

Efficiency of powered systems for interproximal enamel reduction (IER) and enamel roughness before and after polishing—an in vitro study

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Abstract

Objective This aims to evaluate the efficiency of three different powered interproximal enamel reduction (IER) systems and to assess enamel roughness before and after polishing using different polishing times.

Material and methods Four metal strips of the G5 ProLign Set (swissdentacare, SDC, Grancia, Switzerland), four segmental discs of the ASR-Set 4594 and two sonic tips of the SonicLine Set (both Gebr. Basseler GmbH & Co. KG, Komet, Lemgo, Germany) were evaluated. Human extracted incisors served as the medium. Enamel reduction was determined in five intervals of 15 s each. Polishing was performed for 15 and 30 s using the manufacturers' recommended polishing systems. Enamel roughness (Ra) was quantitatively assessed by confocal laser scanning microscopy (CLSM).

Results Significant differences in terms of enamel reduction were found among the working ends of all tested systems. The time needed to remove 0.1, 0.2 and 0.3 mm of enamel was determined. Surface analysis showed significantly higher mean Ra values for nine out of ten working ends before

polishing. This was still the case for five working ends after 15 s and for two after 30 s of polishing.

Conclusion The graining and the system used have a significant influence on enamel reduction. The time needed for polishing depends on the last working end used; a polishing time of 30 s is not always appropriate.

Clinical relevance Knowledge about the cutting efficiency of powered IER working ends might help the clinician to estimate better the amount of enamel reduction during the stripping process.

Keywords Powered IER systems · Interproximal enamel reduction · Cutting efficiency · Enamel roughness · Enamel surface

Introduction

Dental crowding is one of the most frequent dental anomalies orthodontists have to deal with. Analysis of data from the Household Youth Questionnaire and the National Health and Nutrition Examination Survey (NHANES III) showed that around 50 % of the untreated population between 15 and 50 years of age display mandibular incisor irregularities. Mild to moderate crowding (2–7 mm) is the most prevalent degree of crowding [1].

Interproximal enamel reduction (IER) involves the reduction of tooth size by removal of enamel from the mesial and distal tooth surfaces and is a common clinical procedure in orthodontics for gaining space in the dental arch [2, 3]. The amount of space that can be gained by IER depends primarily on the enamel thickness every proximal tooth surface has. The general recommendation is not to remove more than 50 % of the initial enamel thickness [4–6]. Previous studies have shown that proximal enamel thickness can be subject to

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considerable individual variation [7, 8]. Taking this into consideration, minimum values of reference data on proximal enamel thickness would seem to indicate reduction maximums per surface of 0.3 mm for the upper incisors [9], 0.2 mm for the lower incisors [10], 0.3 mm for the upper and lower canines [11], 0.3 mm for the premolars [7] and 0.4 mm for the molars [8]. Thus, up to 6.8 mm of space in the maxilla and 6.0 mm in the mandible can be gained from the mesial surface of the left to the right first molar.

Further indications for IER are removal of black gingival triangles [12], correction of tooth-size discrepancies [3] and the enhancement of retention and stability after orthodontic treatment [13]. IER should not be used on hypersensible or very small teeth [14].

Various methods for IER have been suggested [3] and manual methods, such as traditional handheld abrasive strips, have been criticized as time-consuming and hardly applicable in the posterior teeth [2]. Powered IER systems, such as motor-driven abrasive strips or oscillating diamond-coated segmented discs, have recently gained in popularity [2]. More recently, sonic-activated diamond-coated tips have also become available.

Regardless of which IER system is used, it is important that the clinician is able to reduce the enamel by the exact amount which has been predetermined in the context of orthodontic treatment planning [2]. IER systems that do not work predictably, together with operator error, can result in over-reduction and iatrogenic damage [15, 16].

IER is often part of current CAD/CAM-based orthodontic systems, such as aligners (i.e. Invisalign®, CA® Clear Aligner). Although the amount of enamel reduction may vary individually, common reduction recommendations are standardized between 0.1 and 0.5 mm per proximal surface. Thickness gauges have been suggested to control clinically the amount of enamel reduction during the stripping process [2].

However, Johner et al. showed that there were significant differences between the intended and actual amount of enamel stripped [17].

So, in addition to the use of thickness gauges, efficiency data of IER might help the clinician to estimate better the amount of enamel reduction during the stripping process, and this might in turn help to improve the predictability of interproximal enamel reduction. However, to date little information is available on the efficiency of differently grained or formed powered IER systems [17–19].

Therefore, the first aim of the present study was to evaluate the efficiency of commonly used working ends from three different powered IER systems. In addition, we aimed to determine the time needed to reduce 0.1, 0.2 and 0.3 mm of enamel. Since a number of studies have shown that IER can significantly increase enamel roughness [16, 20–22], the second aim of the present study was to quantitatively assess enamel roughness before and after polishing using different polishing times.

