Chemical and morphological analysis of the human dental enamel treated with argon laser during orthodontic bonding

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Abstract

Introduction: The main utilities of the argon laser in orthodontics are the high speed curing process in orthodontic bonding and the caries resistance promotion of the tooth enamel. **Objective:** To evaluate the chemical and morphological changes in the tooth enamel treated with the argon laser in the orthodontic bonding parameters. **Methods:** Fifteen sound human first premolars, removed for orthodontic reason, were selected and sectioned across the long axis in two equal segments. One section of each tooth was treated and the other remained untreated. A total of thirty samples was analyzed, creating the laser (n =15) and the control groups (n =15). The treatment was done with 250 mW argon laser beam for 5 seconds, with energy density of 8 J/cm^2. **Results:** The X-ray analysis demonstrated two different phases in both groups, the apatite and the monetite phases. The reduction of the monetite phase was significant following laser treatment, suggesting higher crystallinity. The EDS analysis showed an increase in the calcium-phosphorus ratio in the laser group, linked with the decrease of the monetite phase. The surface morphology was smoother after the laser exposure. **Conclusion:** The results of high crystallinity and superficial enamel smoothness in the laser group are suggestive of the caries resistance increase of the tooth enamel.

Keywords: Argon laser. Tooth enamel. Orthodontic bonding.

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INTRODUCTION

The laser-tissue interaction is controlled by the irradiation parameters and optical properties of the tissue. When the laser energy strikes the tissue, it may be absorbed by the tissue, transmitted through it, scattered on it or reflected.[18,22,33] Based on these interactions, the argon laser has five main utilities in dentistry: early caries detection by fluorescence,[7] soft tissue cutting,[21,27] bleaching agent activator,[27] laser curing of dental materials,[2,6] and promotion of tooth enamel resistance against demineralization.[9,10]

High-speed polymerization and enamel resistance promotion are the most significant clinical properties in orthodontic treatment that justifies laser application. In 1999, Blankenau et al[5] showed that 5 seconds of argon laser exposure created a composite with higher compressive strength than 20 seconds of visible light curing. Losche[16] reported a greater conversion rate of canphoroquinone with the argon laser when compared with visible light. Many authors tested the different properties of dental materials cured with argon laser or visible light. Better or equal results in argon laser polymerization were found in these studies.[3,12,21] Pulpal histology from "in vivo" tests confirm that the argon laser used at the energy levels used in restorative dentistry creates neither short-term nor long-term pulpal pathology.[21]

Sedivy et al[24] tested the argon laser in the bonding of orthodontic metallic brackets. They concluded that with 1 W power, the argon laser took 87% less time to obtain similar bond strength than conventional light cure. In a similar study, Lalani et al[13] confirmed that 5 seconds polymerization using argon laser produced bond failure loads comparable to 40 seconds of conventional light cure. Weinberger et al[29] investigated the bonding of ceramic brackets and showed that it can be done with 231 mW power for 10 seconds of argon laser.

Another important effect of the laser on human enamel is related to a prevention characteristic. Hicks et al[9,10] concluded that the human dental enamel became more resistant to dental caries after a single exposure to argon laser radiation of 250 mW for 10 seconds. The same group associated the use of the argon laser with fluoride treatment and found better results in terms of caries resistance. In a clinical study, Anderson et al[1] demonstrated that argon laser radiation with 325 mW for 60 seconds reduced in 90% the depth and the area of caries lesion.

Using the argon laser in the orthodontic bracket bonding, the enamel around the bracket is modified. The effects of the argon laser therapy in tooth enamel vary with the several combinations of power and time curing described, although most of them are for the caries resistance treatment. Nevertheless, the power and the curing time for bonding and for resistance promotion are different.

The purpose of the present study was to investigate the chemical and morphological effects of argon laser irradiation on human enamel treated in a protocol of high speed curing of orthodontic brackets.

MATERIAL AND METHODS

Fifteen human first premolars extracted for orthodontic purposes were selected for this "in vitro" study. Following the extractions, the soft tissues were removed and the teeth were evaluated using a halogen light,[32] only sound elements were selected (Fig 1).

The dental elements were stored in a 0.1% thymol waterish solution and kept in a temperature of 361° C.[4,8] All the teeth underwent prophylaxis, using pumice, water, and brush in low speed for 10 seconds.[23] It was followed by washing with water for 10 seconds and drying with a hair dryer for 15 seconds, so the surface became free from oil contamination.[17] In order to produce uniform abrasion on the enamel surface on the entire sample, a new brush was used for each tooth, and just one operator prepared the sample.

