Year: 2011

Root canal preparation of maxillary molars with the self-adjusting file: a micro-computed tomography study.

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Abstract: INTRODUCTION: The aim of this study was to describe the canal shaping properties of a novel nickel-titanium instrument, the self-adjusting file (SAF), in maxillary molars. METHODS: Twenty maxillary molars were scanned by using micro-computed tomography at 20- m resolution. Canals were shaped with the SAF, which was operated with continuous irrigation in a handpiece that provided an in-and-out vibrating movement. Changes in canal volumes, surface areas, and cross-sectional geometry were compared with preoperative values. Canal transportation and the fraction of unprepared canal surface area were also determined. Data were normally distributed and compared by analyses of variance. RESULTS: Preoperatively, mean canal volumes were 2.88 ± 1.32, 1.50 ± 0.99, and 4.30 ± 1.89 m(3) [corrected] for mesiobuccal (MB), distobuccal (DB), and palatal (P) canals, respectively; these values were statistically similar to earlier studies with the same protocol. Volumes and surface areas increased significantly in MB, DB, and P canals; mean canal transportation scores in the apical and middle root canal thirds ranged between 31 and 89 m. Mean unprepared surfaces were 25.8% ± 12.4%, 22.1% ± 12.0%, and 25.2% ± 11.3% in MB, DB, and P canals, respectively ($P > .05$) when assessed at high resolution. CONCLUSIONS: By using SAF instruments in vitro, canals in maxillary molars were homogenously and circumferentially prepared with little canal transportation.

DOI: https://doi.org/10.1016/j.joen.2010.08.047

Originally published at:
Peters, O A; Paqué, F (2011). Root canal preparation of maxillary molars with the self-adjusting file: a micro-computed tomography study. Journal of Endodontics, 37(1):53-57.
DOI: https://doi.org/10.1016/j.joen.2010.08.047

Root canal preparation of maxillary molars with the self-adjusting file: a micro-computed tomography study

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Key words: self-adjusting file, root canal preparation, micro-computed tomography, Nickel-titanium instruments

Acknowledgements: This study was financially supported by ReDent Nova. Helpful discussions with Dipl.-Ing. Christof Reinhart are also gratefully acknowledged.

Abstract

Introduction The aim of this study was to describe the canal shaping properties of a novel nickel-titanium instrument, the self-adjusting file (SAF) in maxillary molars. **Methods** Twenty maxillary molars were scanned using micro-computed tomography at 20 µm resolution. Canals were shaped with the SAF, which was operated with continuous irrigation in a handpiece that provided an in-and-out vibrating movement. Changes in canal volumes, surface areas and cross-sectional geometry were compared to preoperative values. Canal transportation and the fraction of un-prepared canal surface area were also determined. Data was normally distributed and compared by analyses of variance. **Results** Preoperatively, mean canal volumes were 2.88±1.32, 1.50±0.99 and 4.30±1.89 mm^3 for mesiobuccal (MB), distobuccal (DB) and palatal (P) canals, respectively; these values were statistically similar to earlier studies using the same protocol. Volumes and surface areas increased significantly in MB, DB and P canals; mean canal transportation scores in the apical and middle root canal thirds ranged between 31 and 89 µm. Mean un-prepared surfaces were 25.8±12.4, 22.1±12.0 and 25.2±11.3% in MB, DB and P canals, respectively ($p>0.05$) when assessed at high resolution. **Conclusions** Using SAF instruments *in vitro*, canals in maxillary molars were homogenously and circumferentially prepared with little canal transportation.

Introduction

Cleaning and shaping of root canals successfully requires the presence of irrigation solutions that can only be applied to the apical root canal third after enlargement with instruments (1-4). Nickel-titanium (NiTi) rotary instruments have become an important adjunct for root canal shaping, and outcomes with these instruments are fairly predictable (5). However, rotary instruments perform comparably poorly in long-oval canals such as distal canals in lower molars, specifically as they do not mechanically prepare 60% or more canal surface under these conditions (6).

Very recently a new concept, the so-called self-adjusting file (SAF), has emerged that may allow uniform dentin removal along the perimeter of oval canals. Root canal preparation with this file has been quantitatively described only in anterior teeth (7) but not in molar root canals.

The effects of root canal shaping were assessed, besides other approaches, from double-exposure radiographs (8), from cross-sections using the Bramante technique (9) and more recently using micro-computed tomography (MCT) data (10). The latter technique allows non-destructive quantitative analyses of variables such as volume, surface areas, cross-sectional shape, taper and the fraction of affected surface (11).

