Quantitative evaluation of the progressive wear of powered interproximal reduction systems after repeated use

An in vitro study

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Abstract
Purpose To evaluate the residual surface roughness of 5 common diamond-coated interproximal reduction (IPR) systems after consecutive in vitro applications in relation to system, diamond grain size, and instrument thickness.
Methods IPR was performed on 80 extracted human incisors using motor-driven strips and discs under predefined conditions. The IPR auxiliaries were applied at 5 consecutive sessions of 20 s on intact interproximal surfaces, and the surface profile (R_a, R_z, R_max) was analyzed at baseline and after each session with an optical profilometer.
Results No overall significant difference in the roughness values was found between systems (P = 0.07 for R_a, P = 0.33 for R_z, and P = 0.48 for R_max). There was a significant average decrease of R_a, R_z, and R_max for all systems for every unit increase in time by –0.171 μm (P < 0.001), –3.297 μm (P < 0.001), and –2.788 μm (P = 0.001), respectively. R_a, R_z, and R_max values increased significantly, i.e., by 0.194 μm (P = 0.003), 5.890 μm (P = 0.001), and 5.319 μm (P = 0.010) as instrument thickness increased by one unit. No significant reductions in R_a, R_z, and R_max were observed across grain sizes (–0.008 μm [P > 0.05], –0.244 μm [P > 0.05], and –0.179 μm [P > 0.05], respectively). There was no evidence of interaction between system and time as the P values for R_a, R_z, and R_max were 0.88, 0.51, and 0.70, respectively.
Conclusions All IPR materials presented significant gradual decrease of surface roughness after repeated applications. There were no significant roughness changes among auxiliaries of different grain sizes. Thinner auxiliaries showed significantly more roughness reduction, possibly requiring more frequent replacement than thick auxiliaries in clinical practice.

Keywords Dental high-speed technique · Surface roughness · Optical profilometer · Dental enamel · Enamel stripping methods

Quantitative Untersuchung der fortschreitenden Abnutzung elektrisch angetriebener Interproximal-Reduktionssysteme bei wiederholter Anwendung
Eine In-vitro-Studie

Zusammenfassung
Ziel Beurteilt werden sollte die verbleibende Oberflächenrauigkeit von 5 handelsüblichen diamantbeschichteten Interproximal-Reduktionssystemen nach wiederholter In-vitro-Anwendung, differenziert wurde dabei bezüglich System, Diamantkorngröße und Instrumentendicke.

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Methoden  Interproximal-Reduktion (IPR) wurde mit motorgetriebenen Streifen oder Scheiben an 80 extrahierten menschlichen Inzisiven unter standardisierten Bedingungen durchgeführt. Die IPR-Systeme wurden für 5 aufeinander folgende Anwendungen von 20 s an intakten Interproximalflächen eingesetzt, die Oberflächenrauigkeit (Rₐ, Rₜ, Rₘₐₓ) wurde sowohl initial als auch nach jeder Anwendung mit einem optischen Profilometer analysiert.

Resultate  Es wurden keine signifikanten Unterschiede der Oberflächenrauigkeit zwischen den unterschiedlichen Systemen festgestellt (p = 0,07 für Rₚ, p = 0,33 für Rₜ, p = 0,48 für Rₘₐₓ). Eine signifikante durchschnittliche Abnahme von Rₚ, Rₜ und Rₘₐₓ von –0,171 μm (p < 0,001), –3,297 μm (p ≤ 0,001) bzw. –2,788 μm (p = 0,001) nach jeder Anwendung wurde gefunden. Rₚ, Rₜ und Rₘₐₓ Werte nahmen signifikant zu um 0,194 μm (p = 0,003), 5,890 μm (p = 0,001) bzw. 5,319 μm (p = 0,001) bei zunehmender Instrumentendicke pro Einheit. Bezüglich der Diamantkorngrößen wurden keine signifikanten Unterschiede von Rₚ, Rₜ und Rₘₐₓ (~0,008 μm [p > 0,05], ~0,244 μm [p > 0,05] bzw. ~0,179 μm [p > 0,05]) gefunden. Es gab keine Anzeichen für eine Interaktion zwischen Systemtyp und Anwendungsanzahl für Rₚ, Rₜ und Rₘₐₓ mit p-Werten von 0,88, 0,51 bzw. 0,70.

