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Assessment of radicular dentin permeability after irradiation with CO_2 laser and endodontic irrigation treatments with thermal imaging

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Abstract

Previous studies have demonstrated that the permeability changes due to the surface modification of dentin can be quantified via thermal imaging during dehydration. The CO_2 laser has been shown to remove the smear layer and disinfect root canals. Moreover, thermal modification via CO_2 laser irradiation can be used to convert dentin into a highly mineralized enamel-like mineral. The purpose of this study is to evaluate the radicular dentin surface modification after CO_2 laser irradiation by measuring the permeability with thermal imaging. Human molar specimens (n=12) were sectioned into 4 axial walls of the pulp chamber and treated with either 10% NaClO for 1 minute, 5% EDTA for 1 minute, CO_2 laser or none. The CO_2 laser was operated at 9.4 μm with a pulse duration of 26 μs, pulse repetition rate of 300 Hz and a fluence of 13 J/cm^2. The samples were dehydrated using an air spray for 60 seconds and imaged using a thermal camera. The resulting surface morphological changes were assessed using 3D digital microscopy. The images from digital microscopy confirmed melting of the mineral phase of dentin. The area enclosed by the time-temperature curve during dehydration, ΔQ, measured with thermal imaging increased significantly with treatments with EDTA and the CO_2 laser ($P<0.05$). These results indicate that the surface modification due to CO_2 laser treatment increases permeability of radicular dentin.

Keywords

Root canal therapy; thermal Imaging; CO_2 laser; dentin; permeability

1. INTRODUCTION

Endodontic irrigants are used for debridement and disinfection during the root canal therapy. [1] An irrigant should allow proper removal of debris and smear layer, facilitate instrumentation and have antimicrobial effect. Since one irrigant does not have all of the necessary characteristics, a combination of different irrigants is typically used in endodontic treatments to achieve the optimal outcome.

Several studies have shown that laser systems can be used to remove debris and smear layers during endodontic treatments. [2, 3] Other studies have shown that lasers can be used for root canal sterilization. [4] Previous studies have shown that the CO_2 laser can be used to convert the hydroxyapatite crystals of enamel and dentin to a purer phase hydroxyapatite for improved acid resistance. [5] Other studies have shown that CO_2 laser irradiation can change the permeability of dentin. [6]

In a previous study, we demonstrated that the changes in the permeability of dentin as a result of remineralization could be measured using thermal imaging. [7] The water permeability in the dentin surface is highly dependent on the surface morphology and the structural changes of the organic scaffold and mineral content. We hypothesize that we can measure changes in the permeability of radicular dentin after CO_2 laser irradiation and chemical treatment via dehydration measurements with thermal imaging.

2. MATERIALS AND METHODS

2.1. Sample preparation

Non-carious human molar teeth (n = 12) were partitioned into 4 sections with a pulpal axial surface in each section as shown in Fig. 1. Axial surfaces of the pulp chamber were ground to a 9 μm finish to create a smooth radicular dentin surface. Samples were treated with either 10% NaClO for 1 minute, 5% EDTA for 1 minute, or irradiated by the CO_2 laser. The samples were stored in 0.1 % thymol solution to prevent fungal and bacterial growth.

2.2. Laser Irradiation Parameters

An RF-excited CO_2 laser, Diamond J5-V from Coherent (Santa Clara, CA), operating at a wavelength of 9.4 μm was used with a pulse duration of 26-μs and pulse repetition rates of up to 3 kHz. The laser had a Gaussian shaped spatial profile. The laser energy output was monitored using a power/energy meter, ED-200 from Gentec (Quebec, Canada). The laser beam was focused to a beam diameter of 1.6 or 3.1 mm using a ZnSe scanning lens of f=125-mm. A razor blade was scanned across the beam to determine the diameter ($1/e^2$) of the laser beam. A computer-controlled high-speed motion control system with Newport (Irvine, California) UTM150 stages and an ESP301 controller was used to create controlled movement of the samples during laser irradiation. Samples were scanned across the laser beam at the rate of 2 mm/sec. The pulse repetition rate was 300 Hz and a fluence was 13 J/cm^2. A low volume/low pressure air-actuated fluid spray delivery system consisting of a 780S spray valve, a Valvemate 7040 controller, and a fluid reservoir from EFD, Inc. (East Providence, RI) was used to provide a uniform spray of fine water mist onto the tooth surfaces at 2 mL/min.

