Original Article

Enamel Surfaces Following Interproximal Reduction with Different Methods

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ABSTRACT

Objective: To assess the surface roughness resulting after application of currently available interproximal polishing.

Materials and Methods: The analysis was carried out by means of digital subtraction radiography, profilometry, and scanning electron microscopy. The roughness of natural untreated enamel served as the reference. Five enamel reduction methods were tested (Profin, New Metal Strips, O-Drive D30, Air Rotor, and the Ortho-Strips) and were applied in accordance with their manufacturers' recommendations. Fifty-five teeth were treated by randomly chosen methods, all of which were applied by one person. One proximal surface was only ground and left unpolished while the other received the finishing and polish recommended by the manufacturer.

Results: Loss of tooth substance, as measured by subtraction radiography, was significantly lower ($P < .05$) for the group treated with Ortho-Strips. Profilometric analysis of enamel roughness showed that the use of Ortho-Strips, O-Drive D30, and New Metal Strips in the grinding mode produced equally rough surfaces ($P > .05$). The Air Rotor and Profin system in the grinding mode produced the significantly ($P < .05$) roughest surfaces. A significant ($P < .05$) reduction of the mean roughness values was registered in all groups when treatment was followed by polishing. The Profin system and Ortho-Strips achieved the significantly smoothest surfaces ($P < .05$) with polishing.

Conclusions: In general, interproximal enamel reduction should be followed by thorough polishing. Furthermore, oscillating systems seem to be advantageous.

KEY WORDS: Interdental polishing; Interproximal polishing; Crowding; Digital subtraction radiography; Profilometry; Interproximal enamel reduction

INTRODUCTION

Interdental polishing, also known as interproximal polishing (IPP), is a common and quick procedure in orthodontics. It is used to adjust disproportioned tooth widths and to treat mild and moderate crowding.[1,2]

Regarding its effects on the enamel, different aspects of IPP have to be considered. Hudson[3] could not prove any correlation between the width of a tooth and its enamel thickness. This implies that it is impossible to estimate the possible extent of reduction accurately based on one's sense of proportion. Moreover, lower incisors exhibit great enamel thickness.[4,5] Because of its thorough mineralization, the enamel can serve as a protective layer for underlying tissues. This mineralization is most distinct on the surface. Thus, interproximal reduction of the enamel might impair its resistance.

There are different statements to be found in the literature regarding the amount of enamel reduction. Fillion,[6] for example, recommended that reduction not exceed 0.3 mm of the surface in the upper incisors, 0.6 mm in upper premolars and molars, 0.2 mm in the lower incisors, and 0.6 mm in the lower premolars and molars. Sheridan and Ledoux[1] contemplated the possibility of gaining 6.4 mm of space by enamel reduction of the eight proximal surfaces of the premolars and

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Table 1. Devices Used in This Study

Instrument	Manufacturer	Grit, µm	Hand Piece	Manufacturer
Profin LTB 75	Dentatus, Stockholm, Sweden	15–75	Eva Intra Lux Prophy Kopf 61 LRG	KaVo, Biberbach, Germany
New Metal Strips	GC, Tokyo, Japan	50–140	—	—
Segmental wheels (A-H)	Komet, Besigheim, Germany	8–100	O-Drive D30	KaVo, Biberbach, Germany
Air Rotor standard bur kid	Raintree Essix, Metarie, La	15–100	Gentlepower Lux 25 LP	KaVo, Biberbach, Germany
Ortho-Strips system	Intensiv Dental, Switzerland	15–90	Eva Intra Lux Prophy Kopf 61 LRG	KaVo, Biberbach, Germany

molars. Stroud et al[7] considered it possible to achieve 9.8 mm by means of the same procedure. Various authors have deemed a reduction by 50% of the original enamel coat to be acceptable.[2,8]

A thorough finishing of the treated enamel surfaces is vital for a good long-term prognosis of the stripped teeth because the remaining roughness facilitates plaque accumulation and thereby promotes demineralization or the development of carious lesions.[9–11] Thus, adequate postprocessing using appropriate equipment is crucial.

There are various mechanical or automatic, rotating, or translatory devices for proximal enamel reduction. Recently, oscillating mechanisms with segmental wheels have become available.

Thus, it was the aim of this study to assess the resulting surface conditions after using different methods and devices for IPP.