Schlussfolgerungen  Alle IPR-Systeme zeigten eine signifikante graduelle Abnahme der Oberflächenrauigkeit nach wiederholten Anwendungen. Es gab keine signifikanten Rauigkeitsdifferenzen zwischen Instrumenten mit unterschiedlichen Diamantkorngrößen. Bei dünneren Instrumenten gab es signifikant höhere Rauigkeitsverluste, was möglicherweise in der Praxis einen häufigeren Wechsel als bei dickeren Instrumenten nötig macht.

Schlüsselwörter  Zahnmedizinische Hochgeschwindigkeitstechnik · Oberflächenrauigkeit · Optische Profilometrie · Zahnschmelz · Methoden zur Schmelzereduktion

Introduction

Space gaining procedures, e.g., tooth extractions, arch expansion, and reshaping of interproximal enamel surfaces (i.e., interproximal reduction [IPR]) are commonly applied in clinical orthodontics. Since the original introduction of IPR [1], several authors [2–6] have described in detail IPR indications and protocols for handheld or handpiece-mounted enamel cutting instruments. Overall, IPR has been used to address arch length discrepancies, to enhance anterior esthetics and interocclusal relationships, and to improve long-term stability of the treatment outcome [7].

The residual enamel roughness [8–10], and especially, the increased susceptibility to caries in vitro [11–13] initially discouraged clinicians from performing IPR in everyday practice. This perception has been drastically changed in recent years with the best available evidence indicating that IPR does not increase the incidence of caries on treated teeth [14]. Moreover, regardless of the stripping method used (i.e., abrasive strips, tungsten carbide burs or oscillating perforated diamond discs), finishing with Sof-Lex polishing discs can yield smoother surfaces than intact enamel [15].

While most of the research focused on post-IPR enamel effects, very little has been published so far on the wear of IPR materials after multiple uses [16]. Such information may have direct clinical implications since the particle size of the abrasive determines the amount of enamel reduction as well as the necessary time for polishing [17]. Lione et al. [16] demonstrated by means of tribological testing a 60% decrease in the abrasive capacity of motor-driven strips after 5 min of in vitro use, whereas at the same time almost complete detachment of diamond abrasive grains was observed by scanning electron microscope in three patients receiving IPR on mandibular incisors.

Given the growing acceptance of IPR as a minimally invasive procedure by dentists and orthodontists [18], and the widespread use of aligner treatment in combination with IPR [19], it would be interesting from a clinical point of view to investigate the surface changes on contemporary IPR materials over time. Thus, the aims of this study are to assess the roughness changes of 5 popular diamond-coated IPR systems after consecutive in vitro applications in relation to system, diamond grain size, and instrument thickness. The null hypothesis is that there is no difference in the outcome between any of the parameters.

Materials and methods

Eighty extracted human permanent incisors with macroscopically intact interproximal surfaces, free of caries and restorations were collected from the undergraduate clinic of the Department of Preventive, Restorative, and Pediatric Dentistry, Dental School/Medical Faculty, University of Bern, Bern, Switzerland. Before extraction, patients had been informed about the use of the teeth for research purposes and verbal consent had been obtained. After extraction, the teeth were pooled. The local ethics committee categorizes pooled teeth as an “irreversibly anonymized biobank” and thus, no previous ethical approval was needed. The incisors to be used were cleaned under tap water with a scaler to remove debris and then stored in 2% chloramine solution in a refrigerator (4°C) until needed. The incisors
### Table 1 Technical details of the interproximal reduction (IPR) instruments tested in the study

