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Apical fit of initial K-files in maxillary molars assessed by micro-computed tomography

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Abstract

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Aim To two- and three-dimensionally assess the fit of the first K-file binding at working length after a crown-down canal procedure.

Methodology Twelve maxillary molars with fully developed roots and four separate root canals were selected. Canals were pre-flared using ProFile 0.04 instruments to three quarters of estimated working length (WL). WL was electronically determined using an ISO 06 K-file. Progressively larger K-files were inserted passively to WL. The first binding file was termed initial apical file (IAF). On micro-computed tomography (μCT) scans, cross-sectional areas of IAFs and canals and the largest and smallest root canal diameters were measured 1 mm from instrument tips. Volumes of the apical 2 mm of the instruments and corresponding root canal sections were calculated, and file binding was assessed.

Results IAF sizes ranged from ISO-size 0.08–0.30 and were lowest in second mesiobuccal and highest in palatal canals. Files bound in the apical 2 mm in 96% of the canals. The mean canal area filled by the instruments 1 mm from the tip was below 40% in all canal types, the filled volume below 50% (ANOVA, $P > 0.05$). The mean ratio (±SD) between largest and smallest canal diameter was 3.0 ± 2.6 for first mesiobuccal, 3.3 ± 2.6 for second mesiobuccal, 4.1 ± 3.5 for distobuccal and 1.6 ± 0.4 for palatal canals, indicating oval to flattened cross-sections.

Conclusions Two- and three-dimensional analysis of μCT scans revealed that whilst IAFs bound in the apical area, their fit was poor, because their shape does not correspond to maxillary molar canal anatomy.

Keywords: apical diameter, apical size, canal shape, micro-computed tomography.

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Introduction

The primary goal of root canal treatment in teeth with apical periodontitis is to minimize the number of microorganisms remaining in the root canal system and then seal the canal space to prevent re-infection. Current treatment concepts largely rely on mechanical shaping and chemical cleaning of the root canal system, followed by obturation of the canals (Young *et al.* 2007). In the course of cleaning and shaping the root canal system, the clinician must determine three critical parameters: the length of the canal, the taper of the preparation and the horizontal dimension of the preparation at its most apical extent (Jou *et al.* 2004). This is usually achieved using a hand file.

The introduction of NiTi rotary instruments facilitated root canal preparation particularly in curved root canals (Peters 2004). However, there is still no agreement on how to deal with the ideal apical width and taper of the preparation. Regarding the wide range of apical diameters found in human teeth (Kerekes & Tronstad 1977a,b,c), some authors proposed enlarging the apical part of the root canal by three ISO-sizes more than the first file that apparently binds at working

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length (Grossman *et al.* 1988, Weine 1989, Walton & Rivera 1996). The underlying idea is that dentine can be infected in cases with apical periodontitis (Shovelton 1964), and mechanical removal of infected dentine should yield a more thorough disinfection. However, it is debatable whether this concept predictably removes dentine circumferentially from the root canal walls (Jou *et al.* 2004). Furthermore, the use of endodontic instruments for the determination of apical width appears to be questionable. It has been demonstrated that the tactile sensation of apical file fit does not necessarily occur because of contact at the apex but might be a result of interferences in the coronal and middle thirds of the root canal (Leeb 1983). Anatomical diameter determination based on the tactile sense of the clinician appears to be an empiric and unreliable method (Wu *et al.* 2002). However, it could be demonstrated that preflaring of the coronal and middle thirds of root canals improved the determination of the apical root canal diameter using endodontic instruments (Tan & Messer 2002, Pecora *et al.* 2005, Ibelli *et al.* 2007). In these studies, preflaring allowed an increase in instrument size binding at working length, which was reflected in lower discrepancy values between file and anatomical diameter. However, results in some studies (Wu *et al.* 2002, Pecora *et al.* 2005, Ibelli *et al.* 2007) were obtained by sectioning the roots 1 mm from the apex with the instrument *in situ* canal. The sectioning process could introduce systematic errors, by creating a smear layer or accumulating dentine mud around the instrument. Furthermore, the analyses are restricted to two dimensions and thus influenced by cutting accuracy, cutting angle and number of sections. Taper of canals and their relation to the instrument form cannot be evaluated. Consequently, the use of non-destructive methods yielding three-dimensional images for further analysis such as high-resolution micro-computed tomography (μCT) could add important information in this context.

