Article

Dental Treatment of White Spots and a Description of the Technique and Digital Quantification of the Loss of Enamel Volume

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Abstract: The prevalence of white spots on teeth has increased in recent years. Regardless of their etiology, these lesions are characterized by a reduction in the enamel's mineral phase, which is replaced by organic fluids. This causes an alteration of its chemical composition that affects its optical characteristics. Subsurface demineralization increases the pore volume of enamel, which in turn changes its optical refraction and results in the opaque color of white spot lesions. Here, we examined a non-invasive clinical technique used for eliminating these white spot lesions from enamel via two HCl-based products at different concentrations (6.6% and 15%). We used a digital method for evaluating the volumetric changes produced in dental enamel by the application of both products, one of which involved chemical erosion and the other, abrasive erosion. The mean volume of the enamel eliminated was -0.042 mm in 15% HCl, and -0.12 mm in 6.6% HCl. Thus, both 15% HCl and 6.6% HCl are capable of eroding the surface of the tooth enamel without reaching dentin. Moreover, 6.6% HCl produced a greater erosion of the dental enamel and left the surface a texture typical of an abrasive chemical-erosive product. The 15% HCl, however, produced an etching pattern typical of an erosive chemical with open enamel prisms prepared for subsequent adhesive procedures and restorers.

Keywords: white spots; hydrochloric acid; ICON Etch; chemical erosion; abrasive erosion

1. Introduction

Dental enamel is a highly mineralized acellular connective tissue formed by specialized cells known as ameloblasts. It is composed largely of hydroxyapatite (98%), with some organic components and water (2%) [1]. Developmental defects in enamel may be due to genetic mutations [2], environmental alterations, infection, medication, radiation, or trauma [3,4]. When the composition of dental enamel undergoes a reduction in hydroxyapatite, an increase in organic components that cause dental discoloration appear, which are commonly known as 'white spots' [5]. These are characterized by an intact exterior surface and a deeper demineralized area [6]. The spots are perceived by the human eye as opaque white-colored lesions due to refraction of the light that falls on the demineralized areas that have a refractive index (RI) lower than that of healthy enamel ($RI = 1.62\text{--}1.65$), similar to air or water ($RI = 1.00\text{--}1.33$) [7].

Enamel defects occur as a result of damage occurring either before or after an eruption in the affected tooth [8,9]. Pre-eruptive lesions are considered to derive from dental fluorosis, dental treatments, or from cases of molar incisor hypomineralization (MIH) [5,10,11]. Post-eruptive lesions, also known as white spot lesions (WSLs), are white spots that appear after orthodontic treatment.

The prevalence of these spots is 24%, or anywhere between 50% and 97% following treatment with orthodontic multibrackets and multibands, which mainly affect the gingival third of the vestibular faces of the maxillary incisors [12–15].

Various techniques have been established to improve the esthetics of these enamel surface lesions [16]. In recent years, tooth whitening has become a widely used technique as it is safe, economically feasible, and minimally invasive. It eliminates internal and external discolorations from teeth and camouflages white spots on the surface by increasing the general luminosity of the affected tooth [17,18]. Another option is remineralization with fluoride or casein phosphopeptide, which can also produce good results when restoring the surface layers of caries lesions. However, clinical trials have not reported any cosmetic improvements, since the white spots tend to persist long term [19,20]. It is also considered to be a rather unpredictable treatment that requires prompt application and patient collaboration [21–24]. Lastly, microabrasion with 6.6% hydrochloric acid (HCl)-based products is an effective treatment for white spots that involves the removal of the affected adamantine tissue [16,25–32]. Erosion using 15% HCl-based products and subsequent infiltration of the intercrystalline spaces with low viscosity resin without milling the affected surface is a minimally invasive treatment that camouflages white spots, since the infiltration resin has a similar refractive index (I.R: 1.52) to hydroxyapatite. The refraction of light falling on the resin makes the human eye perceive the tooth color as unaltered in white spot areas [33–37]. As the HCl-based products used in this technique work through the erosion of the enamel, the site of application to the tooth's vestibular surface should be considered carefully in relation to the product's erosive capacity. In this context, Atsu et al. [38] found that in the crown's middle third, within an interval of 3–5 mm from the cemento–enamel junction, the enamel has a thickness of 0.54–0.75 mm to the dentin.