MATERIALS AND METHODS

Fifty-five freshly extracted, caries-free, intact human lower front teeth that had been extracted because of periodontal involvement were included in this study. The soft tissues and the calculus were removed. The teeth were rinsed with water and stored in distilled water. Five systems for enamel reduction were used on five groups containing 10 randomly chosen teeth (Table 1). The proximal surfaces of 5 teeth (control group) were not treated and served as a control for the profilometry.

Grinding was conducted according to the manufacturers' recommendations. In all cases, this included water cooling during the process. Since some devices might be more effective than others, the interproximal reduction procedures were carried out as follows to achieve comparable amounts of enamel reduction using the different methods:

—a preparation time of at least 5 seconds or
—an interproximal enamel reduction of at least 0.25 mm.

Each tooth was ground on both interproximal enamel surfaces with additional polishing on only one side. Thus, one side of each tooth always had a rough surface while the other side's surface was smooth, allowing a direct comparison of the results of grinding with and without additional polishing. Polishing was always accomplished in the limited time frame of 20 seconds.

The grinding with each system was carried out by the same operator, with subsequent polishing using the respective equipment issued by the same manufacturer. However, in the case of New Metal Strips, the polishing was conducted using white fine discs of the Soflex-system (3M, St Paul, Minn). All measurements were carried out by a second examiner who was unaware of the experimental groups.

To simulate in situ conditions, the teeth were mounted on a plaster model. To reproduce a certain amount of physiologic movement of the teeth in the plaster model, teeth were mounted using silicone material (Optosil; Heraeus Kulzer, Hanau, Germany) instead of simply embedding them in the plaster.

Digital Subtraction Radiography

To estimate the substance loss, each tooth was embedded in a rectangular Plexiglas form filled with silicon (Provil Putty Soft; Haereus, Hanau, Germany) that had been mixed directly before use. After the setting time of the silicon, as recommended by the manufacturer, the tooth was removed, leaving an impression in the silicon. This impression allowed an exact repositioning of the tooth in the silicon after enamel reduction.

To provide visible reference lines on the radiographs, two parallel orthodontic steel wires (0.035 inches) were attached to the Plexiglas form at a distance of 2 cm. A high-resolution dental x-ray film (Insight Dental Film, Speed E; Kodak, Rochester, NY) was used.

The x-ray exposures were made using a Sirona Heliodent DS x-ray unit (Bensheim, Germany) with a tube, and a 1.0-mm aluminum filter (CHF Müller, Hamburg, Germany) was added. The tube voltage was 60 kV, and the current was 50 mA. The exposure time

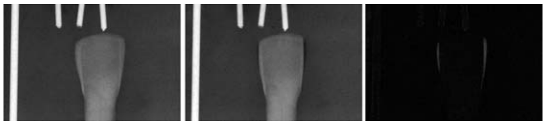

Figure 1. Example of the digital subtraction radiography. (a) Radiograph of a specimen before treatment. (b) Radiograph of a specimen after grinding/polishing. (c) Example of a subtraction image.

was 120 milliseconds with a constant source to film distance of 83 cm. The films were developed, fixed, and dried in an automatic processor (XR 24 Nova; Dürr-Dental, Bietigheim-Bissingen, Germany).

After digitizing the radiographs at 1.000 dpi in grayscale mode with a scanner (UMAX Powerlook III, Willich, Germany), a digital subtraction analysis was conducted according to Eberhard et al[12] using the software Photoshop 7.0 (Adobe, San Jose, Calif) and NIH Image 1.34 (National Institutes of Health, Bethesda, Md).

Size, brightness, and alignment of the postgrinding radiographs were adjusted to fit those of the pregrinding images, thereby making it possible to produce a digital subtraction from the baseline picture (Figure 1). In the resulting subtraction images, the areas of removed enamel were visible as accumulations of bright pixels, the width of which was calculated based on the reference lines by using the rule of three (Table 2).

Differences between enamel reduction systems with respect to their subtraction were analyzed using analysis of variance (ANOVA) and the post hoc Student-Newman-Keuls test for all pairwise comparisons ($P < .05$).

Profilometry

To reduce the water content of the teeth, they were kept in 99% ethyl alcohol. Subsequently, they were dried in an incubator (Memmert TV 15u, Schwabach, Germany) at 37°C for 3 days.

