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ORIGINAL ARTICLE

Experimental validation of mechanical oscillating IPR system

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ABSTRACT

BACKGROUND: Interproximal enamel reduction (IPR) is a clinical procedure which involves reduction and anatomic recontouring of interproximal surfaces of enamel as a method of gaining space. The biological effects related to this clinical procedure have long been discussed. Thus, the aim of this study was to evaluate the enamel reduction efficiency and the effects on enamel surfaces of the oscillating mechanical system for interproximal enamel reduction (IPR).

METHODS: Fifteen complete oscillating IPR sequences included one opener (0.1 mm), two metallic strips for active IPR phase (0.2 and 0.3 mm), three resin strips for active and initial polishing phases (0.4 and 0.5 mm), and one resin strip for polishing phase (0.15 mm). Sequences were selected and tested on fifteen freshly extracted teeth by means of tribological tests with alternative dry-sliding motion (Linear Reciprocating Tribometer; C.S.M. Instruments, Peseaux, Switzerland). A 3D analysis of treated surfaces was performed by using a TayMap software. Then, enamel surfaces were qualitatively evaluated before and after the tribological analysis, with a FEI Quanta 200 (FEI, Hillsboro, OR, USA) in high vacuum at 30.00 kV. Images were acquired at a 30×, 100× and 300× magnification.

RESULTS: Minimum surface irregularities were observed on all treated enamel surfaces when compared with untreated ones. The 3D analysis showed a uniform wear pattern after tribological tests. Meanwhile, the SEM analysis revealed smooth and regular wear lines on treated surfaces after the entire mechanical IPR sequence. The macroscopic irregularities illustrated can be considered similar to those of untreated surfaces.

CONCLUSIONS: The adoption of a standardized oscillating IPR sequence allows an efficient reduction of the interproximal enamel, leaving regular and harmonious surfaces. Adequate polishing procedures should always be performed at the end of active IPR phases in order to guarantee a good long-term prognosis and proper respect of biological structures.

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KEY WORDS: Dental enamel; Orthodontic anchorage procedures; Dental health services.

Nowadays, interdental stripping – also known as interproximal enamel reduction (IPR) – represents one of the main space-gaining orthodontic procedures, especially when it comes to clear aligner treatment.[1-8] Indeed, dental crowding is among the most common findings in orthodontic practice. Transversal expansion, distalization, incisor proclination, interproximal enamel reduction and, extraction protocols are the main methods adopted for solving dentoalveolar discrepancies. As a matter of fact, the severity of clinical conditions drives treatment strategy choices. Interproximal enamel reduction represents a valid clinical alternative to extraction treatment in borderline cases with mild or moderate crowding.[6-8] Reduction of interproximal enamel surfaces was first described by Ballard back in 1944 as a method to correct disharmony in tooth size.[1] Correction of Bolton tooth-size discrepancies, mild or moderate crowding, morphologic dental anomalies, prevention of relapse, and reduction of interdental gingival papilla retraction represent the other main clinical indications.[1-11] Firstly, air-rotor stripping (ARS) was described by Sheridan more than 20 years ago as a valid alternative to extraction borderline cases. Several IPR systems have been introduced over the years[12-15] ranging from traditional manual strips to the newest mechanical ones. More recently, many powered IPR systems have been developed. Among all, mechanical oscillating abrasive strips gained popularity given their accuracy, efficiency, reduced chair-side time, and minimally invasive effects on enamel surfaces.[12, 13] Since these IPR procedures have become more frequently adopted in daily orthodontic practice, several studies have investigated their effects on enamel surfaces.[12, 13] The amount of IPR to be performed should be established considering the level of crowding severity. In this regard, different aspects need to be considered, such us the enamel thickness and the macroscopic modification of treated surfaces. Concerning the amount of enamel that can be safely removed, several authors agree that a 50% reduction of enamel thickness can be acceptable.[1, 4, 10] As for the biological effects, several authors analyzed the enamel surfaces following IPR procedures.[10-12] Recent literature concluded that interproximal reduction is not associated with increased risk of caries or periodontal pathology.[11, 12] Gazzani *et al.*[12] showed higher efficiency in terms of enamel reduction and more regular enamel surfaces of the mechanical oscillating diamond strips compared with manual ones. Mechanical oscillating systems are characterized by the sequential use of different strips with gradually increasing abrasive properties and some dedicated to polishing phases.[12, 16] In 1956, Hudson introduced the use of medium and fine manual metallic strips followed by polishing and topical fluoride application in order to reduce residual enamel irregularities.[17] Regardless of the IPR technique adopted, the clinical sequence should consist of the following standardized steps:[9] 1) opening phase for the access to the interproximal areas; 2) interproximal enamel removal; 3) check of enamel removed; 4) finishing and polishing phases. Indeed, the use of a standardized clinical protocol ensures to treat the enamel surfaces without any alterations of their integrity and morphology. The increasing abrasive properties of the strips used within the sequence and the final polishing phase help to preserve biological surfaces from the risk of residual macro-irregularities. Thus, the aim of this study was to validate the importance to respect the clinical IPR oscillating sequence through a tribological analysis. A qualitative evaluation of enamel surfaces before and after *in-vitro* IPR procedures was carried out by means of SEM analysis.

