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Title: Effectiveness of the Erbium:YAG laser and new design radial and stripped tips in removing the smear layer after root canal instrumentation.

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Abstract: The aim of this study was to analyze, in vitro, the debriding ability of an Erbium:YAG (Er) laser system (2,940 nm) equipped with a newly designed radial and stripped tip of 400 micron diameter, using scanning electron microscopy (SEM) analysis.

Eighty single-rooted extracted human teeth were endodontically prepared with rotary instrumentation and standardized chemical irrigation, using 5.25% sodium hypochlorite (NaOCl). At the end of mechanical instrumentation, four different final protocols were used: (G1) two minutes saline water irrigation as control group; the other groups (G2, G3, G4) were irradiated with an Er laser at 25mJ, 15Hz, 50µs pulse duration with laser spray off, using the tip in the coronal opening of the wet root canal. Different solutions and irradiation times were used: (G2) 20 sec. Er:YAG laser irradiation in sterile distilled water, wet canal; (G3) 20 sec. Er:YAG laser irradiation in 17% EDTA, wet canal; (G4) 40 sec. Er:YAG laser irradiation in 17% EDTA, wet canal. Scanning electron microscopy (SEM) analysis evaluated the debridement and smear layer removal at the apical third.

The study showed that standardized instrumentation, followed by a final Er:YAG laser irradiation in EDTA wet canals, resulted in more cleaning of root canal walls and a higher quantity of open tubules in comparison with the traditional irrigation method.

