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Abrasive effects of diamond dentifrices on dentine and enamel

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SUMMARY

This study was to analyse the abrasive wear of differently composed diamond dentifrices loaded with 2.4 μm diamond particles on dentine and enamel surfaces *in vitro*. Bovine specimens were brushed with a diamond-loaded dentifrice (DD2; 2 g particles/kg), a diamond-loaded dentifrice (1.5 g/kg) containing 20% hydrated silica as extra abrasive (DD1.5+S), or a diamond-loaded dentifrice (3 g/kg) containing 20% hydrated silica abrasive (DD3+S). Values were compared to those obtained with Colgate Total (CT) and Elmex Sensitive plus (ES). Brushing was performed using a cross brushing machine (F = 2.5 N; 120 brushing strokes/min). Abrasive wear [μm] of specimens (n = 12) was measured profilometrically and adjusted to 10,000 brushing strokes (10 kBS). Data were compared between groups using one-way ANOVA and post-hoc pairwise tests with Tukey correction, alpha = 0.05. Diamond dentifrices and ES showed no difference on dentine specimens: DD2 7.7 ± 2.6 μm/10 kBS; DD1.5+S 10.1 ± 2.3 μm/10 kBS; DD3+S 10.1 ± 2.6 μm/10 kBS; ES 7.4 ± 1.1 μm/10 kBS, while CT-brushed specimens exhibited significantly higher dentinal abrasion compared to all other groups: CT 31.0 ± 7.7 μm/10 kBS. Diamond loading significantly influenced enamel wear (mean ± SD μm/10 kBS): DD2 1.8 ± 0.5 μm/10 kBS. Conversely, addition of the silica abrasive reduced these values: DD1.5+S 1.1 ± 0.3 μm/10 kBS; DD3+S 1.6 ± 0.3 μm/10 kBS. CT and ES revealed similarly low values: CT 0.3 ± 0.1 μm/10 kBS; ES 0.2 ± 0.1 μm/10 kBS. These data suggest that abrasion caused by diamond particles in experimental toothpastes is differentially affected by diamond particle load, additional abrasives, and the type of hard tissue.

Introduction

Abrasive particles in toothpastes are common ingredients and incorporated to remove dental stain from brushed surfaces. These particles should ideally be harder than the stain and softer than enamel and dentine to enable cleaning without causing major harm to the dentition. Common abrasive particles include hydrated silica, calcium carbonate and other calcium-containing compounds, sodium metaphosphate, alumina, perlite, nanohydroxyapatite, and sodium bicarbonate (Lippert 2013). The toothpaste cleaning efficacy and abrasion potential on dentine and enamel is mainly based on the incorporated abrasive, its particle hardness, size, shape and concentration within pastes (Wiegand et al. 2008; Franzò et al. 2010), but also correlated to the toothbrush (Wiegand et al. 2006), the brushing force (Wiegand et al. 2013), and brushing technique that are used. Highly abrasive particles may lead to better cleaning efficacies, but may also cause clinical problems such as tooth sensitivity and cervical lesions, which may interfere in pulp integrity and aesthetics (Radentz et al. 1976; Tawakoli et al. 2015). It has been shown that toothpastes with a very good cleaning ability frequently provoke a higher surface roughness and abrasive wear on dentine and enamel (Imfeld et al. 1998; Tawakoli et al. 2015). The abrasivity of toothpastes has been described and measured as relative enamel or dentine abrasivity (REA, RDA) by means of radioactive dentin release measurements or by tooth surface profile changes (Gonzalez-Cabezas et al. 2013). Most commercially available toothpastes have already been subjected to these tests and were categorised according to their abrasive wear (Imfeld et al. 1998; Pickles et al. 2005; Giles et al. 2009; Schemehorn et al. 2011; Tawakoli et al. 2015). Recently, new toothpaste abrasives, namely diamond particles, have been introduced as single or additional abrasives in commercially available dentifrices. Hitherto, it is not determined how diamonds as co-abrasives or single abrasive compounds influence enamel and dentinal wear. The aim of this study was therefore to investigate the abrasive wear of different diamond-loaded dentifrices and range them within reference toothpastes exhibiting different abrasion properties on dentine and enamel.