2.3. Dehydration and Thermal Imaging

Each sample was placed in a mount connected to a high-speed XY-scanning motion controller system, Newport ESP 300 controller and 850G-HS stages, coupled with an air nozzle as shown in Fig. 2. All surfaces excluding the pulpal axial surface were covered with black nail polish, OPI (North Hollywood, CA) in order to confine water loss to the exposed surface. Each sample was immersed in the water bath for 30 seconds while being vigorously shaken to enhance water diffusion. After the sample was removed from the water bath, an image was captured as an initial reference image and the air spray was activated. Seven air nozzles were positioned 5 cm away from the sample and the air pressure was set to 12 psi. After the samples were removed from the water bath, the excess water on the surface was removed with a disposable cotton roll. Each measurement consisted of capturing a sequence of images at 4 frames per second for 60 seconds. The dehydration setup was completely automated using LabView™ software.

An infrared (IR) thermography camera, Model A65 (FLIR Systems, Wilsonville, OR, USA) sensitive from 8 – 13 μm with a resolution of 640 × 512 pixels, a thermal sensitivity of 50mK and a lens with a 13 mm focal length was used to record temperature changes during the dehydration process. The area per pixel was approximately 0.02 mm^2. The ambient room temperature, flowing air temperature and water bath temperature were approximately 21°C (294.15 K) and were consistent throughout the experiment. The object emissivity was set to 0.92, and the atmospheric temperature was set to 294.15 K. Relative humidity was set at a default value of 50%; humidity values were not recorded, but every sample was measured under the same conditions. Previous studies have shown that ΔQ, the area enclosed by the time-temperature curve, can be used as a quantitative measure of porosity and can be used to discriminate between the demineralized dentin and the remineralized or sound dentin *in-vitro*. [8]

2.4. Thermal Imaging Analysis

Thermal images were processed and analyzed using a dedicated program written in LabView™. The thermal camera outputs a series of temperature measurements over time. The initial reference temperature measurements varied slightly (± 0.5 K) due to the different emissivity, lesion structure, mineral composition and water content among samples. Calibration was carried out via matching the measurements from the initial reference image to the ambient temperature. ΔQ was calculated from the area enclosed by the initial temperature and the time-temperature curve, acquired from an average measurement of a 3 × 3 pixel ROI for each sample.

2.5. Depth Composition Digital Microscopy (DCDM)

Sample surfaces were examined after treatments using an optical microscopy/3D surface profilometry system, the VHX-1000 from Keyence (Elmwood, NJ). The H-Z100R lens was used with, a magnification of 100–1000×. DCDM images were acquired by scanning the image plane of the microscope and reconstructing a depth composition image with all points at optimum focus displayed in a 2D image.

3. RESULTS AND DISCUSSION

Figure 3 shows the DCDM images of the radicular dentin surfaces treated with different endodontic irrigants and the CO_2 laser. There was no visible difference in surface morphology between the sound, Fig. 3A, and the NaClO treated radicular dentin, Fig 3B. The EDTA treated radicular dentin surface, Fig. 3C, shows dissolution of mineral on the surface exposing dentinal tubules which appears similar to the phosphoric acid etching treatments of dentin for bonding composite. The laser treated radicular dentin surface, Fig 3D, shows formation of melted enamel-like mineral structures and closer inspection at 1000x magnification shows translucent globules with darker carbonized collagen. Such structures are evident at temperatures exceeding 1200 °C, the melting point of hydroxyapatite. Thermal decomposition of collagen occurs at much lower temperatures leaving a carbon residue.