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4 **Effectiveness of the Erbium:YAG laser and new design radial and**
5 **stripped tips in removing the smear layer after root canal**
6 **instrumentation**
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8 **INTRODUCTION**
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10 The ability to successfully treat and remove the smear layer and bacteria continues to be a
11 challenge in non-surgical endodontic treatment of the root canal system. The shaping and
12 cleaning of root canals is a key step during root canal treatment and unless all remnants of debris
13 are removed, subsequent stages of obturation may also be jeopardized [1,2]. Clinically,
14 endodontic procedures use both mechanical instrumentation and chemical irrigants in the attempt
15 to debride, clean and decontaminate, three dimensionally, the endodontic system [3,4]. Some of
16 these irrigation techniques include manual irrigation with needles and canulas, machine assisted
17 agitation systems as well as sonic and ultrasonic energy sources [5]. All file systems generate
18 smear layer and leave debris in the root canal. Irrigation with 5.25% sodium hypochlorite
19 (NaOCl) alone is unable to remove debris and smear layer [6]. Other irrigants such as 2%
20 chlorhexidine gluconate, 17% ethylene diamine tetra acetic acid (EDTA) and 10% citric acid
21 have been used to help remove debris accumulation, but many studies have demonstrated the
22 limited ability to effectively reach all internal aspects of seemingly complicated root canal
23 architecture [1,2,4,6-8]. Although a recent study [9] reported excellent results of a new file
24 system operated with a continuous irrigation device in removing debris and smear layer also in
25 the apical third, the literature shows that when compared to the coronal and middle thirds of
26 relatively clean canals, the apical third of the root canal always presents a problem in regard to
27 the ability to achieve the same cleanliness [5,6,10-12]. This fact may be of significance during
28 root canal treatment because the presence of smear layer and debris may prevent sealer
29 adaptation to the canal walls and impede penetration of irrigants into dentinal tubules and
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4 accessory canals. Accordingly, some alternative, more effective method to debride, clean and
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6 penetrate the dentinal walls should be explored.
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9 The effectiveness of lasers in dentistry continues to be an area of discussion. Although the use of
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11 lasers for non-surgical endodontic treatment of the root canal system has been described since
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13 the early 1970's [13,14], acceptance has been slow. A common feature of dissatisfaction has
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15 been the thermal damage associated with the application of laser photonic energy [15-19]. Laser
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17 treatment can be a valuable tool for the removal of the dentinal smear layer, as a debridement
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19 device during endodontic treatment. The Erbium:Yttrium Aluminum Garnet laser (Er:YAG,
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21 2940 nanometer wavelength) is FDA-approved for cleaning, shaping and enlarging the root canal
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23 [20]. Previous studies tested the ability and the effects of this laser on root canal walls and
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25 indicated that the Er:YAG laser is a suitable instrument for removal of the smear layer in root
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27 canals [21-26]. Furthermore a 2008 paper, investigated the ability of both Er:YAG and
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29 Er,Cr:YSGG lasers equipped with conical shaped radially firing tips and plain tips, for removing
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31 smear layer from the apical third; the results showed a laser activation of EDTA and a better
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33 performance of conical fibers compared to plain fibers for improving the action of EDTAC in
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35 dissolving smear layer [27].
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43 The aim of this in vitro study was to evaluate, by SEM analysis, the ability and effectiveness of
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45 an Er:YAG in removing the smear layer and debriding the root canal. A newly designed tip was
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47 used: it has a tapered radial firing end with 3mm of the polyamide sheath removed. Using
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49 specific Hertz (Hz) rates, short microsecond (μ s) pulse duration and low millijoules (mJ) of
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51 energy during application, the thermal morphological effects described in the literature were
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53 minimized [21-29].
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4 **MATERIALS AND METHODS**
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6 **Sample preparation**
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9 In this study, 80 recently extracted single-rooted human teeth were stored in physiological saline
10 solution until used.
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15 **Root canal treatment**
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17 The access cavity to the canal orifice was first prepared with a tapered diamond bur creating a
18 glide path for insertion of the first instrument (size #10 K file). The teeth were then minimally
19 prepared using nickel titanium rotary instruments in a sequential crown down method to a size
20 20/.06 (Profile GT, Dentsply Tulsa Dental, Tulsa, OK, USA). Irrigation of the canals during
21 preparation was accomplished using sodium hypochlorite. After reaching the final
22 instrumentation size of 20/.06, additional irrigation was completed using two cycles, 30 seconds
23 each, of irrigation with saline only. These samples were then ready to be treated with the various
24 laser protocols described.
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38 **Laser parameters**
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40 An Er:YAG laser with a wavelength of 2940nm (Fidelis AT, Fotona, Ljubljana, Slovenia) was
41 used to irradiate the root canals after traditional instrumentation. A newly designed 12mm long,
42 400micron quartz tip was used. The tip was tapered and had 3mm of the polyamide sheath
43 stripped back from its end, directly from the manufacturer (Fig. 1A). Laser operating parameters
44 (using the free-running emission mode) of 20mJ per pulse, 15Hz, 50µs pulse duration, were
45 employed for all of the treatment groups. The co-axial water spray feature of the handpiece was
46 set to off. The tip was placed into the coronal access opening of chamber only, remaining
47 stationary and not advanced into the orifice of the canal (Fig. 1B).
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4 **Laser irradiation and irrigation methods**
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6 After the mechanical preparation, the teeth were randomly divided into four groups (n=20 each)