The aim of the current study was to evaluate the fit of the first K-file binding at working length after a crown-down procedure. Evaluation was performed two- and three-dimensionally using micro-computed tomography in human maxillary molars.

Materials and methods

Selection of teeth

Three-rooted maxillary molars with fully formed apices were selected from a pool of extracted teeth stored in 0.1% thymol. The age and reason for extraction were unknown but not important for this study. Teeth were pre-scanned using a high-resolution micro-computed tomography system (μCT 40; Scanco Medical, Brüttisellen, Switzerland) with an isotropic resolution of 72 μm at 70 kV and 114 μA. After three-dimensional reconstruction, only teeth with four independent root canals and separate apical foramina were selected for further investigations. Thus, 12 teeth fulfilling these criteria could be selected for the current study.

Preparation of teeth

The apical third of the roots were isolated using wax, whilst the remainder of the outer root surfaces were sealed with two layers of nail varnish before mounting and embedding on SEM stubs (014001-T; Balzers Union AG, Balzes, Liechtenstein) to allow exact superimposition of the teeth before and after each root canal instrumentation step. After mounting of the teeth, the root apices were exposed by removing the wax to allow subsequent electronical measurement of the root canal length.

Endodontic access cavities were prepared using diamond burs (Dentsply Maillefer, Ballaigues, Switzerland), and the occlusal surfaces were flattened to ensure clearly defined reference points. The canal orifices were explored using hand instruments (ISO 10 K-file) and were then enlarged with Gates Glidden burs (nos. 4 – 1; Dentsply Maillefer) resulting in a step-down preparation with a maximal insertion depth of 3 mm. Pulp chambers were irrigated with tap water.

Canal preparations were performed using ProFile .04 instruments (Dentsply Maillefer) by an experienced endodontist (M.M.) who was familiar with the preparation system. All files were used with light apical pressure and constant speed in a handpiece powered by a torque-controlled electric motor (ATR Technica, Dentsply Maillefer). Sodium hypochlorite (1% NaOCl) served as irrigant and was delivered with a 27-gauge needle (Max-i-probe, Dentsply Maillefer), and 2 mL of irrigation was used per canal between each file size.

The coronal and middle third of the root canals were preflared using ProFile .04 instruments (sizes 45, 40, 35, 30, 25, 20) in a crown-down sequence without probing the canals further for patency to avoid modifying the canal's apical anatomy. Crown-down preparation was performed until 3/4 of the estimated working length was reached.

Determination of the individual working length was established electrometrically (Root ZX; Morita, Tokyo, Japan) in a physiological saline (0.9% NaCl) bath to simulate the clinical situation (Weiger *et al.* 1999). Size 06 K-files (Dentsply Maillefer) attached to the Root ZX fileclip were inserted until the display indicated 'apex'. From this recorded length, 0.5 mm was subtracted to determine the individual canal working length.

Progressively, larger K-files were inserted passively to working length until the operator felt a file was binding. This file was termed initial apical file (IAF) and was recorded for each individual canal. The position of the IAF was verified electrometrically.