The profilometric examination was conducted by means of interferometry. In the framework of this technique, a specimen is illuminated by white or monochromatic light through a beam splitter. Measurements with monochromatic light provide better depth resolution but require relatively smooth specimens. The profilometer, Veeco NT 3300 (Veeco Instruments Inc, New York, NY), was used for analysis at a fivefold magnification. Image processing was carried out by means of the corresponding Software WYKO Vision-32. The surface analysis was preceded by photomicrographs of the treated surfaces to identify the position of the most affected area for the analysis as well as for the direction of grinding and polishing.

The computer analysis of the surface characteristics permitted a numeric and graphical description of the surface. For every surface that was analyzed by means of profilometry, the arithmetic average of the roughness of the profile's deviance from the average (R_a) was calculated. The arithmetic mean (R_a) of the treated surfaces and that of the control group were measured. The differences between the teeth with respect to their arithmetic mean (R_a) were analyzed by means of ANOVA and the post hoc Student-Newman-Keuls test for all pairwise comparisons ($P < .05$). The *t*-test was used for the comparison of two means.

Scanning Electron Microscopy

Scanning electron microscopy **(**SEM) was used to visualize the surface structure after treatment. Thus, specimens were fixed with conductive glue to aluminum stubs (Leit C Plast; SPI Supplies, West Chester, Penn). After coating the specimen with a 4-nm-thick layer of silver in a Polaron SC 7640 sputter coater (Polaron, Hertfordshire, UK), they were observed at 125× magnification using SEM (LEO 1530 VP; Kammrath & Weiss, Dortmund, Germany).

RESULTS

Digital Subtraction Radiography

The enamel reductions measured by subtraction radiography are summarized in Table 2. Some of the surfaces that received polishing showed a slight additional substance loss compared to those that received grinding only. However, this difference between rough and fine processing was not significant in any group ($P > .05$, *t*-test).

Table 2. Enamel Reduction (mm) After Grinding and After Grinding and Subsequent Polishing as Determined by Digital Subtraction Radiography

	Grinding				Grinding and Polishing				*P* Value Between Groups
	$\bar{x}$*	SD	Min	Max	$\bar{x}$*	SD	Min	Max	
Profin	0.22^{A}	0.04	0.14	0.27	0.24^{ab}	0.03	0.19	0.30	.065
New Metal Strips	0.25^{A}	0.07	0.11	0.46	0.25^{b}	0.05	0.16	0.35	.855
O-Drive D30	0.32^{B}	0.06	0.19	0.41	0.32^{c}	0.05	0.22	0.41	1.000
Air Rotor	0.25^{A}	0.04	0.19	0.30	0.26^{b}	0.03	0.22	0.33	.165
Ortho-Strips	0.20^{A}	0.03	0.16	0.27	0.21^{a}	0.03	0.16	0.27	.139

* Means with the same superscript letters were not statistically different at $P < .05$.

Table 3. R_a Values After Grinding and After Grinding and Subsequent Polishing of the Five Experimental Groups and of the Control Teeth as Assessed by Profilometry

	Grinding				Grinding and Polishing				*P* Value Between Groups
	x̄ *	SD	Min	Max	x̄ *	SD	Min	Max	
Profin	3.7^D	0.5	3.1	4.3	0.4^a	0.1	0.3	0.5	.000
New Metal Strips	1.8^B	0.3	1.5	2.3	1.4^c	0.1	1.3	1.6	.030
O-Drive D30	2.0^B	0.2	1.8	2.3	0.9^b	0.2	0.7	1.1	.001
Air Rotor	3.0^C	0.3	2.8	3.5	1.5^c	0.2	1.2	1.7	.001
Ortho-Strips	2.1^B	0.5	1.7	2.8	0.4^a	0.1	0.3	0.5	.002
Control	0.9^A	0.2	0.7	1.3					—

* Means with the same superscript letters were not statistically different at $P < .05$.

A significantly smaller amount of removed enamel was detected on those surfaces that were ground and polished using the Ortho-Strips when compared with those processed using the New Metal Strip, Air Rotor, and O-Drive D30 ($P < .05$, ANOVA). Reducing the enamel thickness by 0.32 mm, the O-Drive D30 attained the significantly ($P < .05$) greatest substance loss regardless of whether grinding only or polish was applied.