7 and treated with different methods, according to the following protocol:
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11 Group 1 (G1, n=20) two minutes saline water irrigation as control group
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14 Group 2 (G2, n=20) laser irradiation 20s cycle in sterile, distilled water
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17 Group 3 (G3, n=20) laser irradiation 20s cycle in 17% EDTA
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20 Group 4 (G4, n=20) laser irradiation 40s cycle in 17% EDTA
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22 During laser irradiation cycles, the root canals were continuously irrigated with 2mL of fluids to
23 maintain hydration and levels, using an hand syringe with a #25 gauge needle positioned above
24 the laser tip in the coronal aspect of the access opening, accordingly to above protocol.
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29 **Temperature measurements**
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32 To identify possible thermal side effects, temperature change measurements were carried out on
33 the external root surface of three samples for each laser group (for a total of 9 samples).
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37 A modified thermocouple measurement sensor of 1.5mm diameter (K-Type NiCr-Ni Immersion
38 Sensor, TEL-Atomic Inc., Jackson, MI, USA) was placed on the root surface and attached with a
39 silicon-based heat-conductive compound (Dow Corning 340 Heat Sink Compound, Dow
40 Corning, Midland, MI, USA) at 5mm from the apex. The temperature changes were monitored
41 continuously during all the irradiation procedure periods (20s for Group 2 and 3 and 40s for
42 Group 4), starting from a room temperature of 21°C and recorded using a digital thermometer
43 (Digital Quick Response Pocket Thermometer, TEL-Atomic Inc.). The average value and the
44 standard deviation of the three measurements per laser group were calculated. The temperatures
45 were digitally displayed on the thermometer and subject to sensor errors of $\pm 0.2^{\circ}\text{C}$.
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4 **SEM observations**
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6 A F4000 field emission scanning electron microscope (Hitachi, Tokyo, Japan) was used to
7 examine the specimens. The prepared samples were sectioned longitudinally, dried, sputter
8 coated and examined only at the apical third (5mm); over 150 photographs were taken at varying
9 magnifications ranging from 300x to 10200x by the same operator and then used for evaluation
10 by two additional blinded observers.
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20 **Quantitative evaluation**
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22 Smear layer was defined as the film retained on the dentin surfaces after rotary NiTi application.
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24 A scoring method for smear layer removal following the suggestions by Hülsmann, et al. was
25 applied [10]. The three observers evaluated the amount of remaining smear layer. SEM images
26 at magnification from 1000X to 2000X were used for this quantitative assessment. A mean
27 smear layer score was calculated for each specimen; the overall agreement of the observers was
28 very good as indicated by a Fleiss' kappa of 0.82. A scoring index of 1 through 5 was used as
29 described below:
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39 Score 1: No smear layer and dental tubules open
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41 Score 2: Small amount of smear layer, many dental tubules open
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43 Score 3: Homogenous smear layer covering the root canals walls, only few dentinal tubules open
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45 Score 4: Complete root canal wall covered by homogenous smear layer, no open tubules
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47 Score 5: Heavy, non-homogenous smear layer covering complete root canal walls
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51 Resulting data was non-parametric in nature and hence statistical analysis was performed using
52 the Kruskal-Wallis test and Mann-Whitney Wilcoxon U tests; a level of $p < 0.05$ was considered
53 statistically significant.
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4 **RESULTS**
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6 **SEM observations**
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9 Control group specimens (G1) consistently exhibited a thick smear layer. SEM examination
10 demonstrated that when only water irrigation was applied, noticeable smear layer and occluded
11 dentinal tubules remained on the treated surface (Fig. 2A, B). Debris, defined as dentin chips
12 and pulp remnants loosely attached to the internal surface of the root canals, was present in G1.
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19 Specimens in group 2, treated for 20s by Er:YAG laser concomitant with a sterile, distilled water
20 irrigation, showed improved cleaning compared to G1 specimens. Root canal surfaces exhibited
21 open tubules, scattered residual debris and a thin smear layer compared to the control specimens
22 (G1) (Fig. 3A, B).
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29 Group 3 specimens, treated for 20s by Er:YAG laser plus EDTA irrigation, exhibited
30 improvement in cleaning and debridement action compared to G2 specimens and control
31 specimens (G1) (Fig. 4A, B). The most effective removal of the smear layer from root canal
32 walls was achieved by use of the Er:YAG laser plus EDTA irrigation for 40s (G4) (Fig. 5A,B).
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38 The results observed with the SEM at higher magnifications (from 2040x to 10200x mag.)
39 showed exposed and intact collagen fibers and evidence of an unaltered collagen matrix (Fig.
40 6A-D). None of the SEM micrographs indicated signs of dentin fusion by excessive heat.
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46 **Quantitative evaluation**
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49 To quantify the differences in smear layer removal, a five-step scoring method was used. The
50 results indicated that all groups differed significantly from each other and from the control
51 group. The mean scores of the four differentially treated sets of teeth were ranked as follows:
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54 Group 1, the control group, received the highest (i.e., least acceptable) ratings; Groups 2 through
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59 4 received progressively lower (i.e., more acceptable) scores (Tab. 1).
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4 Statistical differences in the cleanliness of root-canal wall between the groups were analyzed
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6 using non-parametric tests (Tab.1, 2). The Kruskal-Wallis test showed overall significant
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8 differences among the 4 groups ($p < 0.001$). A subsequent pairwise comparison showed statistical
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10 significant differences in smear layer removal in the apical third of the root-canal walls between
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12 all groups ($p < 0.001$).
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16 17 **Temperature measurements**