Micro-CT measurements

Specimens were scanned several times using a commercially available micro-computed tomography system (μCT-40, Scanco Medical). A first scan of the mounted teeth was carried out before performing any endodontic procedure at an isotropic resolution of 20 μm at 70 kV and 114 μA. After crown-down preparation, teeth were scanned again to allow a three-dimensional analysis of the effect of the crown-down procedure on root canal anatomy (Fig. 1a,b). A fixed threshold was applied to separate dentine from root canals, and binary images of the root canals were produced. Although the mounting on SEM carriers ensured almost exact repositioning of the specimens for both scanning procedures, superimposition was calculated subsequently using recently developed software (IPL Register 1.01beta; Scanco Medical, Brüttisellen, Switzerland). Thus, the outer root contour was automatically registered of the post- versus pre-treatment

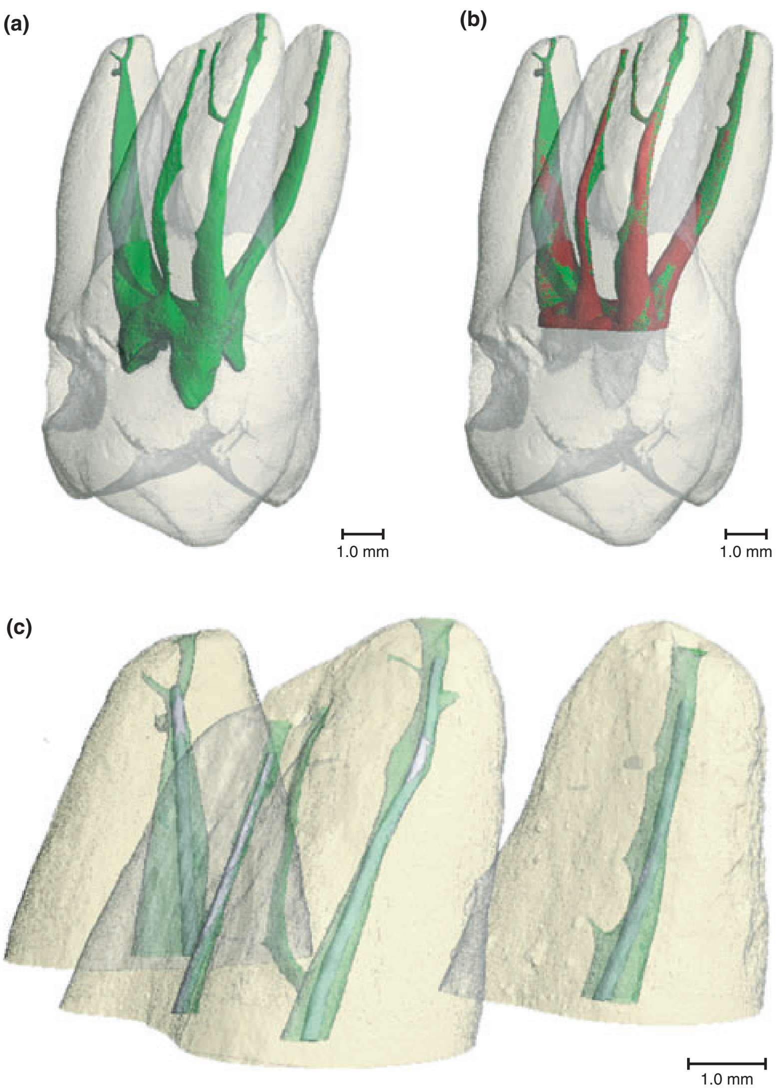

Figure 1 Three-dimensional reconstruction of the tooth and the root canal system prior to any treatment (a) and after crown-down preparation to ¾ of estimated working length (b). Changes in canal shape are shown as superimpositions of unprepared (green) and prepared (red) areas. Red dots on green areas demonstrate overlapping images, i.e. unchanged canal wall section. Matched and superimposed root apices, unprepared apical root canals and binding instruments (c). Note the contact areas of the instruments at the canal walls in a lighter shade of grey.

scan. The two three-dimensional scans were coregistered with each other with rigid rotation and translation, determined by maximizing the cross-correlation of the two overlaid three-dimensional data sets of the outer contour of the tooth which is unchanged by the root canal treatment. This coregistration was performed with an accuracy better than 1 voxel as determined on two test scans of an untreated tooth, where the subtraction image of the co-registered scans showed discrepancies less than 1 voxel (i.e. only a few isolated noise points remained).

