Original Article

In vitro and in vivo evaluation of diamond-coated strips

Roberta Lione[a]; Francesca Gazzani[b]; Chiara Pavoni[a]; Stefano Guarino[c]; Vincenzo Tagliaferri[d]; Paola Cozza[e]

ABSTRACT

Objective: To test in vitro and in vivo the wear performance of diamond-coated strips by means of tribological testing and scanning electronic microscope (SEM).

Materials and Methods: To evaluate the in vitro wear performance, a tribological test was performed by a standard tribometer. The abrasive strips slid against stationary, freshly extracted premolars fixed in resin blocks, at a 2-newton load. At the end of the tribological test, the residual surface of the strip was observed by means of SEM analysis, which was performed every 50 meters until reaching 300 meters. For the in vivo analysis, the strip was used for 300 seconds, corresponding to 250 meters.

Results: The strips presented a fenestrated structure characterized by diamond granules alternating with voids. After the first 50 meters, it was possible to observe tooth material deposited on the surface of the strips and a certain number of abrasive grains detached. The surface of the strip after 250 meters appeared smoother and therefore less effective in its abrasive power. After 300 seconds of in vivo utilization of the strip, it was possible to observe the detachment of diamond abrasive grains, the near absence of the grains and, therefore, loss of abrasive power.

Conclusions: Under ideal conditions, after 5 minutes (300 meters) of use, the strip loses its abrasive capacity by about 60%. In vivo, a more rapid loss of abrasive power was observed due to the greater load applied by the clinician in forcing the strip into the contact point. (*Angle Orthod.* 2017;87:455–459)

KEY WORDS: Interproximal enamel reduction; Diamond coated strip; SEM

INTRODUCTION

The grinding of interproximal tooth surfaces was first described by Ballard in 1944 as a method to correct a lack of harmony in tooth size.[1] Interdental stripping, also known as interproximal enamel reduction (IPR), is a common clinical procedure in orthodontics used to gain space, correct Bolton tooth-size discrepancies, rectify morphologic anomalies, and reduce interdental gingival papillary retraction.[2,3] Currently, IPR is performed by using handheld or motor-driven abrasive strips, handpiece-mounted, diamond-coated disks, and tungsten-carbide or diamond burs.[4] Many studies have investigated the effects of various interdental stripping methods on the enamel surface.[5–7] It has been reported that IPR creates enamel furrows and scratches that might promote greater plaque retention and increase risk of caries.[8–10] For this reason, several treatment protocols have been proposed to achieve a smooth surface. Nowadays, various mechanical or automatic rotating devices can produce enamel surfaces that are even smoother than natural enamel in a reasonable time and with a good acceptance by the patient.[11,12] Danesh et al. reported that after polishing, surfaces that had been treated with an automatic oscillating

[a] Research Fellow, Department of Clinical Sciences and Translational Medicine, University of Rome "Tor Vergata," Rome, Italy, and research Fellow, Department of Dentistry, University Nostra Signora del Buon Consiglio, Tirana, Albania.

[b] Private Practice, Rome, Italy.

[c] Assistant Professor, Department of Engineering, University of Rome "Niccolò Cusano," Rome, Italy.

[d] Professor, Department of Enterprise Engineering, University of Rome "Tor Vergata," Rome, Italy.

[e] Professor and Department Chair, Department of Clinical Sciences and Translational Medicine, University of Rome "Tor Vergata," Rome, Italy, and Head, Department of Dentistry, University Nostra Signora del Buon Consiglio, Tirana, Albania.

Corresponding author: Dr Roberta Lione, Department of Clinical Sciences and Translational Medicine, University of Rome Tor Vergata School of Dentistry, Viale Oxford, 81 - 00133, Rome, Italy
(e-mail: robertalione@yahoo.it)

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system presented with better results in terms of smoothness.[5]

Recently, various methods have been gradually improved with the primary goal of obtaining precise IPR in terms of optimal amount of enamel grinding. Many authors recommend a reduction of no more than half the enamel coating's original thickness to avoid immoderate degradation.[6,7,13] It has been claimed that 0.3–0.4 mm of enamel can be safely removed, making IPR a minimally invasive procedure.[4,14] Several investigators have reported that mechanical stripping can reduce chairside time, achieving more and better interproximal reduction than manual techniques.[15,16]

Johner et al. demonstrated that, when testing three different mechanical stripping methods, the average amount of stripping was generally smaller than the intended amount of enamel reduction.[6]

Although many studies[4,5,7,12,13] have analyzed enamel surfaces after stripping, no data exist on the quantitative and qualitative evaluation of abrasive strips before and after use. In fact, the amount of enamel reduction depends on several factors, such as exerted pressure and enamel hardness, but mostly on particle size of the abrasive and the time used to apply it.