Materials and methods

Ethical approval

The study protocol, including the use of extracted human teeth, was approved by the ethics committee of the medical faculty of the University of Heidelberg (approval no. S-301/2011). Before participation, all participants and their parents/guardian(s) received full oral and written information on the aims of the study and signed a written consent form.

Preparation of enamel samples and group allocation

Teeth were obtained from patients for whom extraction treatment had been indicated for orthodontic or periodontal reasons. Only incisors, free of caries and fillings, were selected for this study. A total of 110 teeth (55 from the maxilla and 55 from the mandible) were divided into 11 groups (one control group and ten test groups) of 10 teeth each using a stratified randomized protocol. Computerized generation of the random allocation sequence was carried out by a statistician (D.S.). Group allocation is shown in Fig. 1. After group allocation, all teeth from each group were cut longitudinally along their oro-vestibular axis into two equal segments using an inner diameter saw (SP 1600, Leica, Wetzlar, Germany) (Fig. 2). During the study, the two halves of the teeth were stored separately in artificial saliva [23].

Tested IER systems

The IER working ends and systems tested are presented in Table 1.

Evaluation of enamel reduction

In the first part of the study, we examined all strips, tips and segmental discs of all tested IER systems with regard to the amount of enamel reduction. This was done using the DMRE microscope (Leica, Wetzlar, Germany) and Leica QWin analysis software (Leica, Wetzlar, Germany) for five-point measurement with distance control. First, proximal surfaces were fixed using a thermoplastic resin on standardized specimen holders. These holders had a standardized and reproducible position under the microscope, as well as on the scale in the reduction procedure. In this way, multiple measurements could be taken with the same holder and teeth. Using the QWin software, five points on each of the fixed, initially untreated teeth were registered as reference points (= baseline values). The first measuring point was positioned in the center of the contact area. From that first measuring point and moving along the longitudinal axis of the tooth, two more points were determined at an equal distance (250 µm) in the incisal and apical directions (Fig. 3). Enamel reduction (in

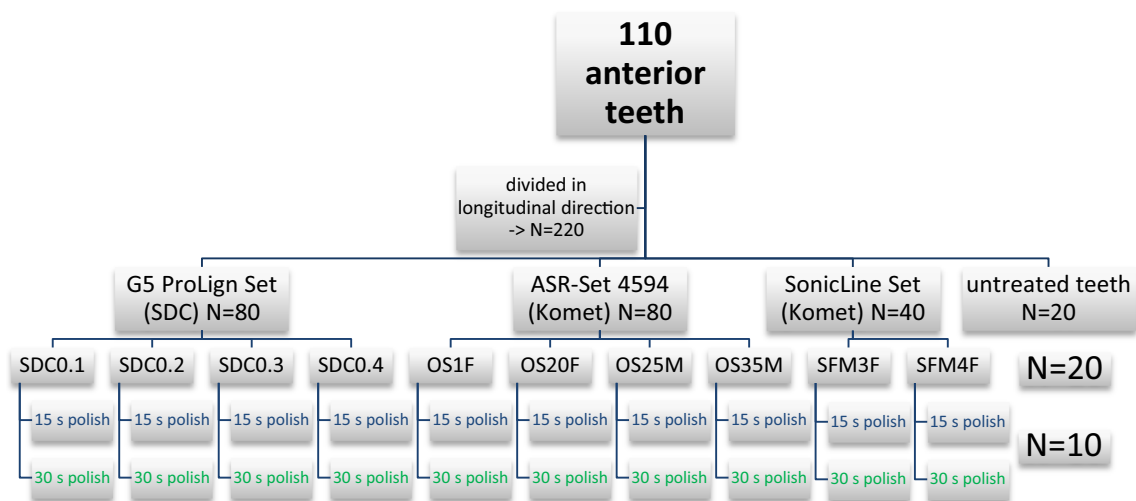


Fig. 1 Group allocation showing the single working ends of the three IER systems used

micrometres) was determined after 15, 30, 45, 60 and 75 s and compared to the initially registered reference points. We used the manufacturer’s recommendations for the speed used: this was 10,000/min for the G5 ProLign Set, 5000/min for the ASR-Set 4594, and 100 % ultrasonic power for the SonicLine Set. Water cooling was used for all tested systems. All working ends were replaced after every fifth tooth. All examinations were carried out by the same clinician (A.S.), who was instructed to apply a force of 1.1 N parallel to the contact area. Force was controlled during the experiment using a set of scales (Fig. 2). The maximum fluctuation range of the force exerted was ±10 g.