Materials and methods

Specimen preparation

Bovine dentine and enamel specimens were produced using bovine incisors. In brief, crowns were cut off from the roots and stored in a 0.1% thymol solution (VWR International, Dietikon, Switzerland) for no longer than six months. The use of bovine teeth as substitute for human teeth has been justified in comparative studies (Imfeld 2001; Wegehaupt et al. 2010). Cylindrical specimens (5 mm in diameter) were prepared out from each crown and ground stepwise from 1,200 to 4,000 Fepa P using water-cooled carborundum discs (1,200, 2,400, 4,000 grits, waterproof silicon carbide paper, Struers, Erkath, Germany). For dentine specimens' preparation, grinding was performed under wet conditions. All specimens were embedded in acrylic resin (Paladur, Hereus Kulzer, Germany). The aspects of all specimens were ground to a 300 µm lower level, which served as reference surface and was covered with a metal template during abrasion, thus mimicking more natural conditions and higher sensitivity to brushing effects by enabling the direct contact of the toothbrush bristles with the enamel and dentine surfaces (Fig. 1).

Treatment

The specimens were allocated into five groups for dentine and five groups for enamel (n = 12, each), and brushed with DD2 (a diamond-loaded dentifrice, 2 g particles/kg, particle size: 2.4 µm) without additional abrasives, DD1.5+S (a diamond-loaded dentifrice, 1.5 g/kg with 20% abrasive), DD3+S (a diamond-loaded dentifrice, 3 g/kg with 20% abrasive), CT (Colgate Total Original, Colgate-Palmolive, Swidnica, Poland), or ES (Elmex Sensitive plus, GABA International AG, Swidnica, Poland). The composition of all tested dentifrices is listed in Table I. Slurries were prepared freshly for all experiments, containing toothpaste and artificial saliva (Klimek et al. 1982) in a ratio of 1:3. Brushing was performed using a standard manual toothbrush (Paro M43, Esro AG, Thalwil, Switzerland) in a cross-brushing machine (F = 2.5 N; 120 brushing strokes/min). The toothbrush bristles were at right angle to the test surface. The toothbrush heads were rotated horizontally at 11 degrees to avoid striation. Abrasive wear of all specimens was measured profilometrically at baseline. Dentine specimens (under moist conditions) were re-measured after 3,600 and 7,200 brushing strokes (BS); enamel specimens after 21,600 and 43,200 BS (Attin et al. 2009). A stylus profilometer (Mahr Perthometer S2/GD 25; Mahr, Göttingen, Germany) was used for all experiments (stylus tip, 2 µm in diameter; force during measurements, about 0.7 mN). A custom-made jig for the repositioning of specimens enabled precise re-measurements. Five parallel profiles (Ra = 3 mm) were recorded at distances of 0.25 mm. Profiles were orientated perpendiculary to the brushing movements.

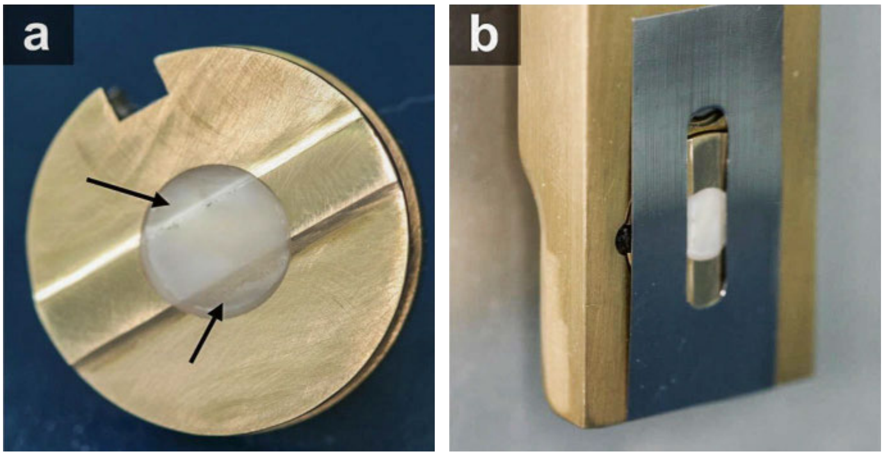


Fig. 1 Enamel specimen before brushing. The central test surface (a) is 300 µm above the reference surface (arrows) and the holding device. A magnetic metal template (b) covers the reference surface during abrasion.