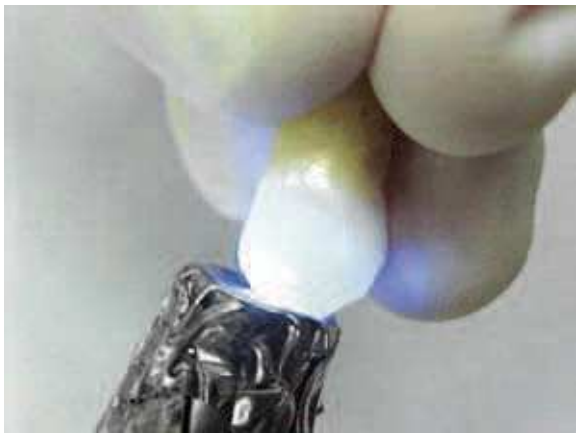

FIGURE 1 - Enamel quality evaluation by halogen light evaluation.

FIGURE 2 - Argon laser treatment with 250 mW power continuously delivered during 5 seconds.

The dental elements were sectioned in two equal segments, cut across the long axis with a carburundum disc in low rotation and water refrigeration. Each tooth had one half treated and the other half remained untreated, thereby creating a laser group (n =15) and a control group (n =15).

The treatment was done with an argon laser (Accucure 3000®, Laser Med, Salt Lake City, USA) with 250 mW power for 5 seconds during each cycle, delivering an energy density of 8 J/cm^2 (Fig 2). The laser power was checked with a calibration meter built into the laser before its use on each sample.

Energy Dispersive Spectroscopic analysis (EDS)

The EDS analysis was done in a 4000 μm^2 enamel area of the buccal surface (Jeol 5800 LV®, Tokyo, Japan). The relative calcium-phosphorus ratio was compared in both the treated and untreated samples, using the technique of least squares fit.

Descriptive statistics were performed on the data to obtain means and standard deviations for each group and the groups were analyzed for significant differences using a paired-sample T test, at 5% significance (SPSS for Windows Release 11.0 SPSS software Corp., Munich, Germany).

Following this analysis, the sample was divided and 10 pairs were submitted to X-ray diffraction analysis and the other 5 pairs were submitted to scanning electron microscopy (SEM).

X-ray diffraction analysis

The sample was laid out with the buccal enamel surface tangent to the diffraction plane and analyzed using an X-ray diffractometer (Rigaku, Dmax 2200, Osaka, Japan) with monochromatized CuK radiation (wavelength λ = 1.540 Å) at 40 kV and 40 mA. The diffractograms were collected in the angular interval of $5° \leq 2\theta \leq 80°$ using 0.05° steps. The fixed time was two seconds per step and the diffractogram of each group was obtained by mean peaks.

The phase identification was done by a matching process using the International Center for Diffraction Data (ICDD) database. The cell refinement report and the crystallinity evaluation were done with the Materials Data Inc Jade® program, version 5.0, California, USA.

Scanning electron microscopy analysis

Five pairs of the sample received a gold layer for 3 minutes in the coater (Pollaron SC 500®, Sputter, VG, Microtec) at 20 mA current and

TABLE 1 - Calcium and phosphorus relative ratio in control and laser groups compared by paired sample test.

Groups	N	Mean	Std. Deviation	Std. Error Mean	Pairs	df	Sig.
Control Ca	15	0.6961	0.0205	0.0053	Pair 1	14	**0.002**
Laser Ca	15	0.7394	0.0319	0.0082			
Control P	15	0.2361	0.0120	0.0031	Pair 2	14	**0.000**
Laser P	15	0.1872	0.0341	0.0088			

200 mTorr vacuum. The enamel surfaces were evaluated by secondary electron detection (Jeol 5800 LV®, Tokyo, Japan) at 500X, 1000X and 1500X original magnification.

RESULTS

Energy Dispersive Spectroscopic Analysis

The paired-sample T test showed significant differences between the relative calcium and phosphorus ratio after the treatment with the argon laser ($p<0.05$). The results indicated higher relative calcium rate and lower relative phosphorous rate after the laser exposure (Table 1).

X-ray diffraction analysis

The phase identification showed a principal and a secondary phase in both groups. The principal phase was the apatite (database card # 09-0432) and the secondary phase was the monetite (database card # 09-0080). The original diffractogram of the control group showed a broad peak between 20° and 35°, which is characteristic phase of amorphous materials (Fig 3).

No new peaks were observed in the laser group when compared with the control group. Nevertheless, the diffractogram of the laser group showed narrower peaks and reduction of the amorphous phase. Furthermore, the monetite phase was significantly decreased, indicating higher crystallinity of the treated enamel surface (Fig 3).

In the cell refinement analysis, both a- and c-axis of the apatite structure showed significant differences between the control and laser groups. After the laser treatment, the a-axis showed a contraction of 0.064 Å and the c-axis an expansion of 0,016 Å.