Therefore, the aim of the present study was to test in vitro and in vivo the wear performance of flexible, oscillating diamond-coated strips compared with unused strips by means of the tribological test and scanning electronic microscope (SEM).

MATERIALS AND METHODS

The strips analyzed presented with diamond abrasive grains on the left side with a granulometry (size and distribution of grains) of about 80 μm (OS80C-L, Intensiv Ortho-Strips System, Zurich, Switzerland). In order to evaluate in vitro wear performance, a tribological test with a linear, reciprocating, dry-sliding motion was performed by a standard tribometer (Tribometer, CSM Instruments, Peseaux, Switzerland) at about 20°C (± 0.2°C). The abrasive strips slide against stationary, freshly extracted mandibular first premolars fixed in resin blocks, at a 2-newton load (frequency, 3 Hertz; stroke, 20 mm; sliding distance, up to 250 meters). All the teeth were collected from patients who had extraction therapy at the Department of Orthodontics of the University of Rome "Tor Vergata."

All the extracted teeth were thoroughly cleaned of debris and soft tissue, then conserved and fixed in 4% glutaraldehyde in 0.2-M sodium cacodylate buffer solution at 4°C. The instrument generates a friction coefficient for both forward and backward displacement of the stroke while the software acquires data on pressure, static counterpart, and sample wear rates.[17]

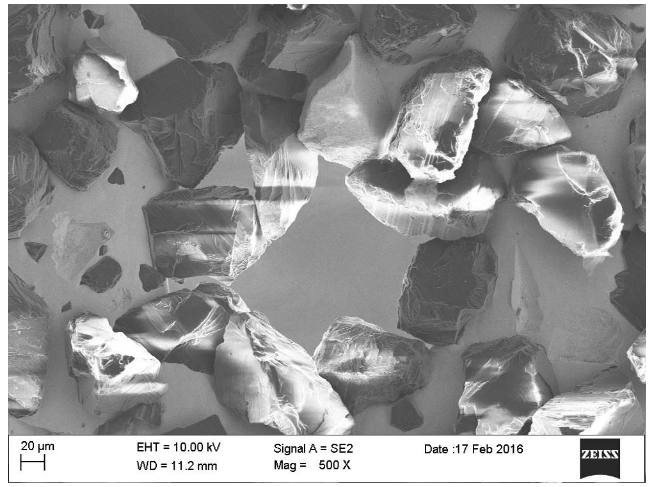

Figure 1. SEM (500×) analysis of unworn strip. The surface is characterized by the presence of diamond abrasive grains and voids.

It is also possible to calculate the variation over time of the friction coefficient. Wear rate of the strip was assessed by the contact probe surface profile, acquiring data every 5 μm (lateral resolution, 5 μm) by scanning the area involved by the action of the counterpart and measuring wear volume and minimum and maximum heights of the wear pattern. Therefore, the friction coefficient was recorded by using an acquisition system and ad hoc software. A decrease in friction coefficient is associated with a decrease in the tangential load of the strip on the tooth, thus, a progressive loss of ability of the abrasive strip. Every 50 meters the resin block was rotated 90° to prevent the strip from losing contact with the enamel surface of the extracted teeth. At the end of the tribological test, the residual surface of the strip was observed for qualitative evaluation by means of SEM (Supra 35, Carl Zeiss SMT, Oberkochen, Germany) and compared with the surface of unused strips with the same granulometry. The SEM analysis was performed every 50 meters until reaching 300 meters, and the morphological observation was made at 500×, 1000×, and 2000×.

For the in vivo analysis, three patients (mean age: 14 ± 1.3 years) requiring IPR on the mandibular incisors with good oral hygiene, no caries, and no white spots were collected at the orthodontic department of the same university. The present protocol was approved by the Ethics Committee at the University of Rome "Tor Vergata." IPR was performed with one strip mounted in a contra-angle handpiece with rotation speed of 20,000 rpm as suggested by the manufacturer. To obtain the working time of the strip knowing the number of meters covered, it was necessary to consider the rotation speed set on the contra-angle. The spinning of the handpiece produces a linear motion of the strip that