A third and a fourth scan for analysing the apical part of the roots were completed after determining the IAF in each root canal. The apical part of each tooth was scanned at 70 kV and 114 μA with an isotropic resolution of 10 μm resulting in 550–800 slices for the apical part for each tooth. The volume of interest was determined to include the apical 2.5 mm of the instrument and the apex of each root. Scans were performed with empty root canals and with fixed IAF in each root canal at working length. For scans with IAFs *in situ*, the integration time of the scanner device was set to maximum (i.e. factor 10×) to reduce the noise and the scattering effect provoked by the radiopaque K-files. This adjustment resulted in scan times for the apical part of the roots of up to 14 h per tooth.

Data generation and analysis

For two- and three-dimensional evaluations of the apical root canals with and without the instruments in place, the slices of interest were calculated back from the root tip which served as a reference point for both scans. Subsequently, the scanned root apices were reconstructed and superimposed over each other. Thus, two sets of segmented root canals (with and without IAF *in situ*) were matched exactly and could be visualized three-dimensionally (Fig. 1c). Cross-sectional areas of the instrument and the canal and the largest and smallest root canal diameters were measured 1 mm from the instrument tip. In addition, volumes of the apical 2 mm of the instrument and the corresponding empty root canal were calculated. Pre-evaluations by means of high-resolution scans of K-files of different sizes revealed that the typical cross-sectional form and size of the instrument was reached approximately 0.25 mm from the instrument tip. For this reason, volumes of the instruments were calculated 0.3 mm to 2.3 mm from the instrument tip, and the corresponding 2-mm volume of the empty root canal was measured.

Values of two- and three-dimensional measurements were grouped according to canal type [first mesiobuccal (MB1), second mesiobuccal (MB2), distobuccal (DB) and palatal (PAL)]. As normality assumptions were warranted, means were compared using one-way analysis of variance (ANOVA) followed by Bonferroni's correction for multiple comparisons. The alpha-type error was set at 0.05.

Results

IAF ranged from ISO size 08-30 and was lowest in MB2 and highest in PAL canals (Table 1). The mean ratio (±SD) between largest and smallest canal diameter at that level was 3.0 ± 2.6 for MB1, 3.3 ± 2.6 for MB2, 4.1 ± 3.5 for DB and 1.6 ± 0.4 for PAL canals, indicating that oval to flattened cross-sections dominated (Fig. 2, Table 2). The mean canal area filled by the instruments 1 mm coronally from working length was below 40% in all canal types ($P > 0.05$ for overall comparison, Table 3). The mean volume filled in the evaluated 2 mm was 39 ± 10%, 47 ± 20%, 38 ± 11% and 38 ± 16% for MB1, MB2, DB and PAL canals, respectively ($P > 0.05$, Table 4). In 44 canals (92%), the IAF was found to touch the canal wall once, whilst it was found to touch the canal wall twice 1 mm coronally from working length in 31 canals (65%). In 96% of all canals (46 of 48), the IAF bound at two opposed locations in the area between 0.3 and 2.3 mm coronally from working length as verified by μCT cross-sections. The large voids between instrument and canal volume were related to both, the canal cross-section and the greater taper of the canal compared to the instrument (Fig. 1).

Discussion

The current investigation showed that the first binding K-file at working length (IAF) in canals of maxillary molars ranged between six ISO-sizes. In 46 of 48 canals, the file touched the root canal wall twice somewhere in the 2 mm evaluated. However, the mean

Table 1 Minimum, maximum and median ISO sizes of the first binding K-file on working length [initial apical file (IAF)]

	Mesiobuccal (n = 12)	Mesiopalatal (n = 12)	Distobuccal (n = 12)	Palatal (n = 12)
Minimum	0.10	0.08	0.10	0.15
Maximum	0.15	0.15	0.20	0.30
Median	0.15	0.10	0.15	0.25