Profilometry

Table 3 shows the results of the profilometric examination carried out by the different IPP systems. The untreated enamel surfaces were used as a reference. The use of Ortho-Strips, O-Drive D30, and New Metal Strips in the grinding mode produced equally rough surfaces ($P >$. 05, *t*-test). The Air Rotor and Profin system in the grinding mode produced the significantly ($P < .05$) roughest surfaces. Without subsequent polishing, the R_a values were in all cases significantly ($P < .05$) greater than those of the untreated controls. A significant ($P < .05$) reduction of the R_a values was registered in all groups when treatment was followed by polishing (Table 3). The Profin system and Ortho-Strips achieved the significantly smoothest surfaces ($P < .05$) with polishing.

Scanning Electron Microscopy

SEM images illustrating surfaces after grinding and after polishing are shown in Figure 2. Although grinding with New Metal Strips and the Air Rotor system caused grooves in the enamel that could be reduced but not removed by polishing, the Profin system and Ortho-Strips produced surfaces that displayed only minor roughness. A visualization of selected enamel surfaces by means of SEM along with profilometric images is presented in Figure 2a to 2j.

DISCUSSION

Interdental stripping or interproximal enamel reduction is a commonly applied technique in orthodontic treatment to obtain more space to align incisors and maintain alignment in the long term.[2,11] Despite its advantages, enamel reduction also entails some disadvantages. Enamel reduction impairs the tooth's resistance against the oral cavities' aggressive environment and makes it sensitive.[13] Generally, this is important in respect to the tooth's resistance against caries, so many authors recommend a reduction of no more than half the enamel coating's original thickness to avoid immoderate degradation.[2,8] Since teeth show a wide range of variation, some authors[3] have even suggested a precedent measurement of the enamel to ensure an exact reduction.

The digital subtraction radiography used in this study monitored enamel reduction quite well with high sensitivity. This method was used in several previous studies to observe the progression of proximal lesion demineralization,[12] artificial recurrent caries,[14] root resorption,[15] and periodontal lesions.[16]

Polishing with finer abrasives is necessary to achieve a subsequent reduction of grooves caused by coarse abrasives.[17] The amount of enamel reduction depends on several factors, such as exerted pressure, enamel hardness, hardness and particle size of the abrasive, and the time used for applying it.[18]

The results of the subtraction radiography revealed that the polishing effect on the enamel reduction was not significant (Table 2). Literature statements about the amount of enamel reduction vary. According to Fillion,[6] only 0.2 mm of enamel should be removed from the lower incisors. All systems that were examined in this study showed a mean enamel reduction of about 0.2 mm, with the exception of the O-Drive D30. The use of the O-Drive D30 device resulted in a mean reduction of about 0.3 mm, with a maximum value of 0.4 mm (Table 2). Therefore, a reduction of the polishing time to less than 5 seconds and/or gradual control of the amount of grinding with measurement gauges is recommended.

The enamel surface configuration resulting from the use of IPP is a common point of dissent.[19] It is a main objective to create surfaces that do not differ signifi-