According to the manufacturer's instructions, the etching time for 15% HCl is two minutes. If the white spots persist, etching can be repeated twice more, making a total etching time of six minutes; however, repeated etching on the enamel surface will cause a greater breakdown of enamel prisms. For this reason, it is important to quantify the capacity for eliminating the products used and ensure that they do not reach the dentin–enamel interface in order to avoid problems derived from HCl infiltration into the dentin tubules. In cases of severe enamel discoloration, treatments generally tend to involve more invasive methods, such as resin composite restoration, ceramic veneers, or even crowns; this will provide excellent esthetic results but will involve an extensive loss of dental tissue, which weakens the tooth's mechanical properties [39,40].

All of the available treatments deal with white spots adequately, and each has well defined indications. For this reason, the least invasive and least costly should be an ethical priority for dentists when selecting treatment types for their patients [40].

The objective of this study was to describe a non-invasive clinical technique that eliminates white spots from enamel using HCl-based products at different concentrations (6.6% and 15%) as variations in acid concentration. Additionally, the mode of application determines the extent of volumetric change on the enamel surface. Along with describing the clinical protocol, the outcomes from this study were analyzed through in vitro digital quantification of the loss of enamel volume.

2. Materials and Methods

2.1. Description of the Clinical Process to Remove White Spots Located in the Enamel

To begin, a clinical protocol was followed to treat white spots using one of two commercially available HCl-based products that involved either a chemical erosion technique or an abrasive erosion technique.

Secondly, an intraoral scanner was used to generate Standard Tessellation Language (STL) files using specialized software to quantify the enamel loss produced with each technique. Then, the following steps were followed in sequence:

1. Isolation of the operative field using anchorage clamps in the posterior regions and ligatures in the anterior regions to ensure unvarying isolation during treatment.
2. Initial scan of affected teeth from which an STL file was generated. Scans were taken before and after different treatment applications to evaluate the quantity of tissue eliminated.
3. Application of the HCl-based product to white spots:
 - 3.1. In cases where the 15% HCl product was applied (ICON etch; DMG), each affected tooth received three applications of chemical erosion treatment for two minutes each. The product was placed with the tip of a sponge applicator on the enamel surface for 2 min. When 2 min had passed, the enamel was washed with abundant water for 30 s (Figures 1, 3 and 5).
 - 3.2. In this study, the abrasive erosion treatment (Opalustre; Ultradent) contained a 6.6% HCl slurry with silicon carbide microparticles; this combination offered a chemical stain removal along with gentle mechanical abrasion. In cases using 6.6% HCl, teeth with white spots were treated with various applications according to the manufacturer's instructions. The product was spread on the enamel surface in a 1 mm thick uniform layer. Afterwards, it was rubbed homogeneously for 1 min using Opal Cups (Ultradent) provided by the manufacturer. The enamel was then washed in abundant water for 30 s (Figures 2, 4 and 6).
4. Affected teeth were then scanned with an intraoral scanner (TrueDefinition, 3M-ESPE) and the data were used to generate STL files.
5. Volumetric change was analyzed by means of superimposing the STL files obtained from the scans. The STL files were imported to use the reverse engineering software Geomagic Wrap (3D system), which aligns the data in each file using the best fit algorithm. To do this, the initial file reference mesh was selected, and subsequent meshes were aligned over it as independent floating meshes. For the alignment process, the vestibular area of the teeth presenting variations from one scan to another was omitted due to HCl application.
6. After the final alignment, each tooth was exported in a binary STL format to a program called GOM Inspect (Precise Industrial 3D Metrology). This program generates a gradient color map representing variations from 250 μm to $-250 \mu\text{m}$ so that any point exhibiting a difference between the initial mesh and the succession of the HCl application is represented by a specific color.
7. After quantifying the volume of eliminated enamel, the data were processed to calculate the depth affected by the treatment within the enamel layer. In this way, the dentist was able to know whether to continue applying HCl, to terminate treatment, or to carry out more invasive treatment.