ΔQ measurements of each surface are plotted in Fig. 4 after treatments with different endodontic irrigants and CO_2 laser irradiation. ΔQ has been shown to be an indirect indicator of permeability of water on dentin surface. There was no significant increase in ΔQ measurements between the control and NaClO treated radicular dentin surfaces, and there were significant increases in ΔQ measurements for both EDTA and CO_2 laser treated radicular dentin surfaces. It was expected that EDTA would increase permeability of the radicular surface as it widens dentinal tubules by dissolving mineral content. Although it was initially hypothesized that the melting of the surface hydroxyapatite may occlude dentinal tubules, the laser irradiation may have caused micro-cracks attributed to the carbonization and contraction of tissue due to loss of water and organic matrix. [9] Such morphological changes and increase in permeability may negatively affect endodontic therapy outcome despite the effectiveness of smear layer removal and disinfection of root canals via thermal action by the CO_2 laser.

Acknowledgments

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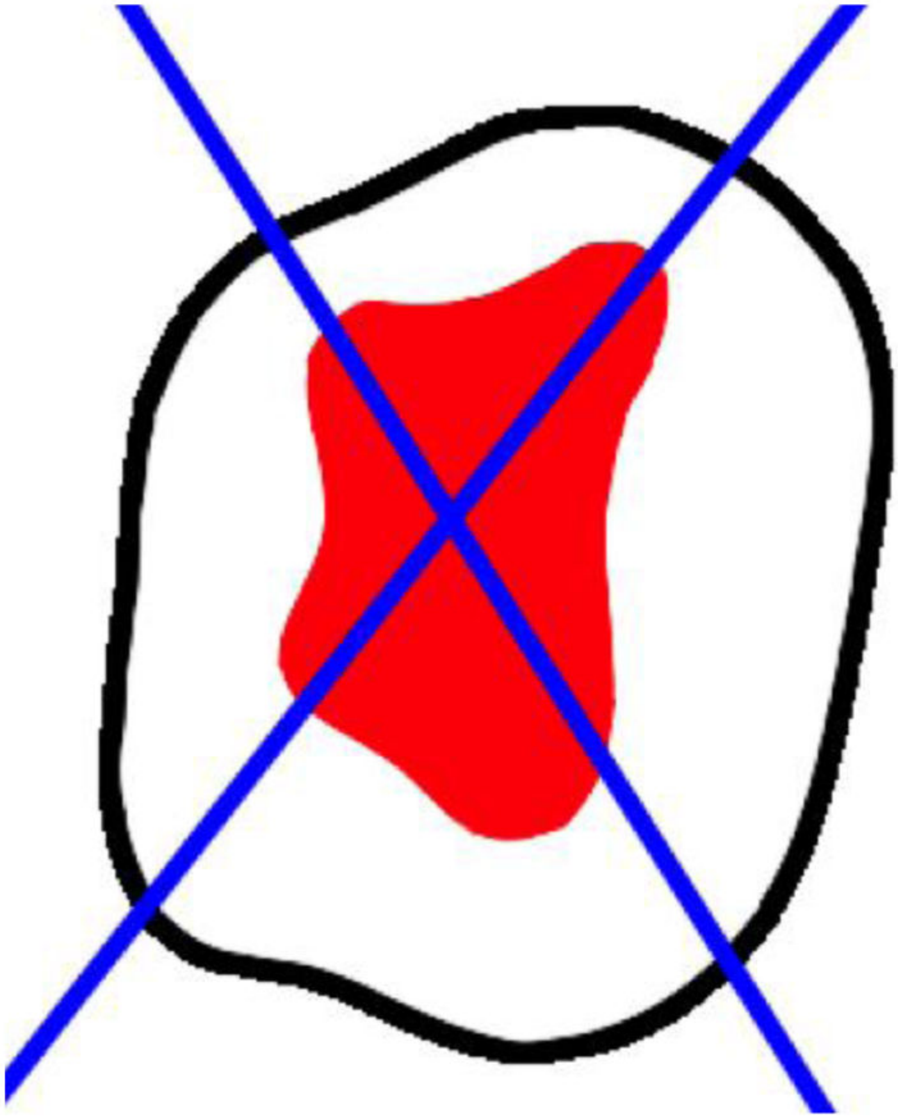

Fig. 1.
A human molar was cut (blue lines) into 4 sections exposing the axial wall of the pulp chamber.