Tab. I Groups and brand names, manufacturers, and ingredients (proprietary amounts) of the tested dentifrices

Toothpaste	Manufacturer	Content of base	Abrasive
DD2 diamond dentifrice	a	Aqua, Glycerin, Sorbitol, PEG-400, Xanthan gum, Texapon Z95P, Aroma, Titanium dioxide, Sodium fluoride, Methylparaben, Saccharin, and Covarine Blue	Diamond particles [2.4 µm, 2 g/kg]
DD1.5+S diamond dentifrice	a	Glycerin, Aqua, Propylen glycol, Xylitol, PEG-8, PEG-40 Hydrogenated castor oil, Cocamidopropyl betaine, Cellulose gum, Potassium phosphate, Aroma, Sodium chloride, Rebaudioside A, Sodium fluoride, Diamond particles, C.I.42090, and Limonene	Hydrated silica, Diamond particles [2.4 µm, 1.5 g/kg]
DD3+S diamond dentifrice	a	see above	Hydrated silica, Diamond particles [2.4 µm, 3 g/kg]
CT Colgate Total Original LOT No: (L)6199 PL 113D1	b	Aqua, Glycerin, PVM/MA Copolymer, Sodium lauryl sulfate, Cellulose gum, Aroma, Sodium hydroxide, Carrageenan, Sodium fluoride, Triclosan, Sodium saccharin, Limonene, CI 77891	Hydrated silica
ES Elmex Sensitive plus LOT No: (L)6167 PL 112F	c	Aqua, Sorbitol, Hydroxyethylcellulose, Olaflur, PEG-40, Hydrogenated castor oil, Aroma, Sodium saccharin, CI 77891	Hydrated silica

a = Microdiamant AG, Lengwil, Switzerland
b = Colgate-Palmolive, Swidnica, Poland
c = GABA International AG, Swidnica, Poland

Scanning electron microscopy

All tested dentifrices were visualized by scanning electron microscopy (SEM; SUPRA 50VP and Genesis, Carl Zeiss, Oberkochen, Germany). The slurry was gradually washed out 7× with Aqua dest. (10 g dentifrice in 3 l) to free the CT abrasive from other supplements. A final washing step with ethanol followed to solve remaining slurry contents from abrasives. The residue was carefully dispensed on polycarbonate SEM stubs (PLANO GmbH, Wetzlar, Germany).

Data analysis

Data of abrasive wear was adjusted to 10,000 brushing strokes (µm/10 kBS) for all groups. Statistical analysis was performed for enamel and dentine separately using one-way ANOVA and post-hoc pairwise tests with Tukey correction. For dentine, variables were first log-transformed to stabilize variance and to achieve normal distribution. The significance level was set to alpha = 0.05 and all calculations were performed with the statistical software R (R Core Team 2013).

Results

On dentine, diamond-loaded dentifrices (DD2, DD1.5+S, and DD3+S) and ES showed no difference between groups (DD2: 7.74 ± 2.64 µm/10 kBS; DD1.5+S: 10.06 ± 2.32 µm/10 kBS; DD3+S: 10.09 ± 2.62 µm/10 kBS; ES: 7.37 ± 1.13 µm/10 kBS), while CT-brushed specimens exhibited significantly higher abrasion compared to all other groups (CT: 30.99 ± 7.7 µm/10 kBS) (Fig. 2). The diamond-loaded dentifrices differed significantly on enamel with increased abrasion potential corresponding to particle load, while the addition of the silica abrasive reduced abrasive wear (DD2: 1.79 ± 0.45 µm/10 kBS; DD1.5+S: 1.06 ± 0.28 µm/10 kBS; DD3+S: 1.61 ± 0.3 µm/10 kBS;). CT and ES showed both significantly lower abrasion potential on enamel, compared to the diamond-dentifrices (CT: 0.27 ± 0.13 µm/10 kBS; ES: 0.19 ± 0.11 µm/10 kBS). SEM images of DD2 show the diamond particles, while DD1.5+S and DD3+S show mainly silica filler particles, comparable to CT and ES (Fig. 3).