| System                  | Manufacturer                      | Instrument coding | Thickness (mm) | Particle size (μm) | Handpiece | Manufacturer                  |
|-------------------------|------------------------------------|-------------------|----------------|-------------------|-----------|-------------------------------|
| DentaSonic Diastrip     | Alpin Orthodontics, Lucerne, Switzerland | DS-25             | 0.15           | 25                | DentaSonic water cooling HP | Alpin Orthodontics, Lucerne, Switzerland |
|                         |                                    | DS-40             | 0.20           | 40                |           |                               |
|                         |                                    | DS-60             | 0.30           | 60                |           |                               |
| Ortho-Strips System     | Intensiv SA, Montagnola, Switzerland | OS-25             | 0.15           | 25                | Intensiv Swingle Reciprocating Contra Angle (WG-69 A) | W&H, Bürnmoos, Austria |
|                         |                                    | OS-40             | 0.20           | 40                |           |                               |
|                         |                                    | OS-60             | 0.25           | 60                |           |                               |
| SDC-G5-Prostrip SDC     | SDC Switzerland                     | SDC-15            | 0.15           | 15                | Ti-Max X55 | NSK-Nakanishi Inc., Kanuma, Japan |
|                         |                                    | SDC-20            | 0.20           | 30                |           |                               |
|                         |                                    | SDC-30            | 0.30           | 40                |           |                               |
| Galaxy IPR Diamond Discs| Ortho Technology®, Lutz, FL, USA    | OT-11             | 0.19           | 64                | KaVo      | KaVo Dental, Charlotte, NC, USA |
|                         |                                    | OT-13             | 0.19           | 64                | GENTLE-power LUX 10LP Straight 1:2 |                               |
|                         |                                    | OT-55             | 0.20           | 46                |           |                               |
|                         |                                    | OT-56             | 0.20           | 46                |           |                               |
| OS Segment Discs        | Komet USA, Rock Hill, SC, USA       | OS-10             | 0.20           | 57                | Komet OS 31 | W&H, Bürnmoos, Austria |
|                         |                                    | OS-20             | 0.20           | 25                |           |                               |
|                         |                                    | OS-18             | 0.18           | 49                |           |                               |

Surface roughness evaluation

The surfaces of IPR auxiliaries were analyzed with an optical profilometer (FRT MicroProf® 100, equipped with a H0 sensor, Fries Research & Technology, Bergisch Gladbach, Germany). Linear traces were recorded at a pixel density of 1000/mm. Due to the different forms of the instruments, different total lengths of the traces were obtained. For the DiaStrip system, the Intensiv Ortho-Strips system, and the G5-ProLign system, the whole abrasive part could be measured. The resulting trace lengths were 13 mm (DiaStrip and Intensiv Ortho-Strips) and 17 mm, respectively (G5-ProLign). The sector-shaped OS Discs were measured at the outer edges of the discs, where trace lengths of 5 mm could be obtained. For the disc shaped Galaxy IPR Diamond Discs, traces were measured radially from the outer edges toward the center. For three of the discs, namely OT–11, OT–13, and OT–55, radial traces through the whole abrasive part could be obtained in that way. The trace lengths were 2.7 mm (OT–11), 2.5 mm (OT–13), and 5.2 mm (OT–55). For the fourth disc, OT–56 containing a perforated surface, not the whole abrasive surface could be measured, as there was no radial linear path through it. Nevertheless obtained 3.7 mm long traces for this disc type. The average surface roughness (Ra; in μm), the maximum roughness depth (R_max; in μm), and the arithmetic mean height of the surface profile (R_z; in μm) where then determined for all the traces measured with a special software (Mark III, Fries Research & Technology GmbH, Bergisch-Gladbach, Germany). Profilometric measurements were performed at baseline, i.e., before initiating IPR (T0), and after each ses-
sion, i.e., at 20, 40, 60, 80, and 100 s (T1–T5) by a second examiner (third author), blinded to the experimental groups.

**Statistical analysis**

Random effects linear regression models were fitted using Ra, Rz, and Rmax as the dependent variables respectively and system, grain size, thickness, and time. Interactions between system and time were also assessed. The level of statistical significance was set at 5%. Statistical analysis was conducted with the Stata Statistical Software (Release 15, StataCorp LLC, College Station, TX, USA).