Earlier studies had indicated that differences in canal anatomy, between palatal (P), mesio- and distobuccal (MB, DB) canals, would play a significant role for shaping outcomes (12). More ribbon-shaped or flat canals such as the MB canal would have more un-prepared canal area; moreover, on average smaller more curved MB canals would have greater canal transportation than P canals.

Based on the fact that the SAF is capable of addressing non-round canal cross-sections, we hypothesized that various canals in maxillary molars can be prepared to similar outcomes with respect to canal transportation and amount of prepared surface.

Studies based on MCT done in our laboratory over the last decade provided data on preparation effects for hand and rotary instruments in maxillary molars (10,12-14). Therefore, the aim of this study was to describe the canal shaping properties of the self-adjusting file in maxillary molars.

Materials and Methods

Selection of teeth

From teeth that had been extracted for reasons unrelated to the current study, 20 human maxillary molars were collected and stored in 0.1% thymol solution at 4°C until further use. Teeth had mature apices and were free of fractures and artificial alterations. They were mounted on SEM stubs and then scanned in a desktop MCT unit at an isotropic resolution of 20 μm (μCT 40, Scanco Medical, Brüttisellen, Switzerland) using previously established methods (10,15). Care was taken to specifically select teeth that did not have a distinct 4th canal orifice so as to include a bucco-lingually flat mesiobuccal canal, as judged from a preoperative MCT scan in low resolution. Teeth were then accessed using high-speed diamond burs and patency of the coronal canal confirmed. Coronal flaring was accomplished with #2 Gates Glidden burs (Dentsply Maillefer, Ballaigues, Switzerland) placed to 2-3 mm below the cemento-enamel junction. Subsequently canal lengths and patency were determined with size 10 K-files (Dentsply Maillefer) and radiographs; working lengths were set1 mm shorter than the radiographic apex. Each canal was then probed with a #20 K file. If it reached the WL, no further preparation was done. If the canal was narrower than that, it was prepared until # 20 could freely reach the WL in order to provide a glide path.

Root canal instrumentation with the SAF

The SAF was operated using a trans-line (in-and-out) vibrating handpiece (GENTLEpower, KaVo, Bieberach a. d. Riß, Germany, combined with a RDT3 head, ReDent-Nova) (16) at a frequency of 83.3 Hz (5000 movements per minute) and an amplitude of 0.4 mm. This movement combined with intimate contact along the entire circumference and length of the canal and the slightly rough surface of the file removed a layer of dentin with a filing motion. The hollow design allowed for continuous irrigation throughout the procedure. A special irrigation device (VATEA, ReDent-Nova) was connected to the irrigation hub on the file and provided flow of the irrigant (3% NaOCl) at a flow rate of 5 mL/min.

An SAF of 1.5 mm was inserted into each canal while vibrating and delicately advanced apically with an intermittent in-and-out hand movement of 5 mm amplitude, until it reached the pre-determined working length. Each SAF was operated for 4 minutes per canal with continuous irrigation (16); all preparations were done by a single general practitioner, who had been specifically trained with the SAF instrument. Each maxillary molar was prepared with a new SAF and canals were instrumented in a random sequence, *i.e* an equal number of MB, DB, and P canals was instrumented as the first canal with a new file.

The clinician was not allowed to see the virtual models of reconstructed teeth before preparing the root canals and during the course of the treatment. This was done so as to avoid bias by an attempt to manually direct the preparation instrument into any potentially un-instrumented area.

Evaluation

Virtual root canal models were reconstructed based on MCT scans and superimposed with a precision of better than 1 voxel. Precise repositioning of pre- and various post-preparation images was ensured by a combination of a custom-made mounting device and a software-controlled iterative superimposition algorithm (11,15,17); the resulting color-coded root canal models (green indicates preoperative, red postoperative canal surfaces) enabled qualitative comparison of the matched root canals before and after shaping.

Original data sets with 20µm resolution were reformatted with a resolution of 34 µm to facilitate direct comparison with earlier studies using the same experimental setup (10,12), resulting in a total of 80 MCT data sets with two different resolutions (20 µm, and 34 µm). For individual canals, evaluation was done for the full canal length up to the level of the cemento-enamel junction (CEJ) as well as in the apical 4 mm, using custom-made software (IPL, Scanco Medical) as described previously (15). The cross-sectional appearance, round or more ribbon-shaped was expressed as the structure model index (SMI). This stereological index varies from 1 (parallel plates) to 4 (perfect ball) and was described earlier in detail (11).