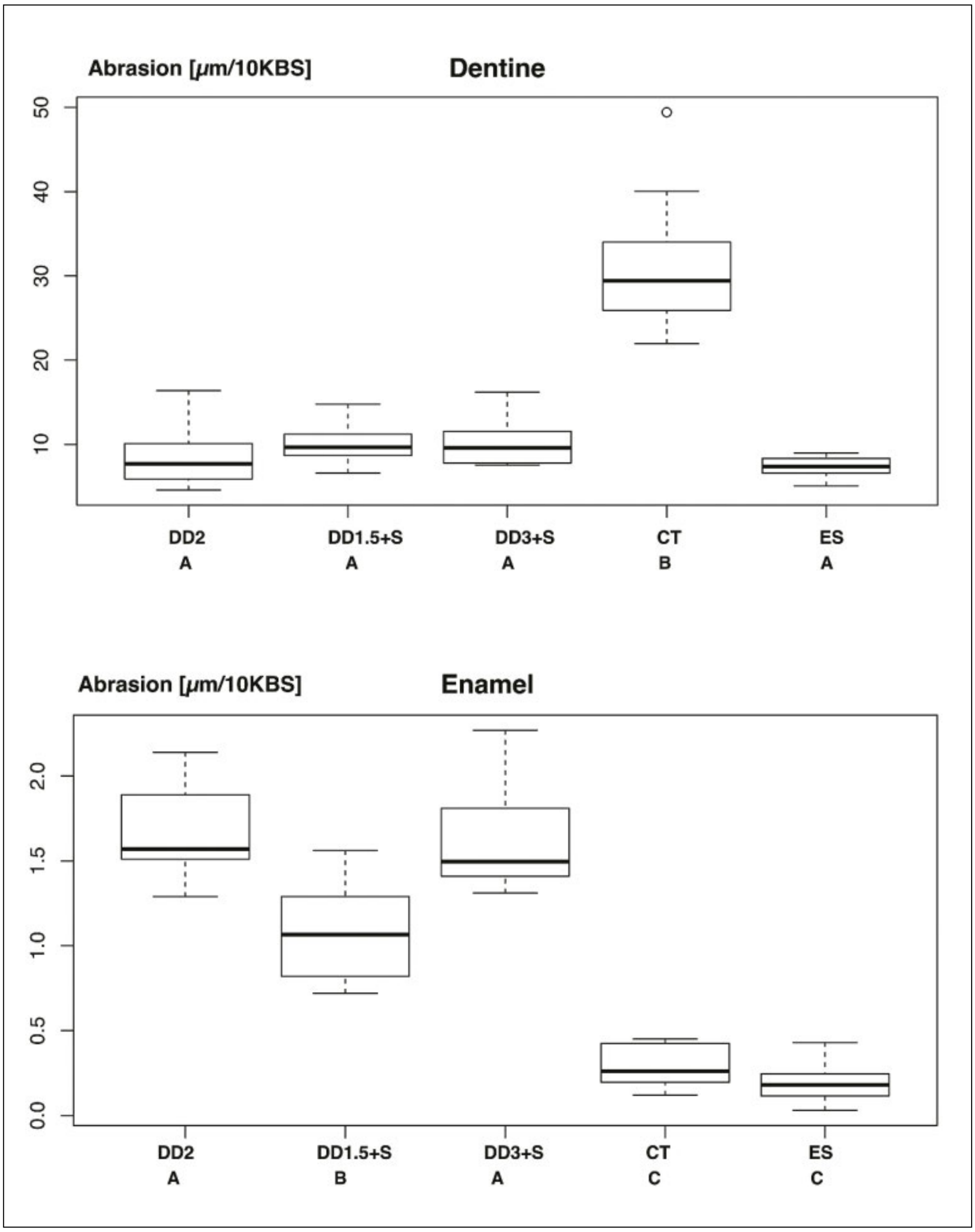
Discussion

The current study showed that the diamond toothpastes with and without additional abrasives merely caused low abrasion on dentine, whilst their abrasiveness was higher on enamel compared to that of other commercially available toothpastes.