**Results**

The surface roughness values (Ra, Rz, Rmax) obtained by the optical profilometer are presented in Table 2. Surface roughness decreased with time across IPR system, thickness, and grain-size groups. No overall significance of system was found using likelihood ratio tests (P = 0.07 for Ra, P = 0.33 for Rz, and P = 0.48 for Rmax).

There was a significant average decrease of Ra, Rz, and Rmax for all systems for every unit increase in time by –0.171 μm (95% confidence interval [CI]: –0.203, –0.139; P < 0.001), –3.297 (95% CI: –4.422, –1.154; P = 0.001), and –2.788 μm (95% CI: –4.422, –1.154; P = 0.001), respectively (Table 3). Ra, Rz, and Rmax values increased significantly, i.e., by 0.194 μm (95% CI: 0.068, 0.321; P = 0.003), 5.890 μm (95% CI: 2.282, 9.497, P = 0.001), and 5.319 μm (95% CI: 1.258, 9.379; P = 0.010) as instrument thickness increased by one unit (Table 3). There was no significant average reduction of roughness values across grain sizes, viz. –0.008 μm (95% CI: –0.025, 0.008; P > 0.05), –0.244 μm (95% CI: –0.709, 0.221; P > 0.05), –0.179 μm (95% CI: –0.695, 0.337; P > 0.05) (Table 3).

There was no evidence of interaction between system and time as the likelihood ratio tests P values for Ra, Rz, and Rmax were 0.88, 0.51, and 0.70, respectively, and thus the interactions terms were dropped from the model. Roughness reduction by time, was comparable among systems (Fig. 1).

**Discussion**

As the popularity of IPR is increasing in nonextraction orthodontic treatment with fixed appliances and clear thermoplastic aligners, it is worthwhile to thoroughly explore the mechanical behavior of IPR systems. To the best of our knowledge, this is the first study designed to investigate the surface roughness changes in an extended list of commonly used handpiece-driven IPR instruments.

The lack of overall significance in roughness changes between systems indicates that no system was found superior to others in withstanding abrasive loss. All tested materials exhibited a significant reduction in surface roughness with time, which was comparable for all IPR systems. Given instrument surfaces were cleaned before each profilometric evaluation, it may be expected that in clinical conditions the decrease in roughness might be more rapid since besides detachment of diamond granules, increasing accumulation of tooth material on the instrument surface during the repeated applications might take place [16]. In addition, in daily practice, IPR is performed between adjacent teeth. In case proper contacts and mechanical access are not provided, forcing the stripping auxiliary into tight contact points and application of a heavy load by the clinician, will result in instrument deformation and a more rapid loss of abrasive power [16].

Thicker IPR auxiliaries showed significantly less abrasive wear compared to auxiliaries with thinner stripping segments. This finding implies that regardless of IPR system, thinner stripping instruments may require more frequent replacement when used in vivo. As other investigators stated, instrument thickness may influence the instrument deflection and achieved enamel reduction. The thicker or the more solid the IPR instrument, the more efficient the distribution of the applied force to the enamel surface [22].

Surface roughness of IPR systems was quantified in the present study by profilometry, a broadly used method for measuring the surface profile of dental materials [23–25]. Nevertheless, profilometry has been criticized for inducing sample damage and its inability to measure overall surface roughness due to scanning a single line in a preselected area [26, 27]. By using a noncontact optical profilometer, we avoided any potential sample damage. Although the profilometer used would allow measurement of the roughness parameters for whole surfaces, the different kinds of perforations of the auxiliaries made it impossible to measure surfaces in a standardized way for all the auxiliaries. Therefore, we decided to rather measure traces of maximal lengths across the cross-sections of the abrasive parts of the auxiliaries. Furthermore, the optical profilometer provides an extremely high vertical resolution (<10 nm) and a set of roughness values that permits statistical analysis [28].