Increases in volumes and surface areas were calculated by subtracting the scores for the treated canals from those recorded for the untreated counterparts. Matched images of the surface areas of the canals, before and after preparation, were examined to quantify the amount of un-instrumented area. This parameter was expressed as a percentage of the number of static surface voxels to the total number of surface voxels. As detailed earlier (11), canal transportation was assessed from "centers of gravity" that were calculated for each slice and connected along the z-axis with a fitted line. Mean transportation scores were then calculated by comparing the centers of gravity before and after treatment for the apical, mid and coronal thirds of the canals.

Statistical analysis

Normality assumptions were verified and therefore data is reported as means±S.D. Original voxel volume in this data set was 8 x 10^{-6} mm^3; volume data is rounded to the nearest $1/100mm^3$, area data is reported to the nearest $1/100mm^2$, data for prepared canal surface area is presented as percentages relative to preoperative canal surface areas and canal transportation is reported to the nearest in 1/mm distance.

Since normality assumptions could be verified, means were compared using one- and two-way ANOVAs with Bonferroni/Dunn's tests for post-hoc comparison; the level of statistical significance was set at $\alpha=0.05$

Results

Preoperatively, mean canal volumes ranged from 1.50 to 4.30 mm^3 in maxillary molar canals (Tab. 1). Reformatting the data set to a resolution of 34 μm resulted in on average 0.07 ± 0.04 mm^3 smaller volumes. Mean initial canal volumes in the apical 4 mm were 0.69, 0.31 and 0.91mm^3 in MB, DB and P canals, respectively ($p<0.01$). Canal cross-sections were rounder in DB and P canals compared to MB ones ($p<0.01$, Tab. 1). Both preoperative volumes and SMI scores were statistically similar compared to samples of maxillary molars used in earlier studies (10,12-14).

Preoperatively maxillary molar root canals presented with various curves and accessory canals. Most accessory canals remained visible in postoperative canals models (Fig. 1A). Canal cross-sections, as assessed by the structure model index (SMI) varied as well, with significantly flatter canals mesiobuccally (Table 1). Overall, canal preparation of root canals in maxillary molars with the SAF resulted in adequate canal shapes with no major shaping errors. In particular no SAF fractured during the course of the study. Based on superimposed red-green coded surface areas (Fig. 1A) overall shapes were satisfactory with similar amounts of dentin removed around the perimeter in most cross-sections (Fig. 1A) and overall fully prepared canal surface areas. Preparing with the SAF for 4 minutes resulted in mean dentin removal ranging from 2.00 to 2.87 mm^3; this represented significant volume changes compared to preoperative data ($p<0.01$). Differences in volume increase were small but significantly different comparing the 3 canal types investigated (Tab. 1). Increases in SMI were only significant for MB canals; 8/60 canals had SMI increases of 1 or more, all of which were MB canals. Slice-by-slice observation indicated that rounding of MB canals occurred mostly in the coronal third.

Mechanically untreated canal areas, calculated using superimposed MCT data sets (Fig. 1), were 25.8±12.4 22.1±12.0 and 25.2±11.3%, for MB, DB and P canals, respectively (Tab. 2); un-treated canal areas were not statistically different comparing the three canal types ($p>0.05$). When restricted to the apical 4 mm, un-instrumented canal areas ranged from 28.8% in DB canals to 47.4% in P canals. When canal models were reformatted to 34 µm resolution, overall un-instrumented areas were 38.5% (Tab. 2).

Mean canal transportation ranged from 31 to 149 µm and was larger in the coronal third compared to the apical and middle canal thirds ($p<0.01$, Tab. 3). Canal transportation was lowest in the palatal canal. Differences between all canal type with respect to canal transportation at the middle and apical level were significant, however the individual canal transportation values exceeded 100 µm only in 15/120 cases at those two levels. No differences were registered when surface areas or canal transportation was recalculated based on 34 µm compared to 20 µm.

Discussion

This study is the second part of a comprehensive, MCT-based evaluation of the shaping potential of a novel root canal preparation instrument, the self-adjusting file or SAF. Design (16) and various mechanical parameters (18) of this new system have been described in detail previously. The first MCT study of the current series detailed shaping in anterior teeth and dentin removal over time (7). The current report focuses on preparation of maxillary molars with curved canals and various cross-sections, for example, round DB canals and ribbon-shaped or flat MB canals.

Teeth selected for this study were statistically similar to teeth used in earlier studies (10,12-14) on maxillary molars with respect to morphological parameters such as preoperative canal volume, structure model index (SMI) and canal curvature.