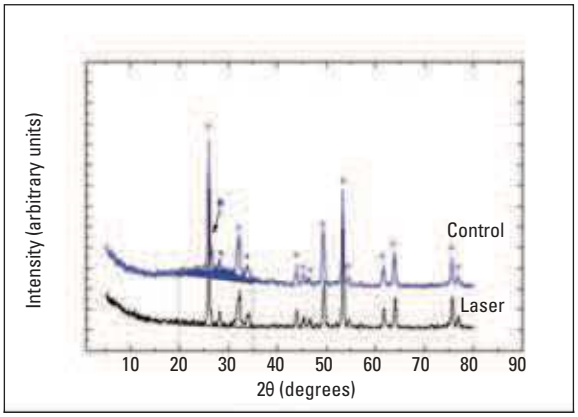

FIGURE 3 - Diffractogram of control and laser groups. (*) Apatite phase peaks, (•) monetite phase peaks. Reduction of amorphous phase (blue area above the diffractogram).

TABLE 2 - Values of experimental and hydroxyapatite cell parameters (database card #09-0432).

Groups	Axis	Mean	Std deviation
Control	a-axis	9.530 Å	0.003 Å
	c-axis	6.861 Å	0.006 Å
Laser	a-axis	9.466 Å	0.006 Å
	c-axis	6.877 Å	0.002 Å
Hidroxyapatite	a-axis	9.418 Å	--
	c-axis	6.884 Å	--

These values obtained from the laser group came close to hydroxyapatite values (Table 2).

Scanning Electron Microscopic analysis (SEM)

Untreated enamel surfaces from the control group showed voids and microvoids, representing the normal enamel prism end markings (Fig 4). In contrast, following argon laser irradiation, the surface morphology was substantially changed, becoming smoother (Fig 5).

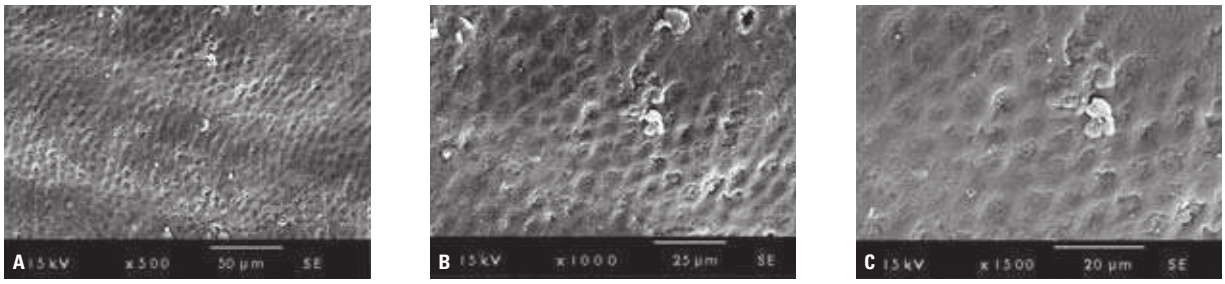

FIGURE 4 - Enamel surface morphology in control group: **A**) SEM at 500X original magnification; **B**) SEM at 1000X original magnification; **C**) SEM at 1500X original magnification (SE detection).

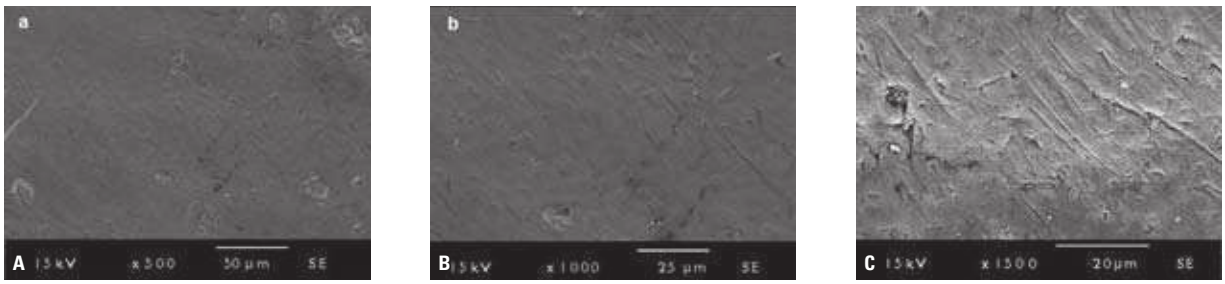

FIGURE 5 - Enamel surface morphology in laser group: **A**) SEM at 500X original magnification; **B**) SEM at 1000X original magnification; **C**) SEM at 1500X original magnification (SE detection).

DISCUSSION

The first laser application in dentistry was done with a ruby laser, which increased enamel resistance to decalcification.[26] Since then, some authors reported this same effect after the enamel treatment with different types of lasers.