The data of abrasion is presented in µm tooth loss per 10,000 brushing strokes. Typical tooth brushing with two brushing cycles per day involves approximately 20 brushing strokes across each tooth daily (Mahmood et al. 2014). Therefore, 10,000 brushing strokes correspond to roughly 1.5 years of brushing. Extrapolating the abrasive wear of the diamond toothpastes on dentine (8–10 µm/10 kBS) over a period of 70 years of brushing would result in 0.4–0.5 mm dentin loss, whereas brushing with CT would result in 1.4 mm dentinal wear over the same period. On enamel, however, wear of the diamond dentifrices (1–1.8 µm/10 kBS) over 70 years would result in 0.05–0.08 mm enamel loss. CT and ES would merely result in 0.01 mm enamel loss over 70 years. The elevated abrasive wear on enamel in comparison to the control groups CT and ES seems therefore (with regard to the enamel thickness of 1–2 mm) clinically rather negligible. However, abrasion is a multifactorial process and other factors such as erosive and mechanical challenges may aggravate dental hard tissue loss, and should be taken into consideration (Attin et al. 2004; Wiegand et al. 2006; Wiegand et al. 2008).

In line with other studies, the abrasion pattern of the toothpastes under investigation correlated to abrasive particle load (Franzò et al. 2010) (Fig. 2). Interestingly, adding additional abrasives to the test dentifrices (DD1.5+S and DD3+S) suggested

Fig. 2 Abrasive wear (µm/10,000 brushing strokes) of diamond-loaded dentifrices DD2 (diamond dentifrice, 2 g/kg), DD1.5+S (diamond dentifrice, 1.5 g/kg + 20% hydrated silica), DD3+S (diamond dentifrice, 3 g/kg + 20% hydrated silica), and of reference dentifrices CT (Colgate Total Original) and ES (Elmex Sensitive plus) on enamel and dentine specimens. Identical uppercase letters indicate that there was no significant difference (P <.05) for this test between respective groups.



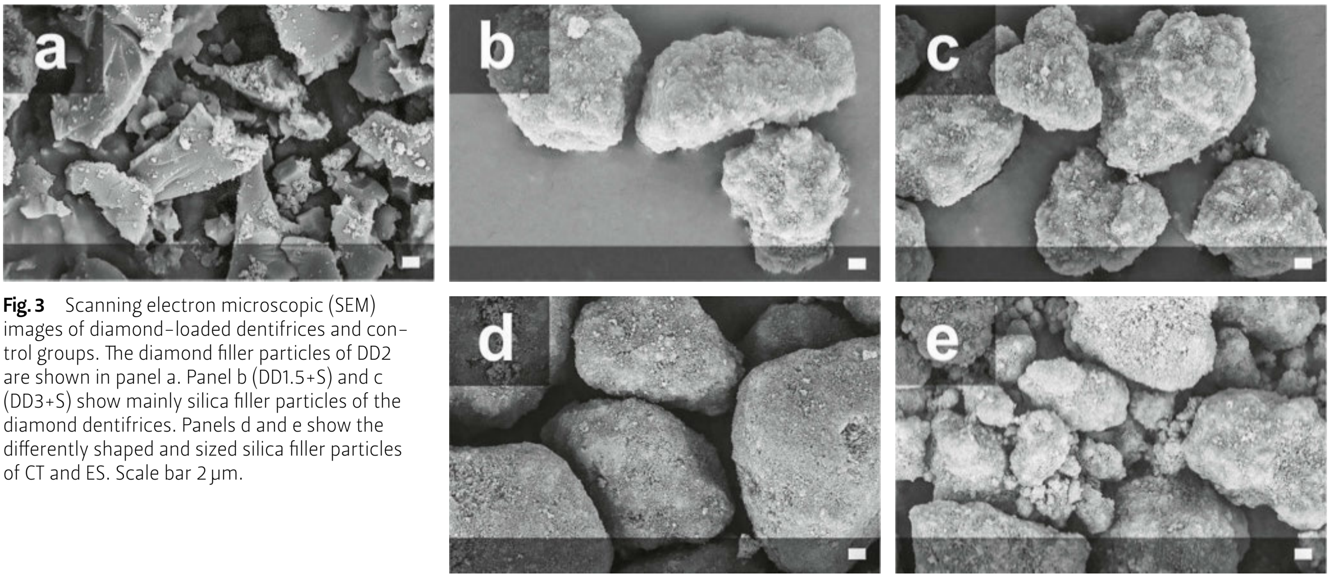


Fig. 3 Scanning electron microscopic (SEM) images of diamond-loaded dentifrices and control groups. The diamond filler particles of DD2 are shown in panel a. Panel b (DD1.5+S) and c (DD3+S) show mainly silica filler particles of the diamond dentifrices. Panels d and e show the differently shaped and sized silica filler particles of CT and ES. Scale bar 2 µm.