It is well-accepted that the amount of enamel reduction is influenced by operator- or technique-related aspects such as exerted pressure, hardness, and particle size of the abrasive, IPR duration, and tooth-related aspects such as enamel hardness [17]. As there is no data in the literature about the optimal applied force [22], to ensure standardization of the experimental IPR technique, enamel preparation was carried out by a single clinician within a predefined period, strictly following manufacturers’ instructions for use.
| Surface roughness measurements (Ra, Rz, Rmax) at T0–T5 provided by the optical profilometer |
|--------------------------------------------------------------------------------------------|
| Surface roughness (Ra, Rz, Rmax) bei T0-T5, bestimmt mittels optischer Profilometrie |

| IPR instrument | T0 | T1 | T2 | T3 | T4 | T5 |
|---------------|----|----|----|----|----|----|
|               | Ra | Rz | Rmax | Ra | Rz | Rmax | Ra | Rz | Rmax | Ra | Rz | Rmax |
| DS-25         | 1.996 | 50.811 | 63.073 | 1.761 | 46.8 | 51.61 | 1.627 | 43.895 | 49.101 | 1.523 | 39.546 | 40.175 |
| DS-40         | 2.706 | 77.553 | 80.898 | 2.272 | 60.146 | 71.697 | 2.318 | 53.886 | 55.318 | 2.069 | 54.128 | 64.354 |
| DS-60         | 3.579 | 92.398 | 96.5 | 2.256 | 52.47 | 55.611 | 2.265 | 55.871 | 63.219 | 2.275 | 67.198 | 76.742 |
| IS-25         | 2.123 | 46.556 | 49.907 | 1.265 | 36.031 | 42.811 | 1.094 | 24.967 | 35.24 | 1.002 | 21.14 | 27.393 |
| IS-40         | 4.223 | 52.262 | 58.385 | 1.797 | 44.448 | 49.165 | 1.534 | 36.608 | 41.795 | 1.443 | 32.385 | 37.767 |
| IS-60         | 3.639 | 77.174 | 77.914 | 2.82 | 70.49 | 75.396 | 3.115 | 64.874 | 72.997 | 2.866 | 60.143 | 57.158 |
| SDC-15        | 1.469 | 37.944 | 41.337 | 1.179 | 28.534 | 37.355 | 0.939 | 20.882 | 28.813 | 0.866 | 24.548 | 37.364 |
| SDC-20        | 2.046 | 49.054 | 46.547 | 1.351 | 32.965 | 41.713 | 1.26 | 31.506 | 36.009 | 1.14 | 39.034 | 47.517 |
| SDC-30        | 2.962 | 88.329 | 102.899 | 2.394 | 60.385 | 60.518 | 2.106 | 59.55 | 60.958 | 1.859 | 63.778 | 68.31 |
| OT-11         | 3.194 | 56.316 | 66.149 | 2.922 | 78.925 | 92.196 | 1.912 | 44.553 | 57.881 | 1.741 | 30.466 | 33.528 |
| OT-13         | 2.609 | 37.305 | 39.579 | 2.551 | 40.367 | 43.287 | 2.064 | 36.415 | 40.861 | 2.087 | 42.491 | 55.831 |
| OT-55         | 2.579 | 57.198 | 61.315 | 2.45 | 59.692 | 65.81 | 2.693 | 48.448 | 57.414 | 2.295 | 52.165 | 55.62 |
| OT-56         | 3.108 | 53.304 | 57.259 | 3.045 | 57.001 | 59.035 | 2.669 | 48.473 | 57.826 | 2.65 | 56.407 | 62.212 |
| OS-10         | 1.815 | 28.514 | 33.391 | 1.327 | 16.332 | 18.311 | 1.205 | 16.762 | 18.659 | 1.093 | 14.958 | 15.885 |
| OS-20         | 2.994 | 61.357 | 64.217 | 2.548 | 59.923 | 55.016 | 2.538 | 61.091 | 69.381 | 2.284 | 55.479 | 60.335 |
| OS-18         | 2.817 | 77.06 | 92.416 | 1.637 | 49.912 | 58.769 | 1.523 | 37.215 | 46.107 | 1.237 | 29.93 | 38.545 |