Evaluation of enamel roughness

In the second part of the study, we assessed enamel roughness before and after polishing procedures. The roughness of natural untreated enamel served as a reference. The mean

roughness (Ra) was defined as the main outcome criterion and was determined using a confocal laser scanning microscope (OLS 4000, Olympus, Tokyo, Japan). Measurements were taken according to the ISO standard (ISO4288:1996). Two polishing times were tested using the polishing systems recommended by the manufacturers. For the G5 ProLign Set, the included G5 UltraSoft file was used. One half of each (initially separated) tooth was polished for 15 s and the other half for 30 s. The three-part Compo polishing system 4416 (Gebr. Brasseler GmbH & Co. KG, Komet, Lemgo, Germany) was used for the ASR-Set 4594 and the SonicLine Set (both Komet). It consists of polishing discs with three different grits (medium, fine and ultrafine). One half was polished for 5 s with each of the three polishing discs and the other half for 10 s with each of the three polishing discs. A speed of 10,000/min with water cooling was used for both systems according to the manufacturer’s recommendation.

Statistical analysis

The study was conducted as a pilot study with exploratory data analysis. The significance level was set to 5 % for all statistical tests. Due to the sample size, nonparametric statistical methods were applied. To investigate possible differences between the three different systems, various comparisons between groups were performed. Comparisons were also made within each group at different time points. For this, we used the Kruskal-Wallis test (for more than two groups) and the Mann-Whitney *U* test (for two groups), conducted with a view to potential dependencies of the data. Respective means and standard deviations with the associated *P* values were presented, and in addition, graphical representations by boxplots were performed. The analysis was performed using SPSS for Windows, version 16.0.

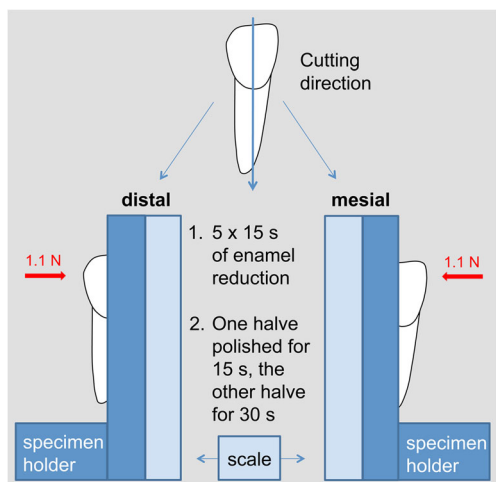


Fig. 2 Experimental set-up

Table 1 Products used in this study

System	Manufacturer	Attachment	Grit (μm)	Hand piece	Manufacturer
G5 ProLign Set	swissdentacare, SDC, Grancia, Switzerland	0.1	6	T1 Profin L Eva Yellow	Sirona, Salzburg, Austria
		0.2	15		
		0.3	25		
		0.4	40		
ASR-Set 4594	Gebr. Brasseler GmbH & Co. KG, Komet, Lemgo, Germany	OS1F	25	O-Drive OD30	KaVo, Biberach, Germany
		OS20F	25		
		OS25M	49		
		OS35M	49		
SonicLine Set	Gebr. Brasseler GmbH & Co. KG, Komet, Lemgo, Germany	SFM3F (flat working end)	40	SF1LM	Gebr. Brasseler GmbH & Co. KG, Komet, Lemgo, Germany
		SFM4F (convex working end)	40		

Results

The amount of enamel reduction measured for the strips, tips and segmental discs of the three tested IER systems is presented in Tables 2, 3 and 4.

G5 ProLign Set

The SDC0.4 file reached a mean value for total reduction of 0.351 mm, the SDC0.3 file of 0.262 mm, the SDC0.2 file of 0.184 and the SDC0.1 mm file of 0.140 mm (Table 2). Mean total reduction differed significantly among all G5 ProLign files ($P < 0.05$).

ASR-Set 4594

The OS35M segmented disc produced a mean value for total reduction of 0.326 mm, the OS25M of 0.230 mm, the OS20F

of 0.199 mm and the OS1F of 0.197 mm (Table 3). Total enamel reduction of the OS35M was significantly higher ($P < 0.05$). The total reduction of the OS1F, OS20F and OS25M did not differ significantly.

SonicLine Set

Mean total reduction of the SFM3F was 0.332 mm, significantly higher than the SFM4F at 0.226 mm ($P < 0.05$) (Table 4).

Regardless of the system tested, enamel reduction produced in each of the five time intervals decreased constantly from the first (0–15 s) to the last (60–75 s) interval. For all tested working ends, the differences between the first and the last interval were significant ($P < 0.05$). The respective differences ranged from 37 to 50 % among the G5 ProLign Set, from 39 to 48 % among the ASR-Set 4594 and from 28 to 36 % among the SonicLine Set. The working ends with the highest amount of enamel reduction from each system reached similar values. The G5 ProLign Set showed the highest variability in terms of enamel reduction, followed by the ASR-Set 4594 and the SonicLine Set.

The time needed to reduce the exact amount of 0.1, 0.2 and 0.3 mm of enamel is shown in Table 5. All working ends achieved a reduction of 0.1 mm over the total time of 75 s. The SDC0.1 and SDC0.2 did not reach 0.2 mm. Finally, 0.3 mm was only reached by the SDC0.4 mm, OS35M and SFM4F.