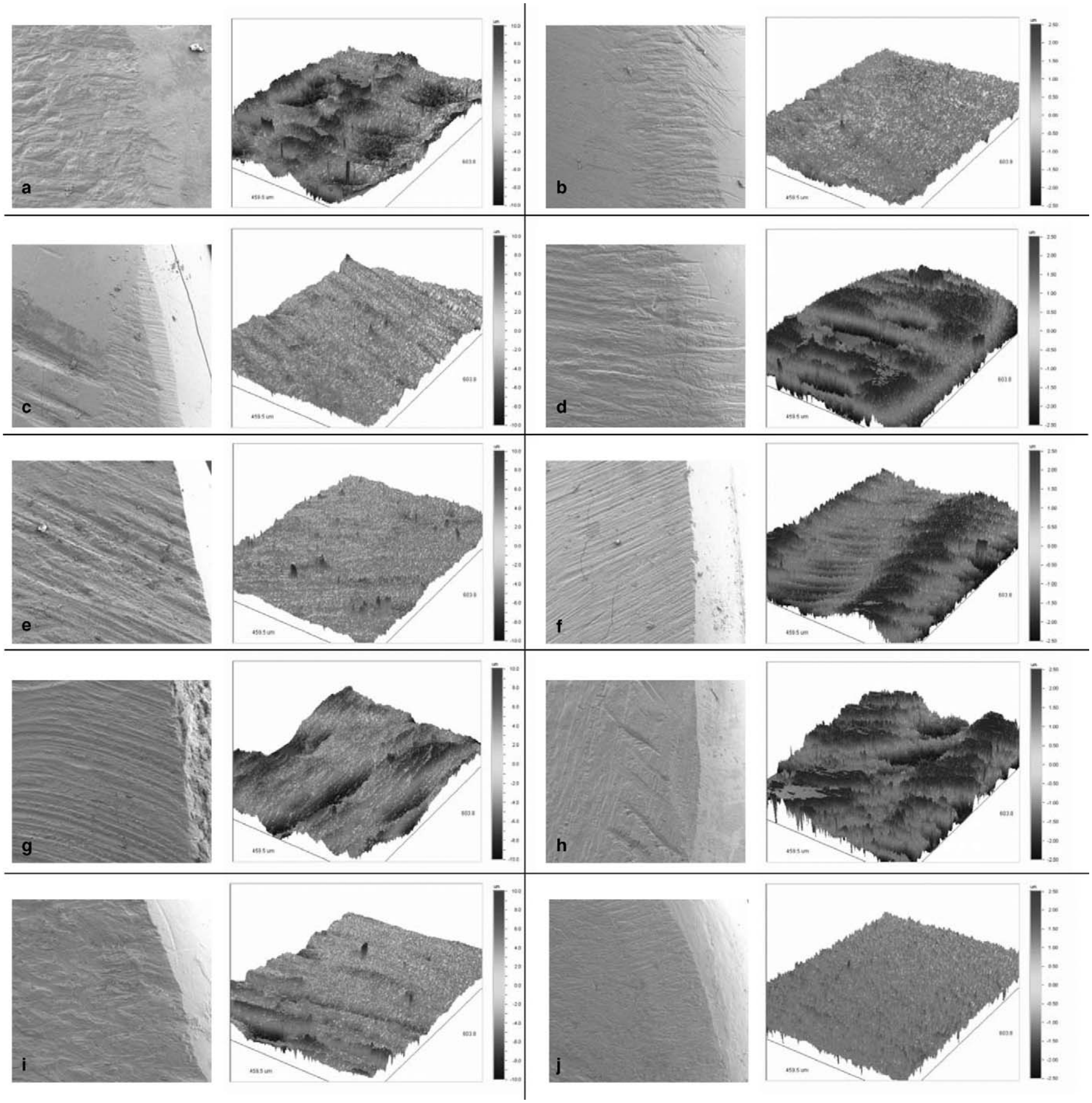

Figure 2. Scanning electron microscopic images and profile curves of enamel surfaces after various treatment. (a) Profin system, coarse (75 μm). (b) Profin system, fine (15 μm). (c) New Metal Strips, coarse (140 μm). (d) New Metal Strips, polishing strip, fine (50 μm) + Soflex fine (15 μm). (e) O-Drive D30 + segmental wheels 0.15 mm, coarse (100 μm). (f) O-Drive D30 + segmental wheels 0.15 mm, fine (15 μm). (g) Air Rotor bur, coarse (100 μm). (h) Air Rotor bur, fine (15 μm). (i) Ortho-Strips, coarse (90 μm). (j) Ortho-Strips, fine (15 μm).

cantly from untreated enamel or feature an even greater smoothness.[17,20]

In this study, widely accepted methods were used to assess surface conditions. Profilometry is a common method to analyze surface configurations[21] and displays a noninvasive approach. The optical profilometry, for example, provides an extremely high depth of focus of ≤1 nm. Furthermore, in this system, the overall roughness is specified by a metric average value, which permits a statistical evaluation.[18]

Moreover, SEM images were taken to visualize grooves and trenches, providing a further visualization of the surfaces. Nevertheless, the main drawback of this method is the observer's subjectivity. Furthermore,