Materials and methods

Fifteen complete oscillating IPR sequences (Dentasonic, Cham, Switzerland) were collected and tested. Each standardized sequence included: one opener (0.1 mm), three metallic strips for the active IPR phase (0.2, 0.3 and 0.4 mm), and one resin strip for the polishing phase (0.15 mm). Fifteen teeth were selected for testing according to the following inclusion criteria: extracted teeth with intact enamel layer, lack of caries and enamel anomalies. All teeth belonged to samples available and collected over the years from patients who underwent extraction therapy at the Department of Orthodontics, University of Rome Tor Vergata, Italy. The Informed Consent Agreement was signed by all patients prior to orthodontic treatment to allow the use of their teeth for research purposes. All extracted teeth were thoroughly cleaned of debris and soft tissue, and later conserved and fixed in 4% glutaraldehyde in 0.2-M sodium cacodylate buffer solution at 48 °C. Each tooth was fixed in resin blocks designed by a 3D printer. The latter were fixed and positioned in a metallic clamp support for tribological tests.

Tribological tests

In order to evaluate the effects on biological structures, tribological tests with alternative dry-sliding motion were carried out by a standard tribometer (Linear Reciprocating Tribometer; C.S.M. Instruments, Peseaux, Switzerland). Each abrasive strip selected was adapted on a dedicated support to move against stationary, freshly extracted mandibular first premolars fixed in resin blocks, at a 1-N load (frequency, 10 Hertz; stroke, 10.4 mm; 300 laps). The sliding time was set at 30 seconds for each strip of the sequence simulating clinical use conditions. The time lapse was decided considering the sliding motion of each strip used during the clinical oscillating IPR sequence.

3D wear evaluation and SEM analysis

Following the *in-vitro* analysis, a 3D evaluation was performed by using a TayMap software. The area and volume involved by the action of the counterpart on the surface sample were examined to qualitatively analyze the 3D wear patterns. Enamel surface conditions were also qualitatively assessed before and after tribological tests by means of a SEM analysis with a FEI Quanta 200 (FEI, Hillsboro, OR, USA) in high vacuum at 30.00 kV at a 30×, 100×, and 300× magnification. SEM provided a qualitative evaluation of the treated teeth. A modified version of a previously adopted scoring scale[8] was used to describe the enamel surface conditions. The integrity level was evaluated as follows:

- score 0 – enamel surface free of scratches and grooves;
- score 1 – scratches and grooves not very accentuated and covering a portion of the surface;
- score 2 – deep furrows with rounded edges evident over the entire surface, without debris;
- score 3 – evident and deep-edged furrows visible on the whole surface, and presence of debris on the enamel.

Results

The 3D qualitative evaluation of treated surfaces is shown in Figure 1. The 3D map revealed a uniform red color of the treated surface (dark gray in the print version). In accordance with the color map, red color indicates an intermediate wear level. The graph obtained from the profilometer analysis shows a regular trend of the enamel profile after the tribological test (Figure 2). The SEM analysis (30×, 100×, and 300×) of enamel surfaces before and after IPR is shown in Figure 3, 4. All treated surfaces revealed traces of wear if compared to untreated ones. Minimal surface irregularities were observed after experimental tests, as can be noticed from the images. All tested enamel surfaces revealed grooves and scratches, differently from non-treated surfaces (Figure 4). However, the qualitative SEM evaluation clearly showed smooth and homogeneous profiles after *in-vitro* IPR procedures. Mechanical oscillating IPR sequence defined regular surfaces with parallel and spaced wear lines, minor 1-3 µm grooves, and a uniform enamel coating. In accordance with Nucci's enamel surface classification adopted for the study, macroscopic configuration of untreated teeth reveals a score 0 corresponding to an intact surface, lacking scratches and grooves. The qualitative analysis