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19 Minimal average temperature rises were observed at the root surface during laser irradiation,
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21 with 1.2°C and 1.5°C measured for the 20s and 40s irradiation time groups, respectively.
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26 27 **DISCUSSION**

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29 Current instrumentation techniques using rotary instruments and chemical irrigations, still fall
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31 short of successfully removing the smear layer from inside the root canal system. This was
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33 confirmed from the results seen in the control group (G1) where the conventional technique was
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35 employed.
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39 The Er:YAG laser used in this investigation was equipped with a novel 400 micron diameter
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41 radial and stripped tip. Using sub-ablative parameters (average power 0.3W, 20mJ at 15Hz)
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43 proved to be more effective than traditional techniques at removing the smear layer. A possible
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45 explanation for this finding could be contributed to the photo-mechanical effect that is seen when
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47 light energy is pulsed in liquid [30-32].
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51 When activated in a limited volume of fluid, the high absorption of the Er:YAG wavelength in
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53 water, combined with the high peak power derived from the short pulse duration that was used
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55 (50 μ s), resulted in a photo-mechanical phenomenon.
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4 We speculate that this phenomenon is responsible for the removal of smear layer in G2, in which
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6 laser irradiation was combined with saline, which alone does not have an effect on smear layer
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8 removal [10-12]. In fact, a profound “shockwave-like” effect was observed when radial and
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10 striped tips were submerged in a liquid filled root canal; as a result of the very small volume, its
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12 effect may remove the smear layer and residual tissue tags and potentially decrease the bacterial
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14 load within the tubules and lateral canals [28,29,33]. By using lower sub-ablative energy (20mJ)
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16 and restricting the placement of the tip to within the coronal portion of the tooth only, it was
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18 shown that the undesired effects of the thermal energy, previously described in the literature, was
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20 avoided [22-26].
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26 The smear layer and debris in the current study were not removed via thermal vaporization, but
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28 likely through a photo-mechanical streaming of the liquids, which were laser activated in the
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30 coronal part of the tooth. The authors describe this light energy phenomenon as photon initiated
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32 photo-mechanical streaming (PIPS). The use of EDTA together with the Er:YAG laser equipped
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34 with a novel designed tip, at sub-ablative power settings (0.3W, 20mJ), have a synergistic effect;
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36 this contributes to improving treatment efficacy leading to significantly better debriding of the
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38 root canal.
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43 The SEM images verified the efficient and minimally disruptive effects on the canal walls,
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45 dentinal tubules and even on the hydroxyapatite surfaces. No thermal damage was found in any
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47 PIPS treated samples and temperature rises at the external root surfaces were minimal (< 1.5
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49 degrees C). Furthermore, the laser energy activated the EDTA solution, amplifying its surface
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51 cleaning action [27]. However, at high magnification, the intertubular dentin around tubular
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53 openings appears to show some signs of erosion with the dentin collagen architecture visible and
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55 intact (Fig. 6A-D).
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4 With conventional treatment protocols (without a laser), an irrigation syringe is more effective
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6 when the tip is placed closer to working length. Using this new laser system, the laser tip was
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8 not placed within the canals themselves, but rather confined to the coronal chamber above the
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10 orifice. It is suggested that this allows easy access for the photo-mechanical effects to occur
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12 within the root canal, which may assist in cleaning canals of various shapes.
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15 A standard ISO size #30 file preparation is needed to allow access for the traditional laser tips
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17 (200-320microns) close to the apex [28,29,33]. Using the radial and stripped design with PIPS,
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19 the apex can be reached without the need to negotiate the tip close to the apex. Correspondingly,
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21 this would allow a less-invasive preparation using an ISO size #20/.06 file, according to the
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23 method described.
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27 The irrigation with chelating agents following the current conventional instrumentation requires
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29 more time to initiate a satisfactory debridement (EDTA placed passively into the prepared root
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31 canal) [34,35]. The PIPS technique resulted in pronounced smear layer removal when used
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33 together with EDTA and at the settings outlined.
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37 Published material on endodontic techniques using the Er:YAG laser reflect differing operating
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39 parameters [36]. These authors cite the use of higher average power (1.125-1.5W), delivered
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41 through end-firing laser tips. Additionally, the positions for these tips require that they be placed
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43 1-2mm from the root apex.
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48 49 50 **CONCLUSION**

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52 The Er:YAG laser used in this study showed significantly better smear layer removal than
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54 traditional syringe irrigation. At the energy levels and operating parameters used, no thermal
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56 effect or damage to the dentin surface was observed. This study indicated that the Er:YAG laser
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4 with the current settings produced a photo-mechanical effect that demonstrated a potential for an
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6 improved alternative method of debriding the root canal system in a minimally invasive mode.
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10 11 **DISCLOSURE**

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14 The authors hereby disclose that they are working with Fotona to manufacture and distribute this
15
16 new and improved delivery system for endodontic treatment. Dr. Giovanni Olivi is an
17
18 independent researcher affiliated with the University of Genoa where he performs laser studies.
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23 24 **ACKNOWLEDGMENTS**