Surface roughness after enamel reduction and polishing

The surface roughness (Ra values) after enamel reduction and polishing for 15 and 30 s are shown in Figs. 4, 5 and 6.

After enamel reduction, all treated surfaces showed significantly higher mean Ra values compared to the untreated control surfaces except the SDC0.1 ($P < 0.05$) (Fig. 4). The SDC0.1 file showed slightly lower mean Ra values (mean

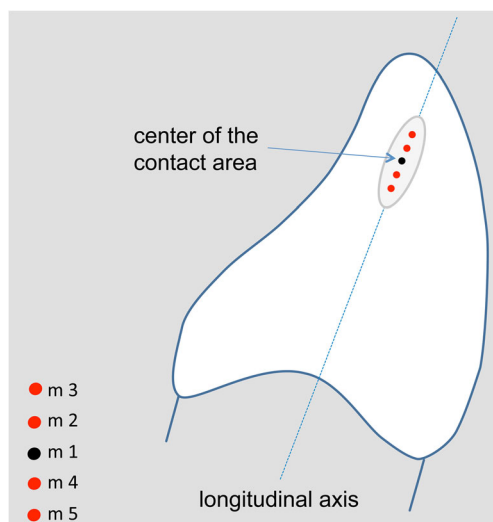


Fig. 3 Five measurement points (m 1–5) at an equal distance of 250 μm

Table 2 G5 ProLign Set including the strips SDC0.1, SDC0.2, SDC0.3 and SDC0.4. Enamel reduction measured in five time intervals of 15 s each (mean values and standard deviations; μm)

Reduction	Number of samples	SDC0.1	SDC0.2	SDC0.3	SDC0.4	P value
15 s	20	40.20 \pm 7.86	56.68 \pm 7.12	71.28 \pm 7.67	91.73 \pm 14.60	<0.001
30 s	20	27.60 \pm 4.25	36.62 \pm 6.71	59.42 \pm 7.82	72.94 \pm 11.80	<0.001
45 s	20	26.98 \pm 5.10	33.92 \pm 7.81	52.53 \pm 4.60	66.08 \pm 14.76	<0.001
60 s	20	24.19 \pm 3.87	30.17 \pm 5.84	43.53 \pm 7.01	63.97 \pm 15.57	<0.001
75 s	20	20.69 \pm 3.81	27.20 \pm 5.12	35.66 \pm 11.53	57.02 \pm 15.49	<0.001
Total reduction	20	140.17 \pm 17.37	184.46 \pm 25.31	261.56 \pm 21.25	350.70 \pm 61.63	<0.001
P value		<0.001	<0.001	<0.001	<0.001	

Ra 0.648 \pm 0.144 μm) compared to the control group (mean Ra 0.676 \pm 0.158 μm). Figure 7 underlines this observation, showing smooth profiles of untreated teeth and teeth treated with the SDC0.1.

After 15 s of polishing, mean Ra values decreased and no significant differences were found between the SDC0.1, SDC0.2, OS1F, OS20F, SFM3F and the control group (Fig. 5).

After 30 s of polishing, mean roughness values further decreased. Only the SDC0.4 (mean Ra 1.039 \pm 0.179 μm) and the OS35M (mean Ra 1.007 \pm 0.375 μm) showed significantly higher mean Ra values compared to the untreated teeth of the control group (Fig. 6). Figure 8 shows scratches and irregularities in the surfaces of teeth treated with SDC0.4 and OS35M after 30 s of polishing.

Discussion

Interproximal enamel reduction (IER) is a treatment method recognized by clinicians and researchers in which tooth size is reduced by removing approximal enamel or restorations and polishing the processed surfaces [24]. Today, various systems for enamel reduction are available. The most commonly used ones are hand- or motor-driven abrasive strips, diamond-coated segmented discs or tungsten carbide or diamond burs in a handpiece [21, 25, 26]. Previous studies on powered IER systems mostly investigated only one [17] or two working ends [27] from each system. However, currently available

systems mostly consist of several working ends which can differ according to their thickness, graining sizes or shapes. Numerous studies have demonstrated that the grain size significantly affects the efficiency of dental abrasives, as well as the attainable enamel surface quality [27–29]. Recently, sonic activated diamond-coated tips have also become available. However, comprehensive data on the efficacy of different IER systems are rare [17, 19, 27]. In this study, we chose commonly used working ends of different grain sizes or shapes from three different powered IER systems and evaluated their efficiency in terms of enamel reduction.

Methodological considerations

We used only incisor teeth because they are most frequently subject to IER [20]. A previous study has shown that 50 % of the untreated population between 15 and 50 years of age display mandibular incisor irregularities [1].

The teeth were split over the groups using a stratified randomized protocol. In this way, we could ensure that all groups included comparable tooth material, enabling us to compare the groups in terms of enamel reduction.