*DS* DiaStrip, *IS* Intensiv Ortho-Strips System, *SDC* G5-ProLign, *OT* Galaxy IPR Diamond Discs, *OS* OS Discs
Table 3  Coefficients, associated confidence intervals (95% CIs), and P-values from the random effects linear models for $R_a$, $R_z$, $R_{max}$ by system, thickness, grain size group, and time

| System $^a$ | $R_a$ Coefficient | P-Value | 95% CI  | System $^b$ | $R_z$ Coefficient | P-Value | 95% CI  | System $^c$ | $R_{max}$ Coefficient | P-Value | 95% CI  |
|-------------|-------------------|---------|--------|-------------|-------------------|---------|--------|-------------|------------------------|---------|--------|
| DS          | 0.181             | 0.505   | -0.350, 0.712 | DS           | 11.852            | 0.144   | -2.851, 26.554 | DS          | 12.263               | 0.141   | -4.060, 28.587 |
| IS          | 0.175             | 0.516   | -0.353, 0.703 | IS           | 5.022              | 0.500   | -9.587, 19.632 | IS          | 5.045                | 0.542   | -11.175, 21.264 |
| SDC         | -0.491            | 0.109   | -1.091, 0.109 | SDC          | -3.543            | 0.676   | -20.153, 13.608 | SDC         | -0.428               | 0.964   | -18.871, 18.014 |
| OT          | 0.695             | 0.009*  | 0.172, 1.219  | OT           | 11.195            | 0.130   | -3.290, 25.680 | OT          | 11.776               | 0.151   | -4.305, 27.857 |
| Thickness   | -0.008            | 0.323   | -0.025, 0.008 | Grain size  | -0.244            | 0.304   | -0.709, 0.221  | Grain size  | -0.179               | 0.496   | -0.695, 0.337 |
| Time        | -0.171            | 0.000*  | -0.203, -0.139| Time         | -3.297            | 0.000*  | -4.493, -2.100 | Time        | -2.788               | 0.001*  | -4.422, -1.154 |

**Fig. 1**  Roughness changes of interproximal reduction (IPR) instruments in relation to time ($R_a$; $R_z$; $R_{max}$).

Certain caveats need to be acknowledged when translating our study findings into clinical practice. The sample teeth were mounted in acrylic resin, and therefore, it may be presumed that no physiologic tooth movement during IPR was simulated. Alternative embedding in silicone, like in past studies [22, 29], has been criticized since silicone may fatigue faster than biological tissues. Possible loosening of the sample teeth was not modelled.
the teeth in the silicone base could lead to insufficient resistance to the mechanical movement of the auxiliary, and eventually insufficient loading by the clinician during IPR [29]. Furthermore, during or after IPR in vivo, stretching of periodontal fibers might occur consequent to the initial aligning, causing tooth movement and underestimation of the stripping outcome [29]. Unlike clinical conditions, IPR in this in vitro investigation was carried out on individual teeth without the need for opening up the interproximal space. This was chosen deliberately to facilitate access to interproximal areas and direct study of surface roughness changes of IPR instruments after multiple applications.

Future studies should aim to evaluate the efficiency of powered IPR systems in vivo as well as user friendliness and patient comfort [22]. It would be useful to couple the abrasive wear of IPR auxiliaries with the actual amount of the stripped enamel, and to assess patient perception during IPR procedures with different systems. In this way, valuable recommendations can be made to clinicians about the lifecycle and frequency of replacement of IPR instruments to maximize treatment efficiency and patient comfort.

Conclusions

No system was found superior to others in withstanding abrasive wear. All tested powered stripping materials presented a significant decrease of surface roughness after repeated in vitro use. The grain size of the stripping segment did not have a significant effect on the observed roughness changes. Significantly less abrasive wear was observed in thicker auxiliaries, implying longer potential clinical use compared to thin IPR auxiliaries.

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Compliance with ethical guidelines

Conflict of interest C. Livas, T. Baumann, S. Flury and N. Pandis declare that they have no competing interests.

Ethical standards The local ethics committee (Kantonale Ethikkommission, Bern, Switzerland; reference number: Req - 2016-00332) categorizes pooled teeth as an “irreversibly anonymized biobank” and thus, no previous ethical approval was needed.

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