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27
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31 32 **LEGENDS**

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35 **Fig. 1A** Diagrammatic representation of the radial and stripped tip used for this laser study.
36 *Courtesy of Medical Dental Advanced Technology Group.*
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39 **Fig. 1B** Radiograph showing positioning of radial and stripped tip placed into the coronal access
40 opening of the fluid filled chamber only and not advanced into the orifice of the canal.
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43 **Fig. 2A,B** Group 1, representative sample image at apical one third (A 1220X-B 300X); two
44 minutes saline water flushing as control group. Noticeable smear layer and occluded dentinal
45 tubules still remained on the treated surface. Smear layer score 5.
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48 **Fig. 3A,B** Group 2, representative sample image at apical one third (1680X); Er:YAG laser
49 irradiation (20 mJ per pulse, 15Hz, 50 μ s pulse duration) 20s in sterile, distilled water, wet canal.
50 Root canal surfaces exhibited open tubules, residual debris and smear layer still present. Smear
51 layer score 3.
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54 **Fig. 4A,B** Group 3, representative sample image at apical one third (A 1820X-B 2470X); Er
55 laser irradiation (20 mJ per pulse, 15Hz, 50 μ s pulse duration) 20s in 17% EDTA wet canal.
56 SEM images show significant improvement in cleaning and debridement action compared to the
57 control specimens. Smear layer score 2.
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Fig. 5A,B Group 4, representative sample image at apical one third (A 1680X-B 1820X); Er laser irradiation (20 mJ per pulse, 15Hz, 50µs pulse duration) 40s in 17% EDTA wet canal. SEM images show effective removal of the smear layer from root canal walls. Smear layer score 1.

Fig. 6A-D Group 4, representative sample image at apical third (from 3600X to 10200X); Er laser irradiation (20 mJ per pulse, 15 Hz, 50µs pulse duration) 40s in 17% EDTA wet canal. SEM at higher magnifications (from 2040x to 10200x) shows exposed and intact collagen fibers and evidence of an unaltered collagen matrix. Smear layer score 1.

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TABLES

Table 1: Results of Kruskal-Wallis tests of differences in mean ranks among study groups.

| Group | N | Mean Rank of Scores | Kruskal- Wallis Chi-square | <i>df</i> | <i>p</i> |
|---|----|------------------------|----------------------------------|-----------|----------|
| 1 (Control: two minutes saline water flushing) | 20 | 70.45 | | | |
| Group 2 (laser irradiation 20 sec. cycle in sterile, distilled water wet canal) | 20 | 46.18 | 66.069 | 3 | <.001 |
| Group 3 (laser irradiation 20 sec. cycle in 17% EDTA wet canal) | 20 | 31.68 | | | |
| Group 4 (laser irradiation 40 sec. cycle in 17% EDTA wet canal) | 20 | 13.70 | | | |

Table 2
Results of pairwise comparison between mean ranks of groups.

| Pairwise comparison | N | Mean Rank | Sum of Ranks | Mann-Whitney U | Distribution mean | Z | <i>p</i> |
|---------------------|----|-----------|--------------|----------------|-------------------|--------|----------|
| Group 1 (Control) | 20 | 30.50 | 610.00 | .000 | 200 | -5.724 | <.001 |
| Group 2 | 20 | 10.50 | 210.00 | | | | |
| Group 1 (Control) | 20 | 30.45 | 609.00 | 1.00 | 200 | -5.696 | <.001 |
| Group 3 | 20 | 10.55 | 211.00 | | | | |
| Group 1 (Control) | 20 | 30.50 | 610.00 | .000 | 200 | -5.724 | <.001 |
| Group 4 | 20 | 10.50 | 210.00 | | | | |
| Group 2 | 20 | 26.98 | 539.50 | .000 | 200 | -3.728 | <.001 |
| Group 3 | 20 | 14.03 | 280.50 | | | | |
| Group 2 | 20 | 29.70 | 594.00 | 16.000 | 200 | -5.236 | <.001 |
| Group 4 | 20 | 11.30 | 226.00 | | | | |
| Group 3 | 20 | 28.10 | 562.00 | 48.000 | 200 | -4.350 | <.001 |
| Group 4 | 20 | 12.90 | 258.00 | | | | |