We stored the extracted teeth/enamel specimens in ‘artificial saliva’, which enabled us to ensure that the mechanical properties of the enamel specimens barely changed [23, 30]. Other studies used thymol, distilled water or physiologic saline solution, which might have a significant influence on the mechanical properties of teeth [31, 32].

Table 3 ASR-Set 4594 including the segmental discs OS1F, OS20F, OS25M and OS35M. Enamel reduction measured in five time intervals of 15 s each (mean values and standard deviations; μm)

Reduction	Number of samples	OS1F	OS20F	OS25M	OS35M	P value
15 s	20	51.96 \pm 15.28	60.59 \pm 41.26	65.51 \pm 18.39	90.67 \pm 11.20	<0.001
30 s	20	41.03 \pm 13.03	41.26 \pm 9.65	49.27 \pm 14.63	63.03 \pm 9.41	<0.001
45 s	20	38.05 \pm 11.19	35.29 \pm 8.09	41.94 \pm 12.81	56.74 \pm 11.79	<0.001
60 s	20	33.41 \pm 10.77	32.55 \pm 9.52	38.91 \pm 12.49	53.69 \pm 8.95	<0.001
75 s	20	31.77 \pm 11.04	29.23 \pm 7.48	34.50 \pm 9.68	48.94 \pm 9.89	<0.001
Total reduction	20	196.98 \pm 53.83	198.89 \pm 43.00	229.96 \pm 61.36	315.68 \pm 40.34	<0.001
P value		<0.001	<0.001	<0.001	<0.001	

Table 4 SonicLine Set including the sonic tips SFM3F and SFM4F. Enamel reduction measured in five time intervals of 15 s each (mean values and standard deviations; μm)

Reduction	Number of samples	SFM3F	SFM4F	P value
15 s	20	81.04 \pm 11.30	57.14 \pm 7.24	<0.001
30 s	20	67.08 \pm 9.82	45.58 \pm 7.11	<0.001
45 s	20	63.05 \pm 7.94	43.36 \pm 6.35	<0.001
60 s	20	61.90 \pm 7.73	42.98 \pm 7.40	<0.001
75 s	20	58.79 \pm 8.37	36.54 \pm 8.79	<0.001
Total reduction	20	331.87 \pm 43.22	225.60 \pm 34.04	<0.001
P value		<0.001	<0.001	

The efficiency of dental abrasives can be significantly influenced by the forces exerted during their application [33]. To ensure the validity and reliability of our data, all examinations were carried out by the same clinician using a standardized force. As there is no data about this force to be found in the literature, we carried out a pre-examination with nine clinicians working at the University of Heidelberg to find a suitable force. Many authors fail to report the forces used [17, 22, 24, 34–36]. Danesh et al. limited conduction of all experiments to one person [19] and Lombardo et al. to two persons [18].

The present in vitro study cannot, as with in vitro studies in general, represent several patient-related factors. One aspect not included in the present study is the opening up of the approximal space usually necessary in clinical routines. In a laboratory experiment, this is not realistically representable, however. We wished to concentrate solely on enamel reduction on one tooth, under standardized conditions, within a defined period of time, while minimizing other factors. Therefore, we were unable to simulate natural tooth movement. In another study [17], teeth

Table 5 Mean values and standard deviation for the time needed to reduce 0.1, 0.2 and 0.3 mm of enamel (seconds) (missing value: enamel amount was not reduced within 75 s)

	0.1 mm	0.2 mm	0.3 mm
SDC0.1	49.3 \pm 9.5		
SDC0.2	33.9 \pm 5.6		
SDC0.3	22.5 \pm 2.7	51.3 \pm 6.1	
SDC0.4	17.2 \pm 3.2	39.1 \pm 7.4	65.4 \pm 14.6
OS1F	37.0 \pm 14.1	78.9 \pm 25.5	
OS20F	32.2 \pm 11.7	72.8 \pm 16.4	
OS25M	28.1 \pm 10.7	68.9 \pm 24.4	
OS35M	17.6 \pm 2.6	42.4 \pm 5.1	71.7 \pm 9.5
SFM3F	19.6 \pm 2.7	43.2 \pm 6.2	68.1 \pm 9.7
SFM4F	29.8 \pm 4.9	67.4 \pm 13.1	

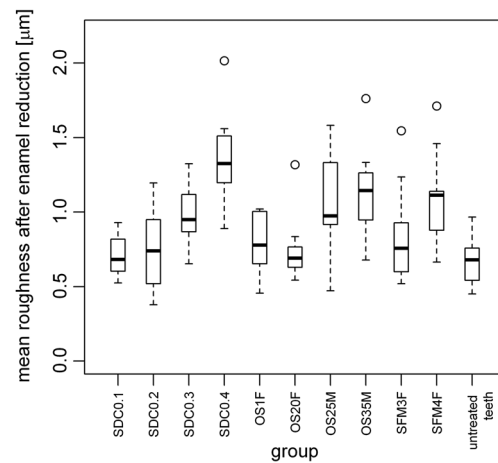


Fig. 4 Mean roughness (Ra) after IER compared to untreated teeth (in μm)

were embedded in silicone prior to the experiment in order to simulate natural tooth movement, but this procedure is also controversial because the characteristics of the silicone can alter during the experiment and thus call into question the reproducibility of the results.