Figure 1. The initial situation of a white spot from a traumatic etiology.

Figure 2. The initial situation of a molar incisor hypomineralisation (MIH) white spot.

Figure 3. The treatment of the same white spot with 15% hydrochloric acid (HCl) (ICON etch).

Figure 4. The treatment of the same white spot with 6.6% HCl (Opalustre).

Figure 5. The situation after camouflaging the white spot with an application of 15% HCl.

Figure 6. The situation after the removal of the white spot with the application of 6.6% HCl.

2.2. In Vitro Volumetric Study of Application of HCl-Based Agents

The digital quantification method described above will help dentists avoid the clinical complications that complete enamel loss can cause, as well as the subsequent restoration to overcome them. An in vitro pilot study was performed to show that it is possible to manage enamel loss objectively by using the superimposing STL files method. Type IV dental plaster models were fabricated following the protocol adopted in previous studies to support two extracted natural human central incisors without white spot lesions [41,42], as white spots show higher prevalence in the central incisors (between 8.3 and 51.6%) [43,44]. Several previous in vitro studies used bovine teeth [45,46] (Figure 7). The University of Valencia Research Ethics Committee approved the study design (Registration number: 1,226,464).

The product based on 15% HCl, Icon Etch (DMG, Germany), was applied to the tooth in position 1.1 4 times at 2 min each, as per the manufacturer's instructions. The tooth at position 2.1 received the product based on 6.6% HCl (Opalustre, Ultradent) with silicon carbide particles applied with OpalCups (Ultradent). This tooth received 4 applications at 1 min each, as per the manufacturer's instructions.

Figure 7. The master model that demonstrated the fabrication of a customized tray used as a container for applying the product; it has a perforation vestibular to the affected tooth made with a 5 mm diameter trephine.

The teeth were scanned with the intraoral scanner (TrueDefinition, 3M-ESPE) after each application, generating STL files used to analyze enamel volume changes by superimposing the files and using the specialized software. Specifically, we used the Geomagic Wrap (3D system), which aligned the data in each file by means of the best fit algorithm, and the GOM Inspect program (Precise Industrial 3D Metrology), which generated a gradient color map that represented variations in enamel volume changes (Figure 8).

Figure 8. The superimposed STL files.

2.3. Scanning Electron Microscopic (SEM) Analysis

After overlapping the files, we decided to visualize the samples under a scanning electron microscope (SEM) to observe the etching pattern obtained following the application of both HCl products. To do this, we adhered the samples to a metal support using an adhesive strip. Once fixed, the samples were introduced into metallization equipment and following an evaporation technique, the samples were metalized with Au–Pd. The samples were then introduced into a specific attachment used to capture images under the scanning electron microscope (Carl Zeiss Ultra 55, Cambridge, U.K.). They were then observed at the following magnifications: 1000×, 2500×, 5000×, and finally at 10,000×.

3. Results

The superimposition process of the STL files resulted in the following:

- In chemical erosion treatment cases, i.e., those that used 15% HCl (Icon Etch; DMG), the mean volume of enamel eliminated was -0.042 mm (Figure 9).
- In cases that used the erosive abrasion treatment, i.e., those treated with 6.6% HCl (Opalustre; Ultradent), the mean volume of enamel eliminated was -0.12 mm (Figure 10).

Figure 9. The mean erosion values after applying 15% HCl.

Figure 10. The mean erosion values after applying 6.6% HCl.