Dentin removal with the SAF is most effective during the first 2 minutes of use (18). However, additional time may be needed to ensure a full canal wall preparation in some cases; for example 4 and possibly 5 minutes of activation were required in anterior teeth (7). Preparation with the SAF did not result in obvious preparation errors such as perforation and ledging, with canal transportation values typically below 100 µm for the middle and apical canal section. The slightly larger canal transportation in the coronal section, particularly in MB canals, could have been possibly caused by Gates Glidden drills in an attempt to facilitate straight-line access. Overall canal transportation is likely a cumulated effect of coronal flaring, glide path preparation and the action of the SAF. Similarly, adding instruments for further apical enlargement tends to increase canal transportation as shown in a MCT-based pilot study with sequential scanning (19). An earlier study with the same experimental setup had shown overall canal transportation scores of 123.7, 89.8 and 97.7 µm, for the coronal, middle and apical thirds, respectively, after preparation with NiTi rotaries instruments or K-files (10). These scores and also those described for MB, DB and P canals shaped with ProTaper (12) and FlexMaster (13) indicate larger canal transportation for rotary instruments than for the SAF in maxillary molar canals.

The present study uses MCT to evaluate canal preparation with the SAF. MCT evaluation was introduced to experimental endodontics more than a decade ago (11); it has been used to assess, in a quantitative and three-dimensional approach, the performance of various canal instrumentation techniques (10,15,20-22). The cited studies vary with regards to the type of the MCT systems used and their spatial resolution as well as in the software used for evaluation.

However, a direct comparison between existing MCT data regarding NiTi rotaries generated by the authors (10,12-14) and the present study was made possible with the recalculation of the data in a 34 μm resolution, which had been used earlier. The reformatting did not result in significant changes for canal volume, surface area or canal transportation data.

A potential limitation of this study as in the majority of MCT-based studies is the relatively small sample size of 60 canals in total. It is, however, larger compared to earlier (10,12,21) and similar to more recent (22) MCT-based studies.

An obvious strength of the present non-destructive approach was that it permitted repeated evaluation before and after canal preparation. Moreover, quantitative data for morphological parameters and canal transportation were obtained.

As in the previous study on the use of the SAF in maxillary incisors (7), cases with accessory canals were present in this study sample and larger accessory canals may contribute relevantly to the amount of un-prepared surface. Therefore manual editing was used to eliminate such accessory canals from the evaluation.

A major question addressed with MCT studies is the amount of “un-prepared surface”. The software used in the present study, described in more detail earlier (11,17) counts a surface voxel as belonging to any given structure when the full voxel belongs to it. Therefore, to be counted as “treated”, at least one full voxel has to be registered as removed from the pre-operative canal model after superimposition. In other words, it may very well be the case that a sub-voxel amount of dentin is being shaved off canal wall (the walls were “touched”) and no canal wall preparation is registered. In fact, our earlier study on the effect of SAF preparation on maxillary incisors (7) indicated that 5 minutes of shaping with the 2.0 mm SAF resulted in 91.4% treated surface but only 56.6% surface had more than 100 μm dentin shaved off.

The present study, based on 20 μm resolution, demonstrates overall un-affected canal area of 25.2%. However, a recalculation to 34 μm resolution results in overall 38.5% un-affected area. One earlier study on canals prepared to apical sizes #40 (MB, DB) and #45 (P) (10) indicated similar amounts of overall un-prepared surface as in the present study (38.1%). However, rotary preparation of flat MB canals in maxillary molars in earlier studies (12,13) resulted 43.0% and 47.4% mean un-affected areas, respectively, which is higher than the scores in the present study. Taken together, cross-sections from various slices (see Fig. 1) and low scores for un-affected canal surface in particular for flat canals suggest that canal preparation with the SAF does indeed result in homogenous preparation and a circumferential removal of a layer of hard tissue.

In the present study, there were no significant differences in respect to affected canal surface among the canal types. Nevertheless, when the same SAF size is used (e.g., 1.5 mm) for multiple canals in the same tooth it may be prudent to increase preparation time for larger canal diameters. This will compensate for lesser forces of the cutting SAF elements against canal walls (18) in larger canals such as the palatal or the distal canal in molars. Alternatively, it may be advisable to instrument large canals before any smaller canals, based on the tactile feedback during confirmation of the glide path.