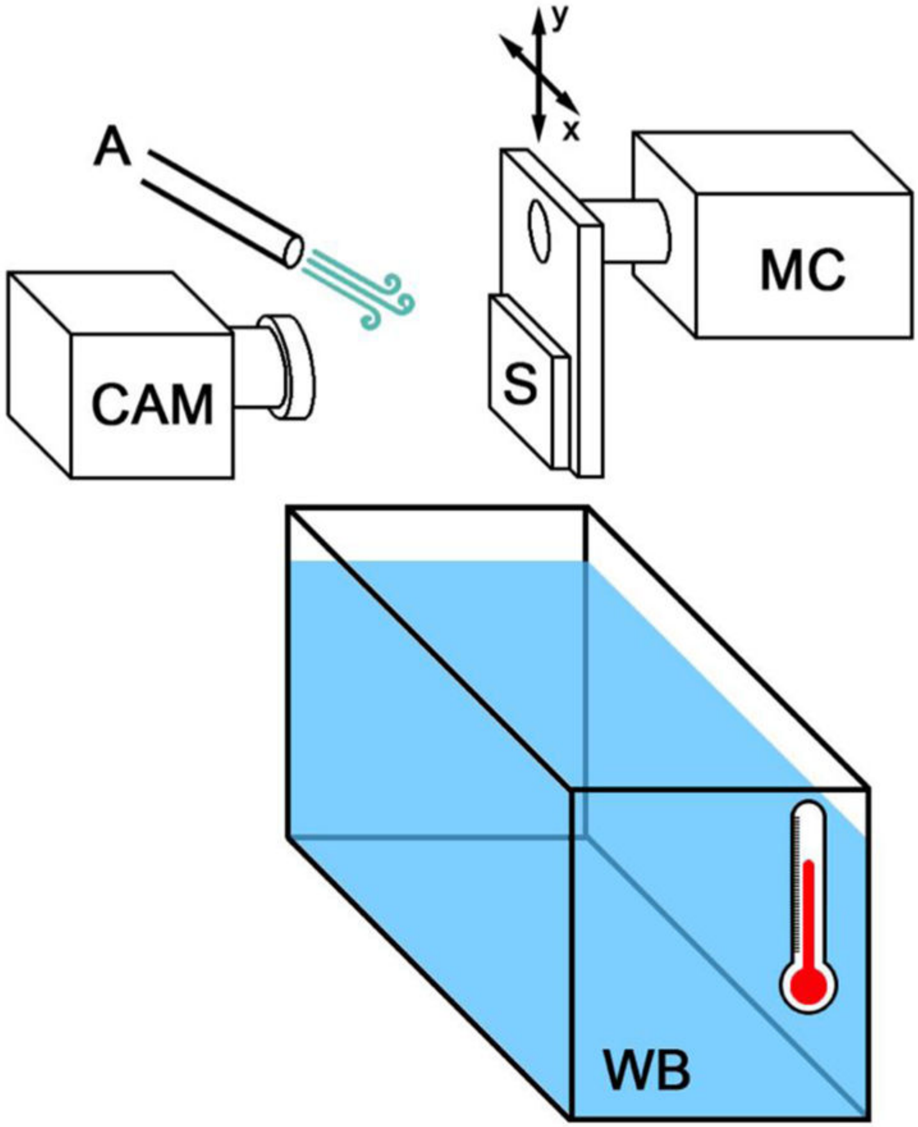

Fig. 2.
Dehydration experimental setup. CAM: thermal camera, A: compressed air nozzle, S: sample, and WB: water bath