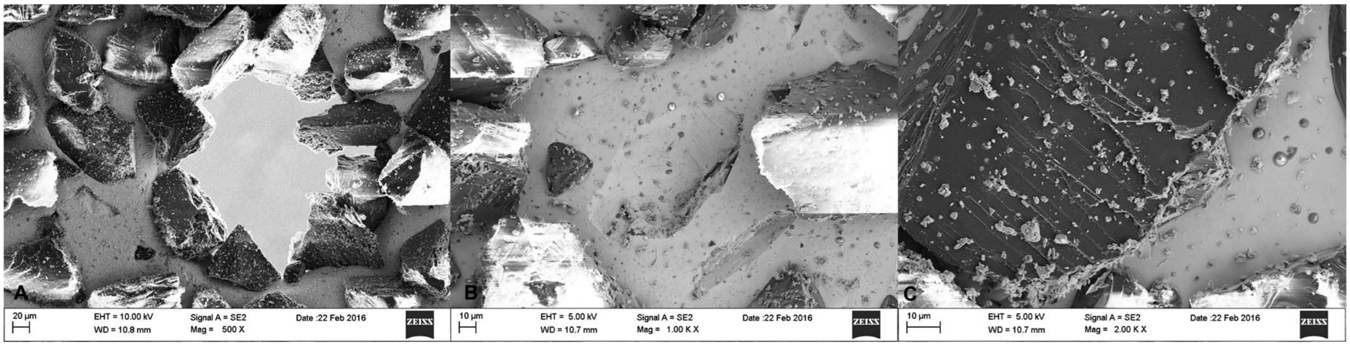

Figure 2. SEM analysis after 50 meters. A. 500×. B. 1000×. C. 2000×.

can be expressed in meters per minutes. Overall, the strip was used with adequate water spray for 300 seconds, corresponding to 250 meters (250 meters = 20,000 rpm × 300 seconds). Referring to the distance-speed-time formula, it is possible to calculate usage time. Finally, the structure of the in vivo worn abrasive strip was analyzed by means of SEM to characterize the surface damage of the tool.

RESULTS

The SEM analysis of the unworn strips highlighted the structure of the abrasive track. The surface of Ortho-Strips consists of diamond abrasive grains arranged on a steel substrate. The surface has a fenestrated structure on which diamond granules alternate with voids that help remove the waste produced (Figure 1). Compared with the various unused strips having the same granulometry of 80 μm, the number of diamond grains and their distribution varied considerably. At the end of the tribological test, the residual surface was observed every 50 meters until reaching 300 meters of distance covered. Morphological analysis of all the images made at different magnifications after the first 50 meters showed the presence of tooth material deposited on the surface of the strip and the detachment of a certain number of abrasive grains (Figure 2). These two phenomena produced a progressive loss of abrasive power as the distance increased. The surface of the strip after 250 meters of use appeared totally covered with the enamel residue. Many of the abrasive grains were detached from the surface, which appeared smoother and therefore less effective in its abrasive power (Figure 3). After 250 meters, the friction coefficient was reduced about 60% compared with initial conditions. In terms of time, this corresponds to an operating time of about 5 minutes. Before reaching the established distance of 300 meters, the strip broke.

After 300 seconds of in vivo utilization of the strip, it was possible to observe the detachment of diamond abrasive grains as a result of loading stresses, the near absence of grains and, therefore, the loss of strip abrasive power (Figure 4).

DISCUSSION

Although many studies[4–7] have analyzed the effects on the enamel produced by various stripping methods, no data are available on a quantitative and qualitative evaluation of abrasive strips before and after use. To our knowledge, this is the first attempt to evaluate in vitro and in vivo the wear performance of the diamond-coated strips. In particular, the abrasive power of the strips was tested every 50 meters to provide clinical information about their useful life.

The strip morphological features and the mechanical response were experimentally analyzed by the tribo-