Figure

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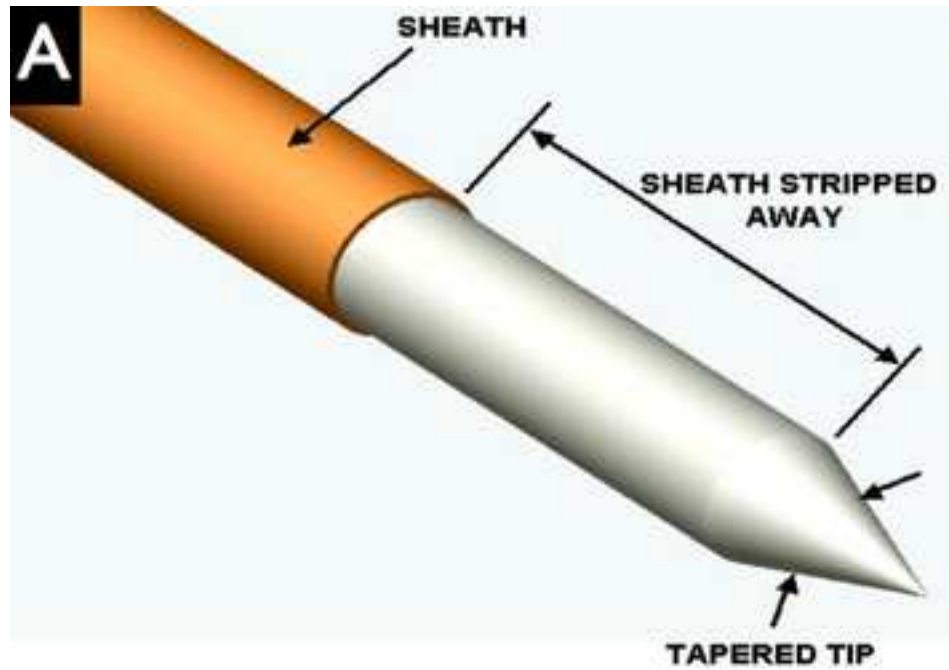