Preparation with the self-adjusting file resulted in less SMI changes in P and DB canals compared to earlier results (10); slice-by-slice evaluation indicated that the increase in cross-sectional roundness in coronal canal third of MB canals, as opposed to retaining the bucco-lingual flat shape, could be explained by the use of Gates Glidden burs. A recent study (22) detailed SMI scores after rotary preparation in the apical 1 mm of shaped canal and found scores of 2.63 to 2.83 for a sample of maxillary and mandibular molars; this is similar to finding in the present study for the apical 4 mm (data not shown) and may indicate that apical canal sections may be prepared round with the SAF.

Rotary NiTi root canal files have been linked to a 3 to 5% incidence of intracanal breakage (23); while a retained instrument fragment per se may not significantly alter healing outcomes of periapical lesions, it is preferable to have no impediment to disinfection inside canals. In the present study we did not observe any SAF breakage with retained fragments.

Eradication of microorganisms, a critical step for endodontic outcomes (24), is the result of a combination of mechanical preparation (25) and irrigation (26). Irrigation alone is not always effective (27) and mechanical action of instruments on canal walls, including removal of infected dentin may be needed. In fact, a recent scanning electron microscopic study suggested that preparation with the SAF leaves very clean dentin walls, probably due to concurrent irrigation possible with this system (6). Moreover, accessory canals remained visible in postoperative canal models after SAF preparation, suggesting little or no deposition of dentin shavings under the conditions of the current study (17).

The preparation of the apical most canal section remains a challenge. In the present study, mechanical preparation with the SAF resulted in limited prepared surface. Hence, sufficient deposition of disinfecting irrigation solutions remains important. Antibacterial efficacy of canal surface preparation was not directly determined in the present study. Mechanical preparation per se may affect bacterial biofilms (28) rather than only microorganisms in their planktonic state. With further improvement in hard- and software it may be possible in the future to directly determine the amount of biofilm removed from canals surfaces based on MCT-based experiments. Furthermore it is presently unknown if the canal preparation with the SAF and in particular its potential to debride canal walls better will lead to improved clinical outcomes but clinical studies are under way to address this question. Another important clinical question is how best to obturate canals prepared with the self-adjusting file; initial data (29) suggest that lateral compaction resulted in a better obturation quality following SAF preparation compared to rotary instrumentation.

In conclusion, using SAF instruments *in vitro*, canals in maxillary molars were homogenously and circumferentially prepared with little canal transportation or other procedural errors.

Acknowledgement: The authors report that a financial affiliation exists for this paper: this study was financially supported by ReDent Nova. Helpful discussions with Dipl.-Ing. Christof Reinhart are gratefully acknowledged.

Figures and Tables

FIG. 1: Representative example of micro-computed tomography data of maxillary molar root canals prepared with the SAF. Preparation time was 4 minutes; black length bars are 1 mm. Note accessory canals that are visible in postoperative images.

A Preoperative, postoperative and superimposed reconstructions (from top to bottom) and in clinical and angled view (left and right columns).

B Cross-sections in the apical, middle and coronal root canal thirds showing the amount of removed dentin in the canal periphery. Green and red areas are pre- and postoperative cross-sections, white lines in A indicate section levels.

TAB. 1: Morphometric data (means ± S.D., n=20 each) and their changes for root canals in maxillary molars and changes after preparation with the SAF. Significantly different results among root types are indicated by horizontal lines ($p<0.05$).

	Mesiobuccal	**Distobuccal**	**Palatal**
Volume [mm^3]	2.88 ± 1.32	1.50 ± 0.99	4.30 ± 1.89
Δ Volume [mm^3]	2.87 ± 1.14	2.00 ± 0.53	2.20 ± 0.71
Area [mm^2]	25.54 ± 8.42	13.26 ± 4.77	23.30 ± 5.20
Δ Area [mm^2]	4.89 ± 1.82	7.13 ± 2.41	5.31 ± 2.00
SMI [units]	2.11 ± 0.47	3.14 ± 0.23	3.29 ± 0.18
Δ SMI [units]	0.85 ± 0.31	0.19 ± 0.18	0.11 ± 0.11

SMI: structure model index

Tab. 2: Root canal surface area not affected by preparation with the SAF (means ± S.D., n=20 each) for root canals in maxillary molars. There were no significantly different results among root types.

	Mesiobuccal	**Distobuccal**	**Palatal**
Unprepared area (20µm resolution)	25.8 ± 12.4	22.1 ± 12.0	25.2 ± 11.3
Unprepared area (34µm resolution)	37.8 ± 13.0	35.6 ± 13.6	42.1 ± 12.3

TAB. 3: Mean (± S.D., n=20 each) canal transportation [in µm] and range determined for coronal, middle and apical root canal thirds after preparation with the SAF. Significantly different results within levels are indicated by horizontal lines ($p<0.05$).