a masking effect on the abrasive wear of the embedded diamond particles. The impact on cleaning efficacy by diamond toothpastes with or without additional abrasives has not yet been investigated. Further studies should compare the cleaning efficacy of different diamond toothpastes with and without the addition of common abrasives. The diamond particle size used in this study (2.4 µm) was based on preliminary testing (data not shown), which revealed increased abrasion potential corresponding to particle size. The SEM images in Figure 3 visualize the difference in particle size between particles embedded in diamond-loaded dentifrices and in the reference dentifrices. Common abrasives as shown in Figure 3b range in size and agglutinate in different forms. The diamond particle concentration was 0.15–0.3% (1.5–3 g/kg), which differs highly from hydrated silica and calcium carbonate, which are typically used at concentrations between 8–20% w/w, or sodium bicarbonate, which can be used up to 50% w/w (LIPPERT 2013). The diamond concentration in toothpastes may seem very low compared to other abrasives, but is in line with diamond based products used in other technical areas (SAMUELS 2003; SURATWALA ET AL. 2007), and is based on the uniquely high abrasivity of this material.

Overall, data of this study suggest that diamond particles in dentifrices can be adjusted in concentration and particle size to meet minimal abrasive criteria and to be comparable to reference low-abrasive dentifrices. Further studies should investigate the general cleaning efficacy related to diamond particles in dentifrices.

Acknowledgement

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Conflict of Interest

This research was supported by Microdiamant AG (K. Spring, Lengwil, Switzerland). The authors declare no conflict of interest.

Résumé

Introduction

Les composants abrasifs classiques bien connus dans les pâtes dentifrices sont le carbonate de calcium, la silice hydratée, le métaphosphate de sodium, l'alumine, la perlite, la nanohydroxyapatite et le bicarbonate de sodium. Plus récemment, des particules de diamant sont également utilisées comme adjuvant abrasif dans la pâte qui aura des caractéristiques d'abrasion différentes et peu étudiées jusqu'à présent. Le but de cette recherche était d'analyser in vitro l'abrasion sur la dentine et l'émail de diverses formulations de pâtes dentifrices en incorporant les particules diamantées comme seul abrasif ou en combinaison avec des particules de silice hydratées et de comparer avec des pâtes de référence du commerce.

Matériel et méthodes

Trois pâtes dentifrices contenant des grains diamantés d'une taille de 2,4 µm ont été préparées dans des proportions variables: DD2 (2 g diamant/kg), DD1.5+S (1,5 g/kg + 20% de silice), DD3+S (3 g/kg + 20% de silice). Deux pâtes du commerce, Colgate total (CT) et Elmex Sensitive plus (ES) ont servi comme de pâtes de référence. Des dents de bovin ont été brossées au niveau de l'émail et la dentine (n = 12) avec les cinq pâtes dentifrices en utilisant une machine à brosser appliquant des forces de 2,5 N pour une fréquence de 120 passages de brosse à dents (BS)/min. Au niveau de la dentine, 3600 et 7200 BS ont été réalisés, tandis que pour l'émail le nombre était de 21 600 et 43 200. L'usure a été mesurée avec un profilomètre en comparant avant et après brossage les valeurs d'usure indiquées en µm/10 000 BS (µm/10 kBS). L'analyse statistique incluait du ANOVA et des comparaisons multiples (post-hoc) avec correction Tukey et alpha = 0,05.