All of the results obtained were statistically analyzed; that is, the significance level used in the analysis was 5% ($\alpha = 0.05$). To evaluate the change in enamel volume between the different applications and their initial states, a paired *t*-test was used. This test contrasts the homogeneity of the means obtained. These were the conclusions: when each application was evaluated with the initial situation

of the untreated tooth, we observed that 6.6% HCl removes more enamel than 15% HCl in the first application ($P = 0.002$; t -test), in the second application ($P = 0.006$; t -test), as well as in the third and fourth applications ($P < 0.001$; t -test) in a statistically significant way.

The volume reductions were measured in comparison between the results of the different application methods, rather than between each method and their respective initial situation. We observed that in the first application, both products removed the same amount of enamel. In the second application, the 6.6% HCl had a volume reduction that was not statistically significant. Finally, in the third ($P < 0.001$; t -test) and fourth ($P < 0.010$; t -test) applications of 6.6% HCl, statistically significant values were observed (Figures 11–16).

Figure 11. The mean values of the erosion in the dental surface after the first application with a gradient color map representing variations from enamel volume changes. The left tooth was treated with the 15% HCl treatment and the right tooth was treated with the 6.6% HCl treatment.

Figure 12. The mean values of the erosion in the dental surface after a second application with a gradient color map representing variations from enamel volume changes. The left tooth was treated with the 15% HCl treatment and the right tooth was treated with the 6.6% HCl treatment.

Figure 13. The mean values of the erosion in the dental surface after the third application with a gradient color map representing variations from enamel volume changes. The left tooth was treated with the 15% HCl treatment and the right tooth was treated with the 6.6% HCl treatment.

Figure 14. The mean values of the erosion in the dental surface after the fourth application with a gradient color map representing variations from enamel volume changes. The left tooth was treated with the 15% HCl treatment and the right tooth was treated with the 6.6% HCl treatment.

Figure 15. A digital volumetric analysis in a sagittal plane. (a) The volumetric change in the dental vestibular area after applying 15% HCl. (b) The volume reduction in the vestibular area with the greater convexity of the treated tooth.

Figure 16. A digital volumetric analysis in a sagittal plane. (a) The volumetric change of the dental vestibular area after the application of 6.6% HCl. (b) The volume reduction in the vestibular area with the largest contour of the treated tooth.

4. Discussion

The techniques for eliminating white spots by means of HCl-based products described above may represent an alternative or coadjuvant treatment to the more commonly used techniques such as remineralization or restoration with resin composite.

Hydrochloric acid at different concentrations has been used in esthetic dentistry for eliminating enamel marks since 1916, when Walter Kane used 36% HCl and heat to remove fluorosis stains. Due to the high concentration, the technique produced satisfactory results, but given the risk of destroying

the enamel, reports of the treatment were not published. In 1941, Raper was the first to describe the technique of fluorosis stain removal, who did so using HCl at a lower concentration than used by Kane to ensure safety; 18% HCl was applied with a cotton wool swab, was left on the enamel for 10 min, and was followed by an application of sodium bicarbonate to neutralize the effect of the acid [37]. In 1989, a micro-abrasion technique was described by Croll that involved using a solution that combined chemical erosion with 18% HCl and mechanical abrasion using a pumice stone, thus eliminating the surface layer of the enamel and the white spots within it [38]. This practice is still considered a safe, effective, and atraumatic technique for eliminating enamel defects derived from hypomineralization or minimal hypoplasia.

An alternative to microabrasion is enamel infiltration with a low-viscosity photopolymerizable resin [30]. This involves pretreating the spot and completely eroding the enamel's impermeable surface layer to expose the lesion before resin infiltration. The surface layer can be removed mechanically with a bur or disc [39], but this generates a smear layer that obstructs the prisms making subsequent infiltration difficult. A better option is to remove the surface layer by means of acid etching, which allows controlling the reduction of the surface layer and leave the tubules open for later infiltration. The available literature on this topic includes several articles that aimed to compare the erosive capacity of various acids including orthophosphoric acid at 37% and HCl at various concentrations for eliminating the enamel surface layer.