We used a confocal laser microscope for the evaluation of surface roughness, which is a common method used in many other studies [37–39]. It permits an exact quantitative determination of surface parameters and is even more precise than surface profilometry [40]. A qualitative evaluation is also possible since the microscope can take two- and three-dimensional surface pictures [41].

The polishing times of 15 and 30 s were chosen from a clinical point of view. Zhong et al. polished for 1.7 min and reached even smoother surfaces than untreated teeth after using the ASR-Set 4594 [20]. Hein et al. even recommended a polishing time of at least 3 min [34]. Lombardo et al. failed to mention the time needed to polish. Danesh et al. polished for 20 s, which is near to our values.

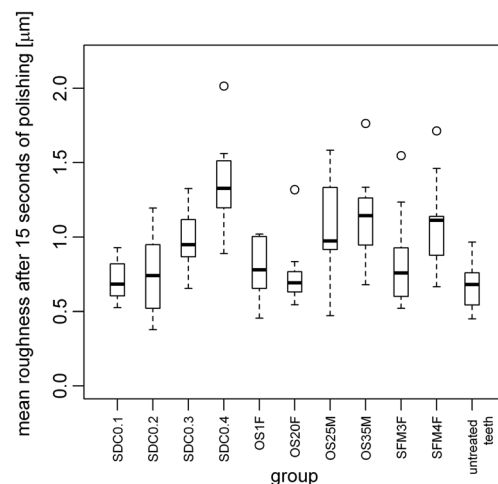


Fig. 5 Mean roughness (Ra) after 15 s of polishing compared to untreated teeth (in μm)

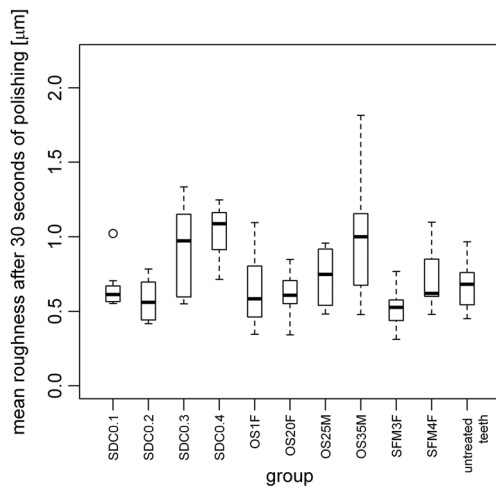


Fig. 6 Mean roughness (Ra) after 30 s of polishing compared to untreated teeth (in μm)

Enamel reduction

We could find significant differences in terms of enamel reduction within each of the tested IER systems. There was a significant difference between all single strips of the G5 ProLign Set in terms of the total enamel reduced. These findings correlate well with the different graining sizes of the four tested G5 ProLign files. As expected, the coarser grained files were more abrasive. This observation is in line with those of Lombardo et al. [18], who noted a higher abrasiveness of a 25- μm grit compared to a 15- μm grit file from the Orthofile system, a forerunner of the G5 ProLign system. The efficiency

of the G5 ProLign files may also be influenced by the varying thicknesses of the matrices. The thicker a matrix is, the less flexible it becomes. So, the constant force is transferred more efficiently to the tooth surface. Compared to the other IER systems tested, the G5 ProLign system offers the highest variability, especially because the SDC0.1 file is able to reduce very small amounts of enamel.

The OS35M segmented disc out of the ASR-Set 4594 reduced significantly more enamel than the other tested discs, although the OS25M has a 49- μm grit as well. The OS1F and OS20F reduce an almost equal amount of enamel, which fits their identical graining. In this case, the thickness difference of 0.05 mm of the working end does not seem to be influential.

Regarding the sonic line system, the SFM3F with its flat tip reduced significantly more enamel than the SFM4F with its convex tip. So, the shape has a decisive influence on the amount of enamel reduced since both tips have an identical graining. With only two different shapes, this system offers the smallest variability.