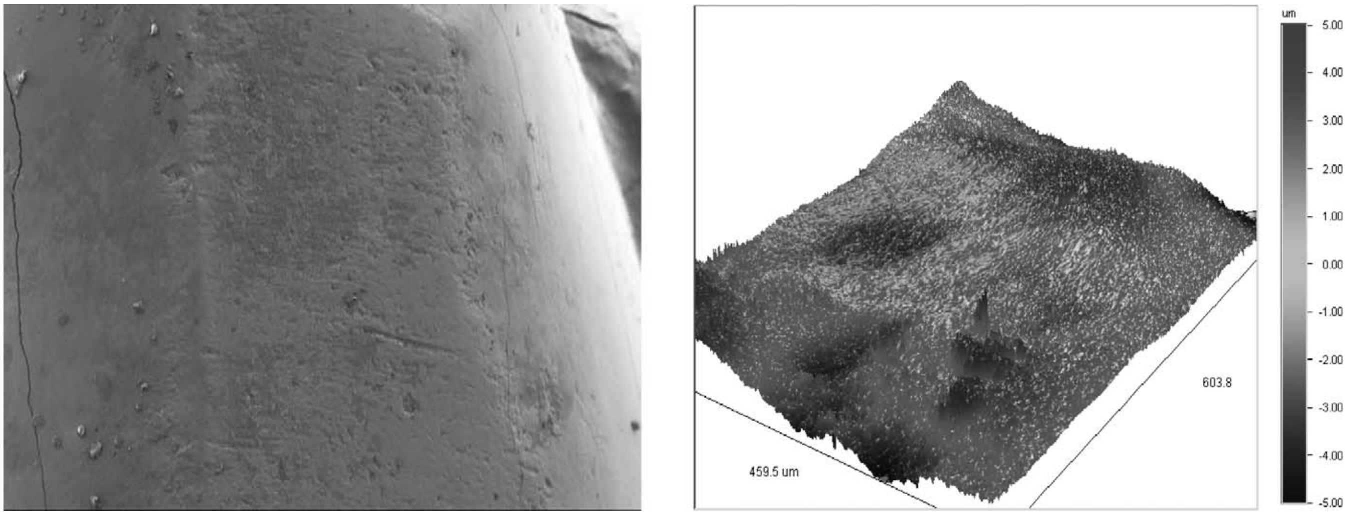

Figure 3. Example of an untreated enamel surface with scanning electron microscopy image and profile curves of the enamel surface surfaces.

not all grooves and every roughness could be measured.[17,22] Thus, SEM served only for supportive visualization of the profilometry results.

The profilometry evaluation revealed that after polishing, the surfaces that had been treated with the Profin system and the Ortho-Strips possessed a significantly ($P < .05$) greater smoothness than the untreated enamel (Table 3). The O-Drive D30 system attained a level of roughness that was equal to that of natural surfaces (Figure 3). These results demonstrate the lapse of a common argument against IPP. The mentioned systems produced surfaces on which the accumulation of plaque might be reduced because cleaning is facilitated. It can be assumed that this effect might result in an increased caries resistance, making sealing of the grinded surfaces as postulated by Sheridan and Ledoux[1] unnecessary. Comparable results were presented by Zhong et al.[22]

Another important aspect is the urgent recommendation to polish ground surfaces. All systems exhibited significant ($P < .05$) differences between grinding and grinding with subsequent polishing (Table 3). For example, the use of the Profin system (Figure 2a, SEM) resulted in the significantly roughest surface after grinding ($P < .05$). In contrast, after subsequent polishing (Figure 2b, SEM) this system left the significantly smoothest surface ($P < .05$), even significantly smoother ($P < .05$) than the untreated enamel surfaces (Figure 3). This observation strongly indicates that all ground surfaces should be polished subsequently to minimize the risk of plaque accumulation.

After polishing, New Metal Strips (Figure 2c,d; SEM) and Air Rotor (Figure 2g,h; SEM) left surfaces that were significantly rougher than those treated with the other examined systems and than untreated enamel surfaces (Table 3). These results are in agreement with previous reports.[23,24] According to Piacentini and Sfondrini,[17] it is impossible to remove the grooves and trenches left on the enamel after grinding them with rough diamond burs and disks using conventional polishing and cleaning methods.

Although some studies[25,26] failed to demonstrate a significant relation between enamel reduction and caries development, it should be kept in mind that a reduction of a tooth's enamel coating might lead to impaired resistibility, facilitates demineralization, and promotes periodontopathogenic processes.[9,10]

CONCLUSIONS

- The use of coarse strips or burs left irregular surfaces that cannot be smoothed effectively by subsequent polishing.
- Automatic oscillating systems presented by Profin, Ortho-Strips, and O-Drive D30 attained the best results.