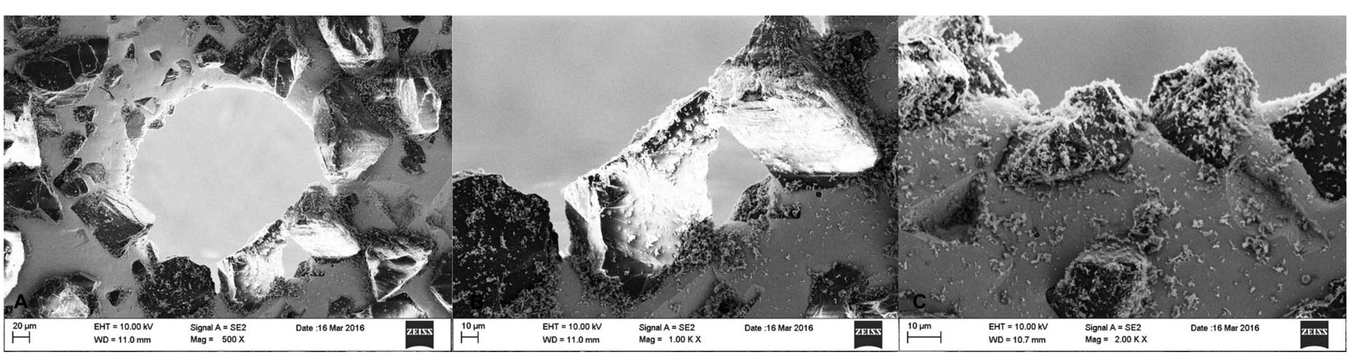

Figure 3. SEM analysis after 250 meters. A. 500×. B. 1000× C. 2000×.

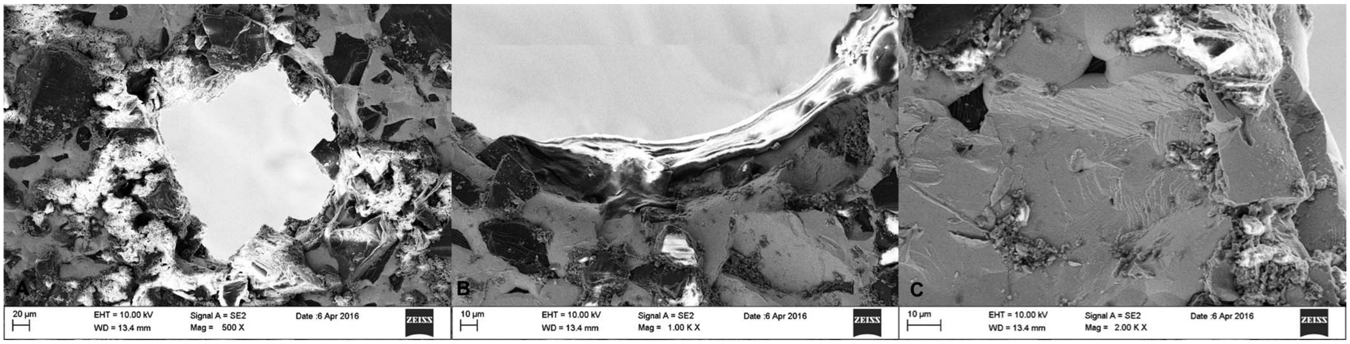

Figure 4. SEM analysis after 300 seconds of in vivo test. A. 500×. B. 1000×. C. 2000×.

logical test and SEM. Setting the test parameters such as speed, frequency, contact pressure, time, temperature, and humidity allowed us to reproduce the real-life conditions of an IPR situation. The tribological test facilitated studying the wear behavior of solid-state materials, measuring the friction coefficient of the strip against the enamel surface at different observation times.[17]

In the present study, it was observed that after approximately 30 meters under ideal conditions, the friction coefficient decreased about 60%. Up to 200 meters, the reduced value of the friction coefficient was almost constant. A decrease of the friction coefficient was associated with a loss of abrasive grains, hence, a reduced efficiency of the strip. This is due to both the detachment of diamond powder from the matrix of the strip and to a progressive deposition of enamel chips on the abrasive track. The SEM analysis revealed that the presence of tooth material on the strip surface and the detachment of diamond granules gradually increased during use, quickly losing a large part of their abrasive power. These results are in agreement with those reported by Grippaudo et al.,[18] who observed that different levels of abrasion made the strips unusable after 40 passages.

When the strip was tested under in vivo conditions on three patients for 300 seconds, an even more significant effect became evident on the abrasive track. This was due to the load applied by the operator's forcing an abrasive strip into the contact point, which was greater than that under ideal conditions. Moreover, during clinical activity, it is necessary to consider that the applied load could vary considerably between different operators. For this reason, the wear behavior information obtained from the experimental analysis can predict the useful life of the strip only when used under standard conditions.

One of our main goals was to maintain control of the force during clinical use. Applying a tool to the contra-angle properly calibrated and equipped with dedicated electronics would alert the operator whenever the force limit is overrun. In this way, by keeping the load within an optimal range, one could predict the useful life of the strip and use it to its best advantage.

CONCLUSIONS

- Under ideal conditions, after 5 minutes (300 meters) the strip lost its abrasive capacity by about 60%.
- When the strip was tested in vivo, a more rapid loss of abrasive power was observed due to the greater load applied by the clinician in forcing the strip into the contact point.

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