In all systems, the enamel reduction per time interval dropped as processing time increased. This effect was least obvious with the SonicLine scaler tips. One possible explanation for the decline in enamel reduction rates could be that the tools gradually wear out over time [18]. However, in the present experiment, working ends were replaced regularly (every fifth tooth). Therefore, this effect might also be explained, in part, by the fact that the treated area of the tooth increases in size as processing time increases. If the applied force remains the same, it is distributed across a larger area, thus leading to a reduction in the pressure per area unit and

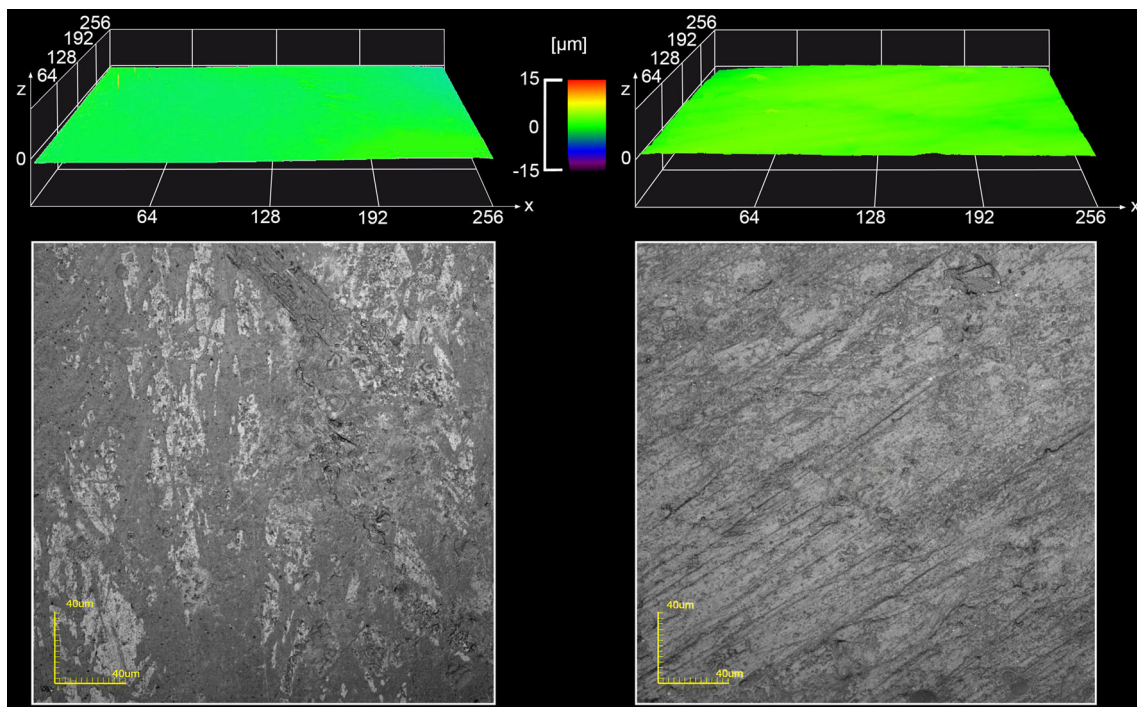


Fig. 7 2D and 3D pictures of untreated enamel (left) compared to enamel treated with SDC0.1 (right) (in μm)

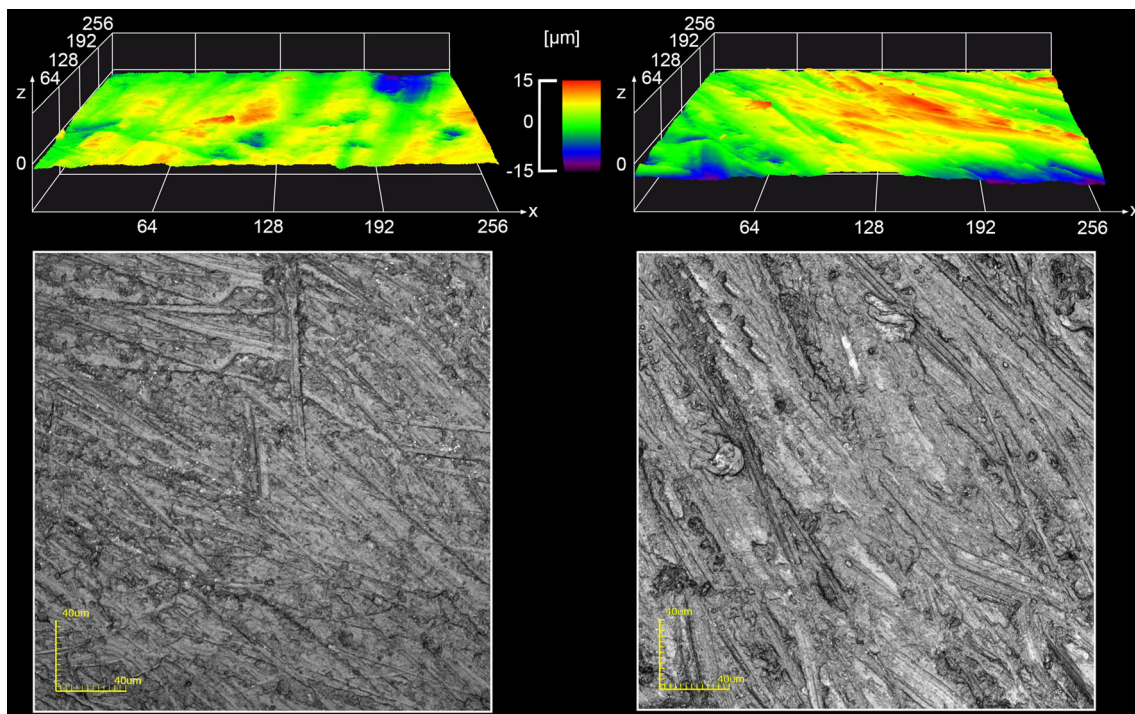


Fig. 8 2D and 3D pictures of enamel treated with SDC0.4 (left) compared to enamel treated with OS35M (right) (in μm)

correspondingly to a reduction in the enamel removed. Force plays less of a role when tips are ultrasound-powered.