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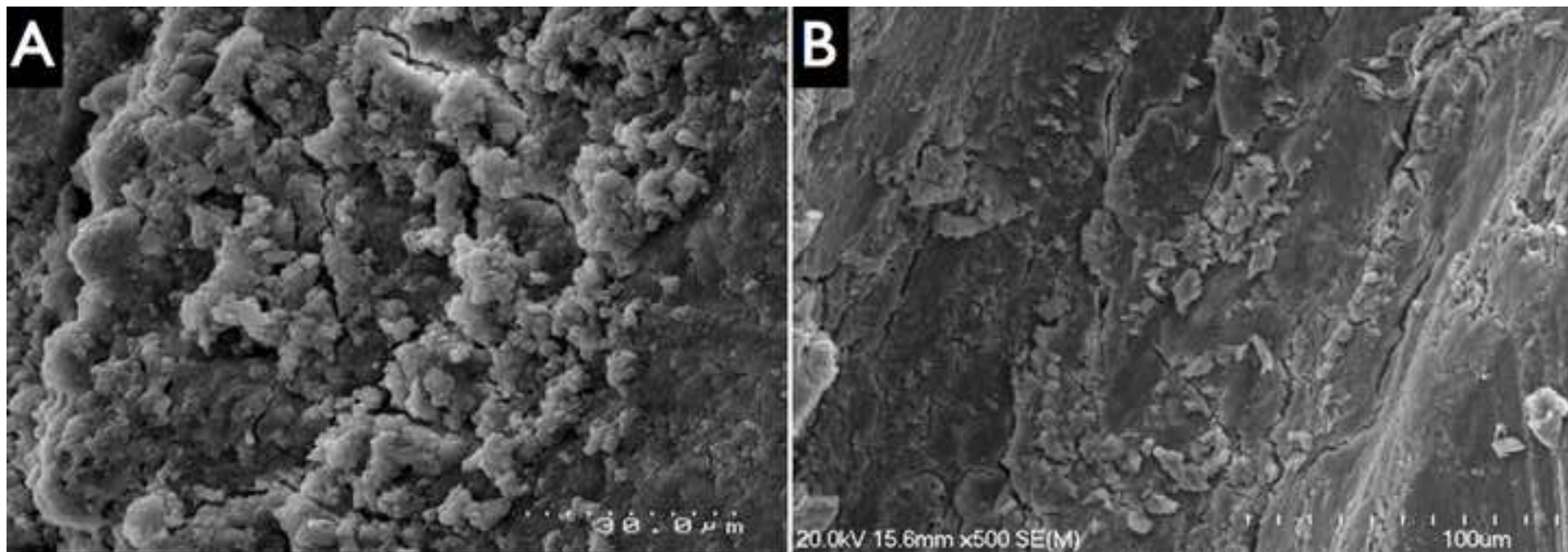
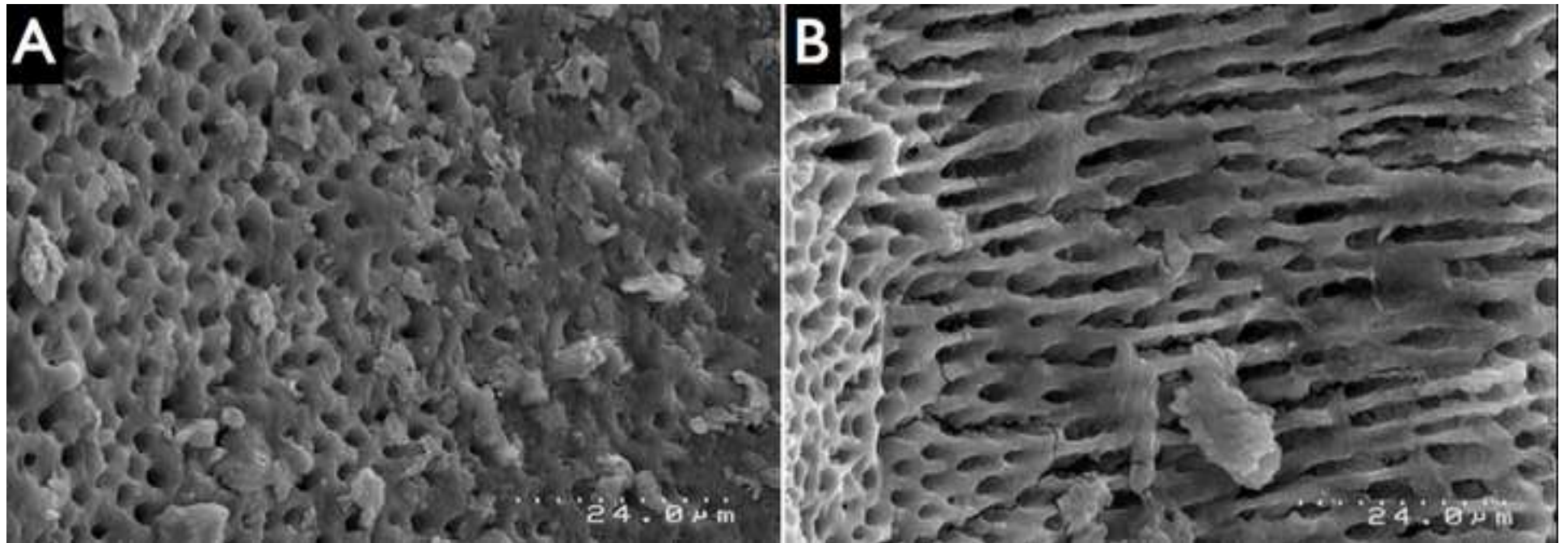