Résultats

Les pâtes diamantées et ES n'ont pas montré de différences significatives sur l'abrasion dentinaire (DD2 7,7 ± 2,6 µm/10 kBS; DD1,5+S 10,1 ± 2,3 µm/10 kBS; DD3+S 10,1 ± 2,6 µm/10 kBS; ES 7,4 ± 1,1 µm/10 kBS, contrairement à la pâte Colgate Total (CT) qui avait des valeurs d'abrasion sur la dentine significativement plus élevées (CT 31,0 ± 7,7 µm/10 kBS). Au niveau de l'émail, les pâtes diamantées ont montré une abrasion plus importante (DD2 1,8 ± 0,5 µm/10 kBS) que celles combinées avec de la silice (DD1,5+S 1,1 ± 0,3 µm/10 kBS; DD3+S 1,6 ± 0,3 µm/10 kBS). Les pâtes de références ES (0,2 ± 0,1 µm/10 kBS) et CT (0,3 ± 0,1 µm/10 kBS) étaitent très similaires et n'ont eu que peu d'effet abrasif sur l'émail.

Discussion

Cette recherche in vitro a démontré que l'abrasion sur l'émail et la dentine de pâtes dentifrices diamantées varie en fonction de la concentration de particules de diamants, de l'adjonction d'autres particules abrasives (silice) et du substrat dentaire.

Zusammenfassung

Einleitung

Neben den bekannten in Zahnpasten verwendeten Abrasivstoffen, wie beispielsweise Hydrated Silica (Kieselsäure) oder Kalziumkarbonat (Kreide), werden mittlerweile auch Diamantpartikel als Abrasivstoffe verwendet. Diese neuen Abrasive weisen andere Eigenschaften auf und wurden bisher kaum untersucht. Das Ziel dieser Studie war es, das Abrasionsverhalten verschiedener diamantbesetzter Zahnpasten auf Dentin und Schmelz *in vitro* zu untersuchen. Dafür wurden drei Zahnpasten mit Diamantpartikeln (Korngrösse = 2,4 µm) hergestellt.

Material und Methoden

Bovine Proben wurden mit einer diamantbasierten Zahnpasta (DD2; 2 g Partikel/kg), einer diamantbasierten Zahnpasta (DD1,5+S; 1,5 g/kg) mit 20% zusätzlichem Silica-Fülleranteil als zusätzlichem Abrasiv oder mit einer diamantbasierten Zahnpasta (DD3+S; 3 g/kg) mit 20% Silica gebürstet. Colgate Total (CT) und Elmex Sensitive plus (ES) wurden als Referenzzahnpasten mituntersucht. Der Abtrag [µm] der Dentin- und Schmelzproben (n = 12) wurde profilometrisch vor dem Bürstvorgang sowie auf Dentin nach 3600 und 7200 Bürststrichen (BS) und auf Schmelz nach 21 600 und 43 200 BS gemessen. Die Werte wurden als µm/10 000 BS (µm/10 kBS) dargestellt und zwischen den Gruppen mittels einfacher ANOVA und Post-hoc-Mehrfachvergleichen mit Tukey-Korrektur statistisch ausgewertet (alpha 0,5).

Resultate

Der Dentinabtrag (Mittelwert ± Standardabweichung µm/10 kBS) bei den Diamantzahnpasten und ES ergab keine signifikanten

Unterschiede: DD2 7,7 ± 2,6 µm/10 kBS; DD1,5+S 10,1 ± 2,3 µm/10 kBS; DD3+S 10,1 ± 2,6 µm/10 kBS; ES 7,4 ± 1,1 µm/10 kBS, während die mit CT gebürsteten Dentinproben einen signifikant höheren Abtrag im Vergleich zu allen anderen Gruppen erzeugten: CT 31,0 ± 7,7 µm/10 kBS. Die Diamantzahnpasten führten auf Schmelz zu einem signifikant höheren Abtrag: DD2 1,8 ± 0,5 µm/10 kBS, während das Vorhandensein von Silica-Abrasiven zu einer Reduktion des Abtrags führte: DD1,5+S 1,1 ± 0,3 µm/10 kBS; DD3+S 1,6 ± 0,3 µm/10 kBS. CT und ES resultierten in gleichermassen geringen Schmelzabtrag: CT 0,3 ± 0,1 µm/10 kBS; ES 0,2 ± 0,1 µm/10 kBS.

Diskussion

Anhand dieser Daten konnte gezeigt werden, dass die Abrasion durch Diamantpartikel in experimentellen Zahnpasten durch die Konzentration der Partikel, der Zugabe von zusätzlichen Füllern und der Art der Zahnhartgewebe unterschiedlich bestimmt wird.

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