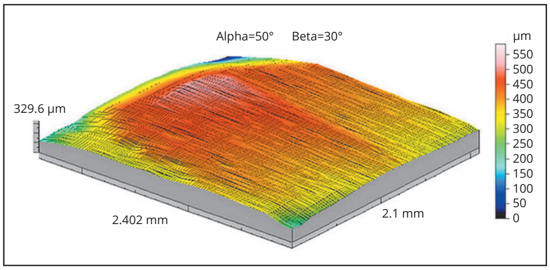

Figure 1.—3D maps of the enamel treated surfaces after complete oscillating IPR sequence sliding test.

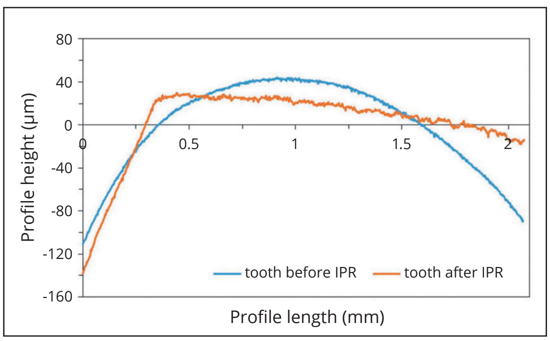

Figure 2.—Macroscopic wear trend observed on enamel surfaces after tribological test.

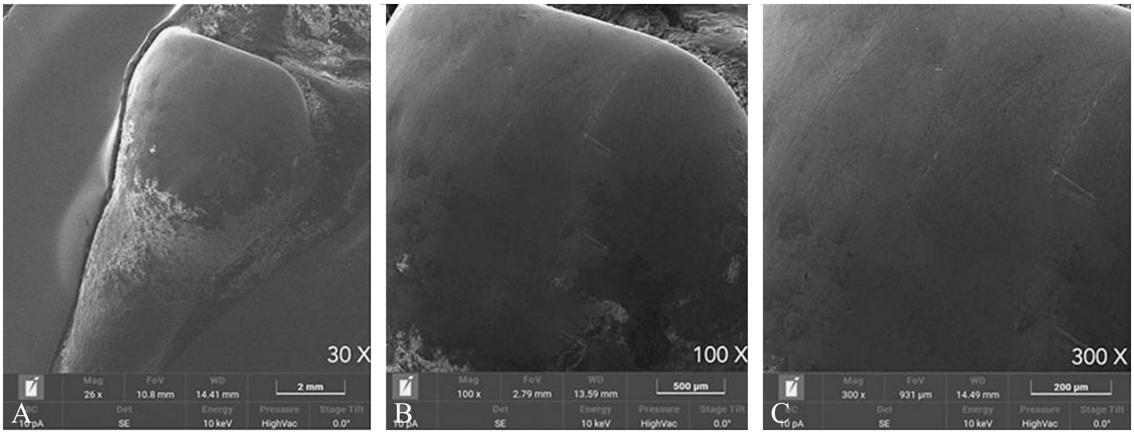

Figure 3.—SEM analysis of untreated enamel surface underwent complete oscillating IPR sequence: A) 30×; B) 100×; and C) 300×.