Different studies by Meyer-Lueckel et al. stated that enamel discoloration can only be eliminated by products based on 15% HCl due to its capacity to etch the tooth surface more effectively than orthophosphoric acid, although the latter is still used in regular practices [31,40]. Yim reported that the enamel surface etching capacity of HCl was 2.7 times greater than orthophosphoric acid and noted that the etching patterns also differed [41].

On the basis of the greater capacity of HCl to erode the tooth enamel surface [31,40,41], the present study's intentions were to conduct an in vitro comparison of two HCl-based products with concentrations of 6.6% and 15%. Our aim was to investigate the influence of the concentration and the application time of these products upon the enamel surface. Previous studies have yet to provide a clear report of the quantity of enamel eliminated by the HCl products with each application [42–46].

An in vitro study by Arnold et al. evaluated the erosive capacity of a 15% HCl solution by means of optical profilometry, reporting that treatment with 15% HCl will erode dental enamel to a greater or lesser degree depending on the application time. The present study obtained similar results, though with lower erosion values than Arnold et al. We found that HCl rapidly destroys the crystalline structure of hydroxyapatite, and repeated applications increase the extent of destruction. For this reason, caution must be used to protect the areas adjacent to the lesion. In the present work, trays were fabricated as containers for the product, which protected the area surrounding the lesion against damage to the enamel structure [47].

Román Rodríguez et al. published a clinical case report that stated they eliminated enamel surface lesions using a 6.6% HCl paste containing silicon carbide particles, thus obtaining erosion values similar to the present study [16].

We used STL files to superimpose and evaluate the amount of erosion produced by the two products tested. The data were processed with image superimposition software to enable a comparative analysis between different STL files with the method known as the best fit algorithm. This superimposition software offers several advantages to both dentists and researchers who need to analyze data quickly and efficiently and compare volumetric changes produced in different oral structures after clinical treatment. This method has been described as an adequate tool for evaluating volume changes in both dental [16] and gingival [48] tissue.

According to our study's findings, both HCl-based products tested are apt for treating white spots, as they are both capable of producing enamel demineralization without reaching dentine. The 15% HCl used in the chemical erosion technique caused less erosion of the enamel's surface but did so

uniformly, whereas the abrasive erosion technique with 6.6% HCl and OpalCups produced twice the amount of erosion in the surface enamel and in a shorter application time.

As in other studies [41,46,47,49], both teeth were analyzed under an electronic microscope in order to examine the surface characteristics produced by the chemical erosion and abrasive erosion processes. We observed that the tooth treated with chemical erosion presented an etching pattern with complete erosion at the centers of the enamel prisms. These enamel prisms retained prominent edges (Figure 17), indicating that the surface produced was adequate for subsequent adhesive and infiltration procedures. On the tooth treated with the abrasive erosion technique, the surface underwent heterogeneous abrasion on which a surface layer persisted without any type of etching pattern that would allow the infiltration by any type of resin (Figure 18).

Figure 17. The etching pattern of the enamel surface after the 15% HCl application (chemical erosion technique).

Figure 18. The etching pattern of the enamel surface after the 6.6% HCl application with OpalCups (abrasive erosion technique).

For this reason, although the 6.6% HCl application has a greater erosive potential according to the data obtained in our study, we must use it clinically to remove superficial stains that do not require a subsequent adhesive procedure, since the surface it leaves is unsuitable for adhesive procedures and restorers. The 15% HCl application will be used to both remove superficial stains and spots in a minimally invasive way as well as to remove and/or camouflage deeper stains along with adhesive and macroabrasion techniques.

5. Conclusions

In this study, we showed that both HCl-based products (at 6.6% or 15% HCl) are adequate options for treating white spot lesions. In both cases, the engraving depth does not exceed the thickness of the enamel layer. The depth of the etched surface layer was dependent upon the etching time and the application mode. Furthermore, the depth of the etched surface layer could be monitored via a digital volumetric analysis to avoid destroying the entire enamel layer, which would impair the prognosis for adhesion and subsequent restoration. The long-term effects of 6.6% and 15% HCl etching products should be followed up with continuous clinical and scientific research.

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