REFERENCES

1. Sheridan JJ, Ledoux PM. Air-rotor stripping and proximal sealants. An SEM evaluation. *J Clin Orthod.* 1989;23:790–794.
2. Sheridan JJ. Air-rotor-stripping. *J Clin Orthod.* 1985;19:43–59.
3. Hudson AL. A study of the effects of mesiodistal reduction of mandibular anterior teeth. *Am J Orthod.* 1956;42:615–624.
4. Bennett JC, McLaughlin RP. Betrachtungen zur Kronenform der Schneidezähne bei der kieferorthopädischen Behandlung. *Inf Orthod Kieferorthop.* 1997;29:255–266.
5. Rosenzweig KA. Tooth form as a distinguishing trait between sexes and human populations. *J Dent Res.* 1970; 49(suppl):1423–1426.
6. Fillion D. Vor- und Nachteile der approximalen Schmelzreduktion. *Inf Orthod Kieferorthop.* 1995;27:64–90.
7. Stroud JL, Englisch J, Buschang PH. Enamel thickness of

the posterior dentition: its implications for nonextraction treatment. *Angle Orthod.* 1998;68:141–146.
8. Boese LR. Fiberotomy and reproximation without lower retention, nine years in retrospect: part I. *Angle Orthod.* 1980; 50:88–97.
9. Arends J, Christoffersen J. The nature of early carious lesions in enamel. *J Dent Res.* 1986;65:2–11.
10. Radlanski RJ, Jager A, Schwestka R, Bertzbach F. Plaque accumulations caused by interdental stripping. *Am J Orthod Dentofacial Orthop.* 1988;94:416–420.
11. Tuverson DL. Anterior interocclusion relations. Part I. *Am J Orthod.* 1980;78:361–370.
12. Eberhard J, Hartman B, Lenhard M, Mayer T, Kocher T, Eickholz P. Digital subtraction radiography for monitoring dental demineralization: an in vitro study. *Caries Res.* 2000; 34:219–224.
13. Dummer PMH, Harrison KA. In vitro plaque formation on commonly used dental materials. *J Oral Rehabil.* 1982;9: 413–417.
14. Nummikoski P, Martinez T, Matteson S, McDavid W, Dove S. Digital subtraction radiography inartificial recurrent caries detection. *Dentomaxillofac Radiol.* 1992;21:59–64.
15. Kravitz L, Tyndall D, Bagnell C, Dove S. Assessment of external root resorption using digital subtraction radiography. *J Endod.* 1992;18:275–284.
16. Janssen P, van Palenstein Helderman W, van Aken J. The effect of in-vivo-occurring errors in the reproducibility of radiographs on the use of the subtraction technique. *J Clin Periodontol.* 1989;16:53–58.
17. Piacentini C, Sfondrini G. A scanning electron microscopy comparison of enamel polishing methods after air-rotor stripping. *Am J Orthod Dentofacial Orthop.* 1996;109:57–63.
18. Lundgren T, Milleding P, Mohlin B, Nannmark U. Restitution of enamel after interdental stripping. *Swed Dent J.* 1993;17: 217–224.
19. Radlanski RJ, Jager A, Zimmer B, Bertzbach F. Scanning electron microscopic research on the clinical use of interdental stripping. *Fortschr Kieferorthop.* 1990;51:117–122.
20. Pinheiro ML. Interproximal enamel reduction. *World J Orthod.* 2002;3:223–232.
21. Zhang XZ, Anderson P, Dowker SE, Elliott JC. Optical profilometric study of changes in surface roughness of enamel during in vitro demineralization. *Caries Res.* 2000;34:164–174.
22. Zhong M, Jost-Brinkmann PG, Zellmann M, Zellmann S, Radlanski RJ. Clinical evaluation of a new technique for interdental enamel reduction. *J Orofac Orthop.* 2000;61:432–439.
23. Joseph VP, Rossouw PE, Basson NJ. Orthodontic microabrasive reproximation. *Am J Orthod Dentofacial Orthop.* 1992;102:351–359.
24. Twesme DA, Firestone AR, Heaven TJ, Feagin FF, Jacobson A. Air-rotor stripping and enamel demineralization in vitro. *Am J Orthod Dentofacial Orthop.* 1994;105:142–152.
25. el-Mangoury NH, Moussa MM, Mostafa YA, Girgis AS. In-vivo remineralization after air-rotor stripping. *J Clin Orthod.* 1991;25:75–78.
26. Crain G, Sheridan JJ. Susceptibility to caries and periodontal disease after posterior air-rotor stripping. *J Clin Orthod.* 1990;24:84–88.