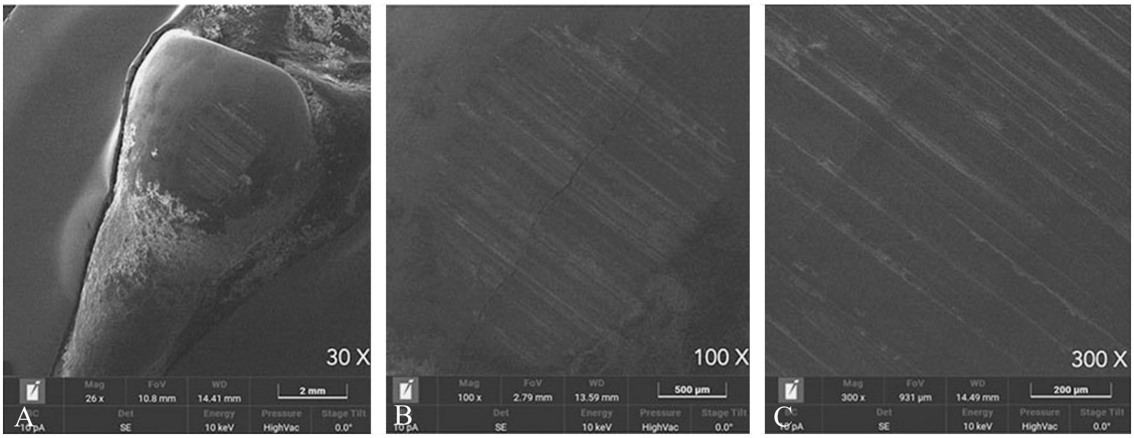

Figure 4.—SEM analysis of enamel surface underwent complete oscillating IPR sequence: A) 30×; B) 100×; and C) 300×.

reported a Score 1 for the tested surfaces highlighting a minimal wear level after the entire oscillating sequence.

Discussion

Considering the increasing use of IPR in orthodontic treatments as a non-extraction option, several techniques have been developed over the years, ranging from traditional manual strips to the newest oscillating systems.[1, 4, 18-25] Nowadays, mechanical oscillating systems are considered the most used and popular ones given their clinical advantages in terms of efficiency, low risks of cutting, and more predictable results.[12, 14-18] However, a common issue is related to all available methods, and it is represented by the surfaces enamel conditions after IPR procedures.[12, 16-20] Since this procedure represents a valid clinical chance as a no-extraction strategy, the possible negative effects related have been widely discussed. Bonetti *et al.* and Arman *et al.*[26, 27] concluded that all stripping methods significantly roughened the enamel surfaces. More recently, Kaaouara *et al.*[28] and Gazzani *et al.*[12] stated that mechanical oscillating systems determine more regular enamel surfaces when compared with traditional manual strips. The main reason of the above conclusions could be explained by different IPR clinical procedures. As a matter of fact, mechanical oscillating systems consist of a standardized sequence, which include the following clinical phases: interproximal contacts opening, interproxi-

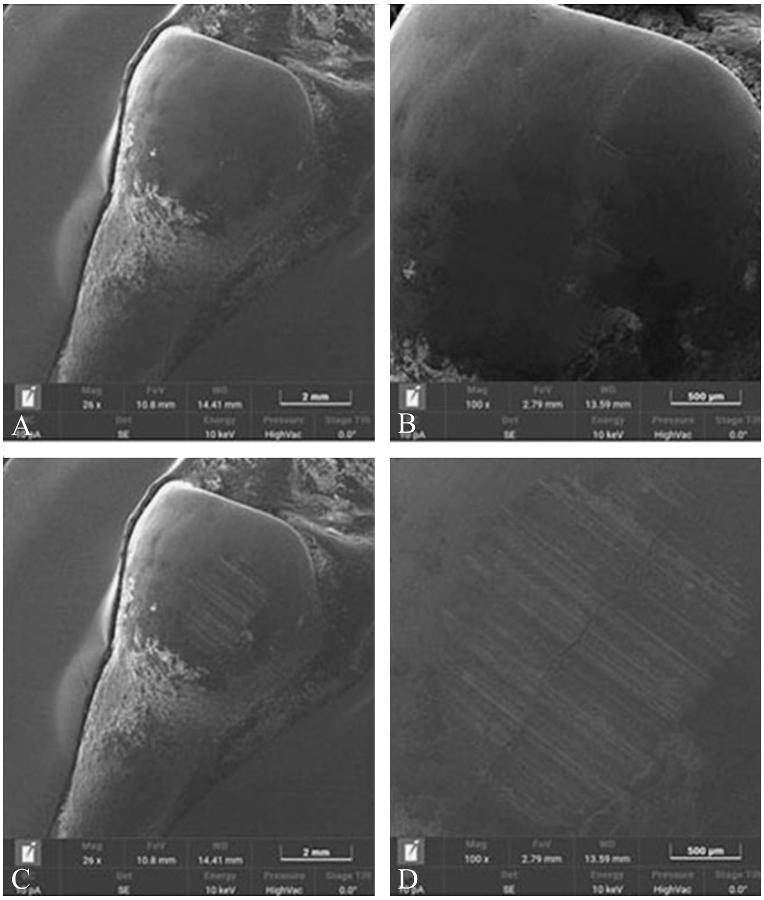

Figure 5.—Qualitative comparison of enamel surfaces: A, B) before IPR sequence; and C, D) after IPR sequence.