Enamel roughness

Nine out of ten working ends showed significantly higher mean roughness values before polishing than the untreated control surfaces. This agrees with the observations of Danesh et al., Gupta et al. and Mikulewicz et al. and underlines the assumption that polishing is always necessary after IER [19, 35, 42]. The SDC0.1 seems to be an exception. Lombardo et al. discovered similar results for a 15- μm grit Orthofile [18]. After 15 s of polishing, mean Ra values decreased and no significant differences were found between the SDC0.1, SDC0.2, OS1F, OS20F, SFM3F and control group (Fig. 5). However, the absolute values of these working ends were still slightly higher compared to the untreated enamel surfaces. Therefore, also for these files, a polishing time of 15 s is only sufficient to a limited extent. The enamel surfaces treated with the SDC0.4 file and the OS35M were significantly rougher even after polishing for 30 s. Only the fine grit working ends (SDC0.1, SDC0.2, OS1F, OS20F) reached mean Ra values equal to or slightly below untreated teeth. Gupta et al. reported similar results [35]. Danesh et al. reached significantly smoother surfaces for two out of five tested systems compared to untreated teeth within a polishing time of 20 s. The remaining three systems, including the ASR-Set 4594, attained a level of roughness that was near to that of natural surfaces after polishing for 20 s [19]. This means that we can only confirm the observations of Danesh

et al. in terms of the fine grit OS1F and OS20F segmented discs. The SFM3F is an exception since it is a high grit tip: nonetheless, we found smooth surfaces after 30 s of polishing. To verify this result, further examinations are necessary.

We therefore assume that the crucial factor when polishing teeth according to IER is the last working end used. This observation agrees with the results of Piacentini et al. [24]. The last IER working end should have a finer grit in order to remove potentially existing coarse serrations before polishing. This recommendation is given by many other authors [19, 20, 34]. A special role is played here by the SDC0.1 since polishing does not seem to be necessary and a further smoothing of the surface could not be achieved by polishing.

No studies published so far could find a higher caries risk after IER [4, 26, 43, 44]. The present study could also demonstrate that a surface corresponding to that of an untreated tooth could be attained with appropriate polishing of the treated area. Nevertheless, a critical aspect of this procedure is that it is performed on healthy teeth. Accordingly, treatment should be conducted with extreme caution, especially when using the coarser working ends in the different IER systems. This also means a correspondingly long polishing interval, as well as the potential use of finer working ends prior to polishing.

Conclusions

This study provides detailed in vitro data concerning the cutting efficiency of commonly used working ends from different

powered IER systems. In addition, important information concerning enamel roughness resulting from IER and subsequent polishing is provided.

Enamel reduction

- (1) Significant differences in terms of enamel reduction were found among the working ends of all three tested systems.
- (2) The tested G5 ProLign strips provided the broadest quantitative range of possible enamel reduction, followed by the selected working ends from the ASR-Set 4594 and SonicLine Set.
- (3) With regard to enamel reduction, the most effective working ends from the systems tested required less than 20 s to remove 0.1 mm of enamel.
- (4) The quantity of enamel removed per time interval decreased for all systems during the course of the experiment. This effect was less distinct for the tested SonicLine tips.
- (5) Regarding the SonicLine Set, the shape of the tested working end has a significant influence on efficiency.

Enamel roughness

- (1) Compared to the untreated enamel surfaces, nine out of ten working ends showed a significantly higher surface roughness after IER. This was still the case for five working ends after 15 s and for two after 30 s of polishing.
- (2) Each system provides working ends which, after 15 and 30 s of polishing, produce surfaces like those found in untreated enamel.
- (3) The time needed for an appropriate polish seems to depend on the last working end used. Especially high grit working ends needed longer polishing times (e.g. SDC0.4 and OS35M). It seems to be acceptable not to polish after using the SDC0.1, which has the finest grit of all working ends tested.
- (4) The last IER working end before polishing should have a finer grit in order to remove potentially existent coarse serrations before polishing.
- (5) A polishing time of 30 s was appropriate for both tips of the SonicLine Set tested, but not for all working ends from the G5 ProLign Set and ASR-Set 4594 Set.

It will be the aim of future studies to assess the efficiency of powered IER systems under clinical conditions. In this context, user-friendliness and patient comfort are also of particular importance and should be evaluated.

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Conflict of interest The authors declare that they have no competing interests.

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