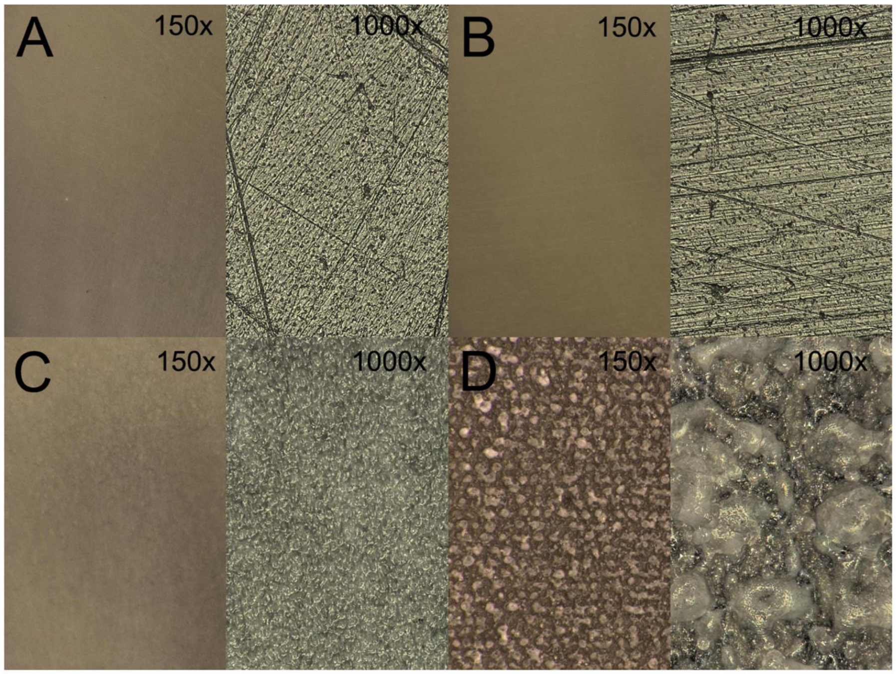

Fig. 3.

DCDM images with magnifications of 150x and 1000x of (A) sound radicular dentin surface, (B) radicular dentin surface treated with 10% NaClO for 1 minute, (C) radicular dentin surface treated with 5% EDTA for 1 minute, and (D) radicular dentin surface treated with the laser.

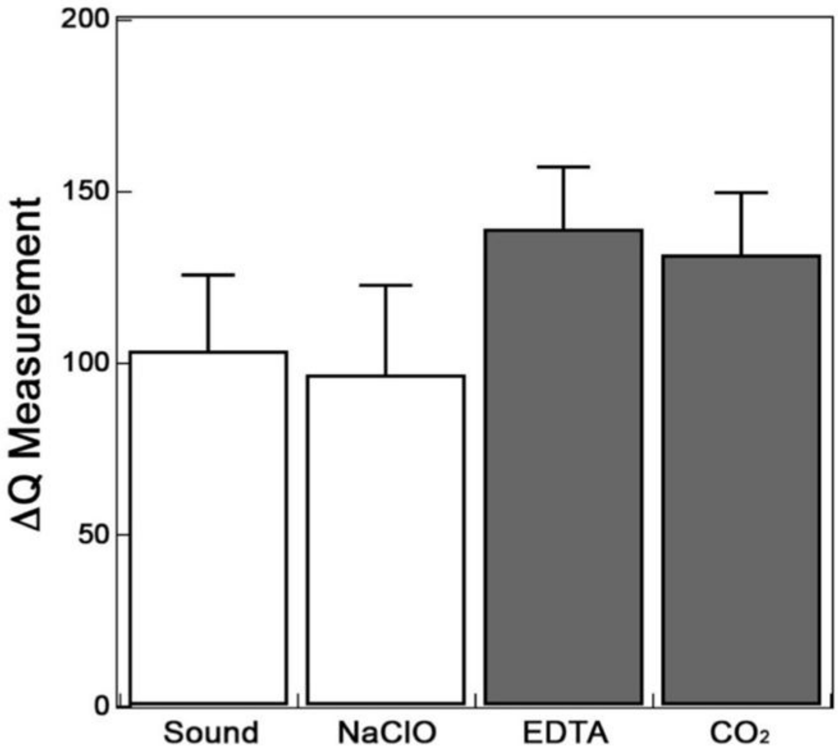

Fig. 4.

ΔQ measurements ± S.D. after treatments with different endodontic irrigation solutions and the CO_2 laser. Bars not sharing any common colors are significantly different, $P < 0.05$.