mal enamel removal, finishing and polishing.[15] Careful compliance to the mentioned protocol favors the preservation of enamel integrity and morphology reducing biological risks incurred by the treated surfaces. Above all, finishing and polishing phases after interproximal reduction help to prevent adverse clinical effects on treated surfaces. Hence, the aim of this investigation was to validate the importance of respecting the clinical sequence through a SEM analysis of the enamel surfaces before and after *in-vitro* IPR procedures. The experimental analysis was carried out by means of a tribological test of the oscillating sequence on extracted teeth. The entire sequence was performed under *in-vitro* conditions following the above-mentioned standardized clinical steps. The treated surfaces were qualitatively evaluated before and after the experimental analysis in order to examine the macroscopic configuration of the enamel. In accordance with Baumgartner *et al.*,[29] our results demonstrated rougher enamel surfaces after IPR compared to those of untreated teeth (Figure 1-5). Interproximal stripping led to enamel irregularity, including several scratches and wear lines. However, the wear level obtained after the experimental procedures could be considered as not clinically relevant. As can been observed by the SEM images, surface wear conditions after IPR can be meant as similar to those of untreated teeth. Smooth and regular areas with minor abrasions can be noticed in all selected samples. The qualitative evaluation demonstrated homogeneous residual surfaces characterized by the absence of deep scratches and severe irregularities. Also, the 3D analysis revealed a uniform wear pattern post-experimental analysis. All the treated surfaces appeared in a red and uniform color, indicating homogeneous residual traces of the abrasive action of the strips. In tune with the results obtained, Kaaouara *et al.*[28] concluded that mechanical oscillating systems produced regular surfaces, with light parallel lines and minor grooves. Moreover, the authors highlighted the importance of the finishing step to reduce the profile abrasions defined by IPR, leaving surface conditions similar to those of untreated elements. More recently, Gazzani *et al.*[30] confirmed our qualitative results with quantitative data concerning surface roughness and waviness following IPR oscillating sequence procedures. Reduced roughness values were observed after the sequence, indicating a homogeneous surface and low wear level. The authors confirmed the importance of the polishing phase to minimize the residual abrasions defined by IPR. As previously confirmed by Lombardo *et al.*,[16] the polishing and finishing stages featuring dedicated strips play a crucial role to limit damage to enamel surfaces and maintain integrity thereof. Existing literature[12, 14, 16, 28, 30-32] and findings highlight the need for adequate polishing after IPR to respect the treated surfaces and guarantee a good long-term prognosis.

Limitations of the study

Despite the experimental analysis simulated clinical conditions of use, a limitation of this study is represented by the *in-vitro* design. Further studies conducted *in-vivo* should be considered for a more accurate validation of the IPR sequence.

Conclusions

IPR oscillating procedures could be a useful treatment for crowding in clinical orthodontic practice without adverse effects. Qualitative SEM analysis showed regular residual enamel surfaces after oscillating mechanical protocol tested. Wear level and surface irregularities determined by IPR can be considered as not significantly relevant. The clinical standardization of an IPR clinical protocol ensures a good long-term prognosis and a great respect of biological treated structures. From a clinical point of view, the adoption of polishing procedures plays a crucial role to guarantee enamel morphologic integrity and maintain wore surfaces conditions close to those of untreated teeth.

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Conflicts of interest
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions
Elisabetta Cretella Lombardo has given substantial contributions to study design, data investigation, and manuscript critical revision for important intellectual content, Saveria Loberto to data acquisition, Alessia Balboni to data investigation and manuscript writing, Francesca Chiara De Razza to data analysis and manuscript revision, Silvia Fanelli to data interpretation and manuscript writing, Chiara Pavoni to study supervision, manuscript editing and critical revision for important intellectual content. All authors read and approved the final version of the manuscript.

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