	Mesiobuccal	**Distobuccal**	**Palatal**
Coronal 1/3	113 ± 37 (60-189)	149 ± 58 (63-295)	65 ± 24 (31-113)
Middle 1/3	59 ± 27 (20-138)	89 ± 45 (29-174)	31 ± 15 (10-62)
Apical 1/3	78 ± 30 (33-146)	81 ± 34 (22-168)	47 ± 21 (22-92)

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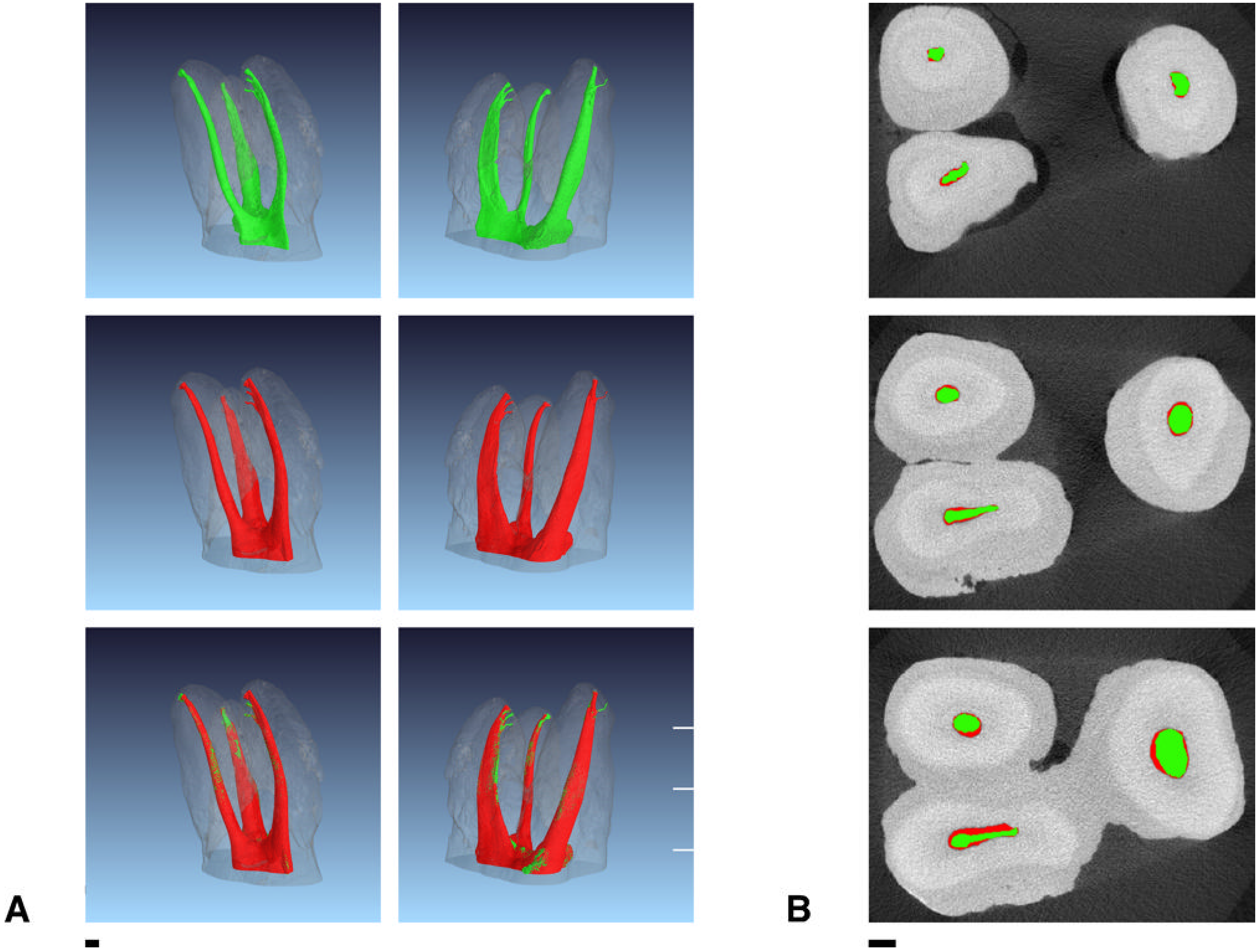
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