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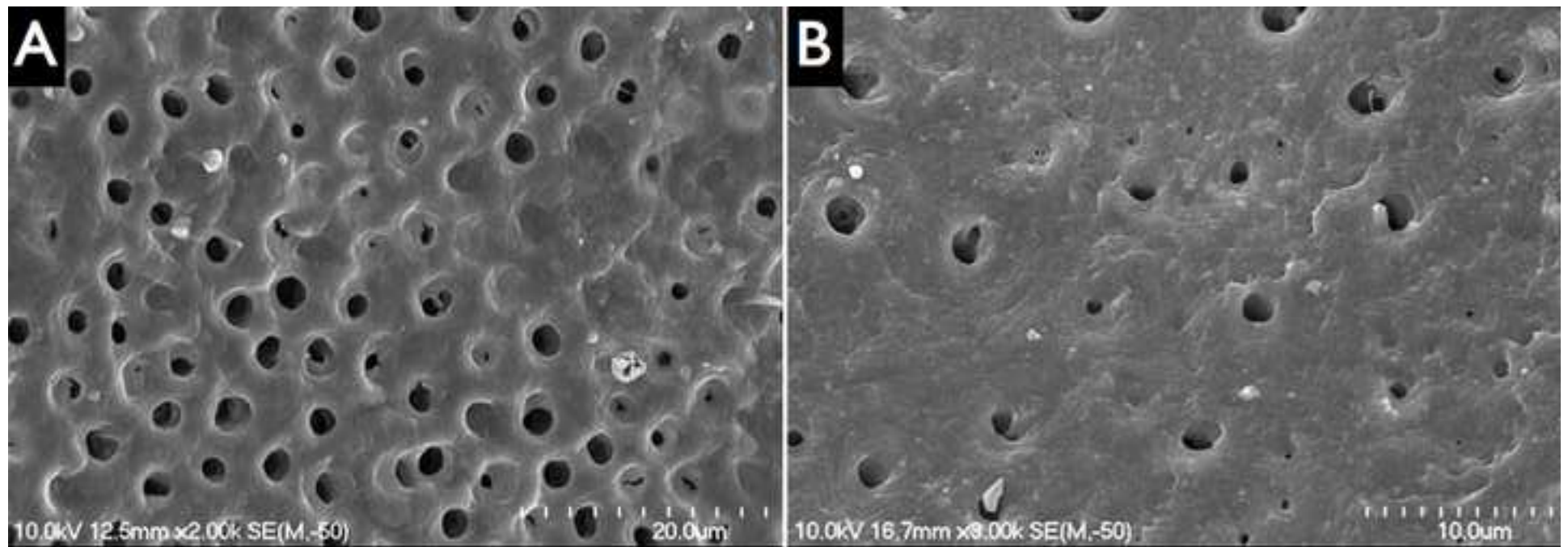
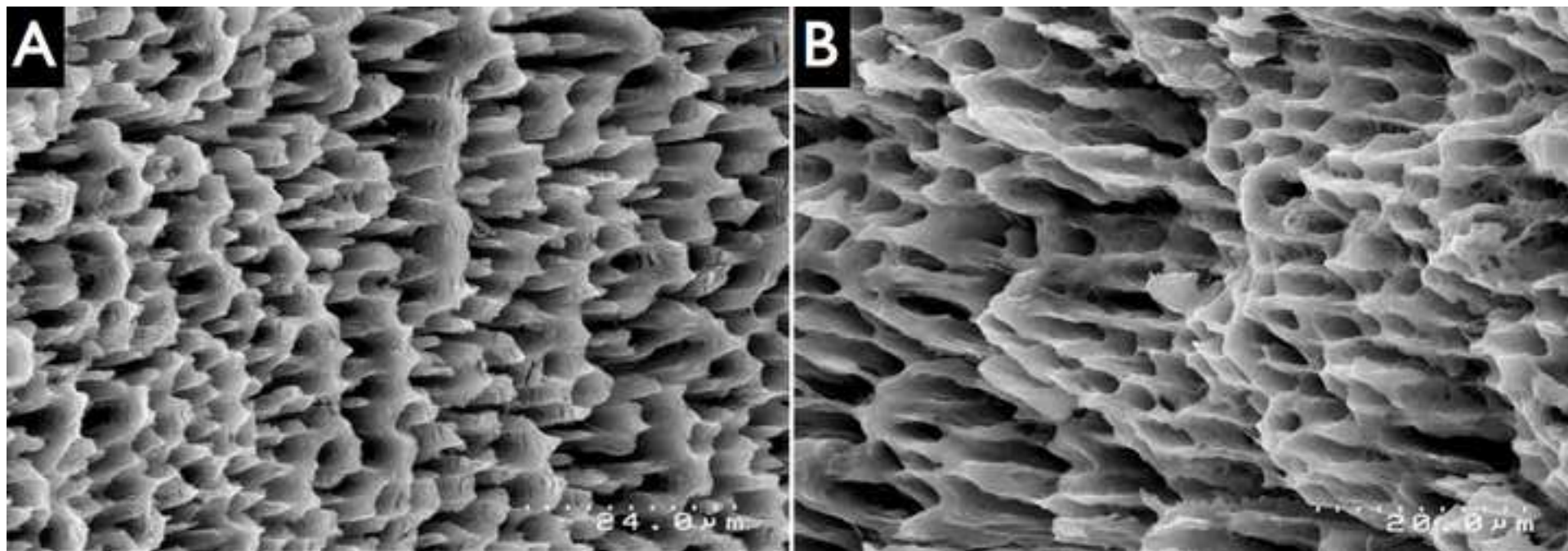


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