The main explanation for the acid resistance of the enamel tissue is less permeability and reduction of carbonate content,[19,20] water and organic substances in the treated enamel[20].

Blankaneau et al[5] reported "in vivo" argon laser radiation effects on human enamel resistance against decalcification. This study described reduction of 29.1% on average lesion depth in a laser treatment with a 250 mW beam for 10 seconds. Anderson et al,[1] using a 325 mW beam for 60 seconds, found reduction of 91.6%. In this way, we could expect similar result on the enamel around the brackets during the orthodontic bonding. Although, the time exposure and the laser power for that are different (250 mW beam for 5 seconds).[13,25,28]

The energy density (ED) could be calculated by the division of the energy (E) by the spot area (S). The energy is expressed by the product of the power (P) and the exposure time[6] (t) (Equation 1).

$$ED = \frac{E}{S} = \frac{P \times t}{S}$$

Nelson et al[19] investigated the effects of pulsed, infrared laser radiation on human dental enamel with an energy density varying between 10 to 50 J/cm^2. They concluded that the laser radiation resulted in a melted surface and the heat delivery was limited to 10-20 µm depth. A new phase of tetracalcium diphosphate monoxide was identified in the treated surface with a

reduction of the carbonate content.

In our study, the argon laser treatment was done with 250 mW power for 5 seconds, delivering an energy density of approximately 8 J/cm^2. No new phase was found in the treated enamel surface. In agreement, Oho and Morioka[20] did not find any new phases in the argon laser treatment with 67 J/cm^2.

The difference among these studies can be attributed to the effect of infrared[19] and the argon laser[20] radiation on enamel surfaces. The higher energy absorption of the infrared spectrum by the enamel results in higher thermal energy conversion[7] and more significant changes in comparison with the argon laser changes.

An interesting finding of this work was the correlation between the EDS and X-ray diffraction results. The EDS analysis showed the increase of the calcium-phosphorus ratio in the laser group. This result was brought into relation with the decrease of the monetite phase found in the x-ray diffraction analysis. In the diffractograms of the control and laser groups, the main phases observed were the apatite and the monetite phase. The apatite phase ($Ca_{10}(PO_4)_6(OH)_2$) had a calcium-phosphorus ratio of 1.67 and the monetite phase ($CaPO_3(OH)$) had a ratio of 1.0. Hence, the decrease of the monetite phase in the laser group, in theory, this should result in an increase of the calcium-phosphorus rate. Actually, the increase of the calcium-phosphorus ratio following the laser treatment was observed, sustaining the change in the enamel surface.

The diffractogram analysis showed the decrease of the amorphous phase after the laser treatment. This result added up to the reduction of the monetite phase and to the narrower apatite peaks in the laser group indicated higher crystallinity in the treated enamel. These results are supported by Oho and Morioka[20] and Nelson et al[19] findings, where a best arrangement of ions in the crystal lattice of the laser treated enamel tissue was found. This feature was related to the higher resistance against enamel acid demineralization[1,9,10]. In addition, the reduction of water, carbonate and organic substances[1,5,19] can also explain the acid resistance of the enamel exposed to laser. So, additional studies are needed to determine the influence of these factors in the orthodontic bonding protocol.

The changes in the apatite structure arrangement were analyzed by the cell refinement of the X-ray analysis. The most significant change found in the present work was the apatite a-axis contraction of 0.064 Å. Based on previous studies, reductions of water and carbonate in the apatite phase[11,15] affected the length of the a-axis of the apatite enamel crystal. The argon laser treatment with energy density of either 11.5 or 100 J/cm^2 induced a contraction of the a-axis of apatite and this result was linked with the reduction of lesion depth and the caries resistance increase of the enamel [9,10,30,31]. In this manner, due to the fact that the argon laser treatment with energy density of 8 J/cm^2 induces an a-axis contraction of 0.064 Å. It is possible that a similar resistance mechanism occurs in the parameters of this study. In such case, it could be suggested that this contraction indicates reduction of water and carbonate, resulting in enamel resistance. However, additional studies are needed to prove this mechanism.

In the SEM analysis, the laser group showed a significantly smoother surface morphology than the control group. The end prism marks observed in the control group were erased after argon laser treatment. This smooth feature is compatible with best arrangement of ions in the crystal lattice of the enamel surface and with the higher crystallinity. Furthermore, a smooth enamel surface reduces the plaque adherence tendency and could be considered by itself as preventive characteristic.

CONCLUSIONS

1. Argon laser treatment with 250 mW for 5 seconds modified the enamel surface resulting in the increase of the enamel crystallinity, suggesting a higher caries resistance.
2. The enamel surface morphology became smoother after the argon laser treatment in the orthodontic bonding parameters.

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Submitted: July 2007
Revised and accepted: November 2007

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