composite was carried out until there were no longer any residuals visible on naked eye observation, and that the enamel surface appeared to be clean even under stereo microscope observation. Whether it would be preferable to have major respect for the enamel, leaving more adhesive residuals, or to completely remove the adhesive at the cost of abrading the outer layer of enamel should be clarified by future studies. As highlighted by a systematic review[20], there is moderate evidence from *in vitro* studies, all with a risk of bias ranging from unclear to high, that adhesive remnants can cause enamel discoloration. Regarding bacterial adhesion, it has been demonstrated that increased surface roughness up to 0.2 μm facilitates bacterial adhesion: beyond this threshold, a further increase in roughness does not influence bacterial adhesion[4]. In addition, the surface free energy of biomaterials also plays a role, facilitating bacterial adhesion through polar and van der Waals interactions, and orthodontic adhesives have roughness (about 0.1 μm for Transbond XT used in the present study) and surface free energy properties that allow adhesion of cariogenic bacteria[21,22].

Other factors that are clinically important are the time needed for composite removal and the dispersion of aluminium oxide particles. Kim *et al.* reported that air-abrasion required longer time than low-speed handpiece bur for composite removal[18]; however, the time for a clinical procedure measured in an *in-vitro* environment should be considered with caution. Regarding the dispersion of aluminium oxide particles, which is considered by some authors one of the main limitations of intraoral sandblasting, hydroabrasion has a significant advantage over air-abrasion, because the amount of powder that gets sprayed around is limited by the presence of a waterjet, thus reducing the need for patients' and operator's protection and the contamination of the operative field[12]. However, these aspects were not evaluated in the present study and need further investigations.

One of the limitations of the present study was the absence of a precise quantitative method to assess the amount of enamel lost during removal of composite residuals. Even if the *in-vitro* nature of the present study could be considered a limitation, the design of an *in-vivo* study that allows to evaluate the ultrastructure of the enamel in a living subjects raises many difficulties. In addition, since no studies on the use of hydroabrasion are present in the current literature, starting a research branch from *in-vitro* testing represents the most logical progression. Further studies are needed to evaluate the enamel surface after polishing of the surface treated with hydroabrasion, and the influence of adhesive remnants on the enamel surface.

CONCLUSIONS

Composite removal through hydroabrasion was found to be the safest method, which left an enamel surface with still appreciable perikymata, with no evident scratches but with a dotted appearance. Among rotary instruments, a WC bur mounted on a micro-motor low-speed handpiece without irrigation allowed effective removal of composite residuals with less enamel damage compared to the other two methods relying on abrasive burs. On the other hand, hydroabrasion left more adhesive residuals compared to a WC bur on a low-speed handpiece. Further studies are needed to evaluate the effect of polishing on the treated enamel surface.

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