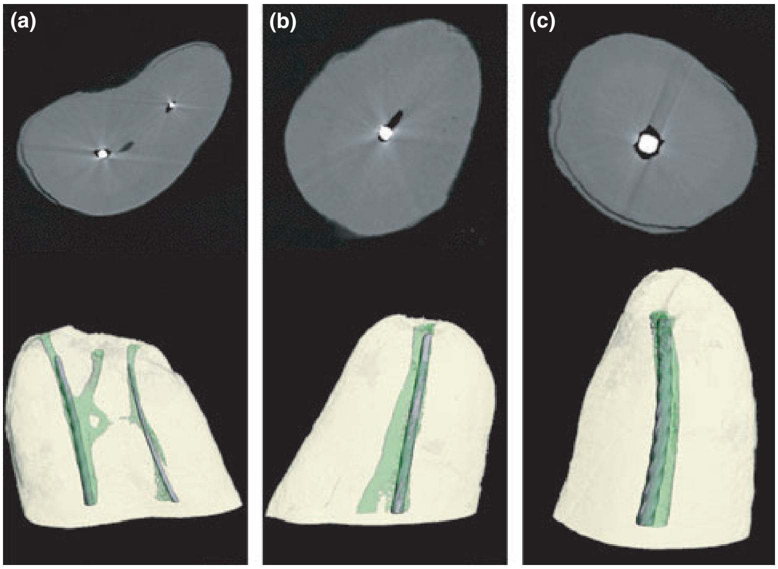

Figure 2 Typical canal shapes and instrument positions as evaluated two- and three-dimensionally for first mesiobuccal (MB1) (a), second mesiobuccal (MB2) (a), distobuccal (DB) (b) and palatal (PAL) (c) root canals. Note the contact areas of the instruments at the canal walls in a lighter shade of grey.

Table 2 Comparison of canal diameters and instruments 1-mm short of working length (mean ± SD, diameters are given in mm)

	Mesiobuccal (n = 12)	Mesiopalatal (n = 12)	Distobuccal (n = 12)	Palatal (n = 12)
Short diameter	0.19 ± 0.07	0.15 ± 0.07	0.18 ± 0.05	0.34 ± 0.05
Long diameter	0.44 ± 0.17	0.38 ± 0.12	0.60 ± 0.34	0.54 ± 0.10
Ratio (long/short)	3.0 ± 2.6	3.3 ± 2.6	4.1 ± 3.5	1.6 ± 0.4
Instrument diameter	0.19 ± 0.03	0.17 ± 0.02	0.21 ± 0.03	0.29 ± 0.05

Table 3 Cross-sectional area of canal, instrument and percentage of canal filled with the [initial apical file (IAF)] 1-mm short of working length (mean ± SD)

	Mesiobuccal (n = 12)	Mesiopalatal (n = 12)	Distobuccal (n = 12)	Palatal (n = 12)
Canal area	0.068 ± 0.033	0.053 ± 0.028	0.082 ± 0.031	0.140 ± 0.043
Instrument area	0.022 ± 0.009	0.018 ± 0.008	0.026 ± 0.006	0.051 ± 0.017
Percentage filled	36.9 ± 14.9	36.5 ± 12.3	36.0 ± 15.8	38.9 ± 15.0

apical volume filled with the inserted IAF was at best 47% (MB2 canals), whilst the canal area filled by the instruments 1 mm from the tip was below 40% for all canal types. This would be the first study on the three-dimensional fit of endodontic instruments in root canals.

Root canal anatomy of human teeth can be rather complex. Average sizes and the cross-sectional form of root canals vary considerably, not only between canals but also within canals (Hess 1917, Kerekes & Tronstad 1977a,b,c, Wu *et al.* 2000). Maxillary molars were used in this study, because these teeth have the greatest variability in root canal shape, size and length. Furthermore, as suggested by epidemiological studies, molars are more frequently associated with apical parodontitis than other tooth types (Kabak & Abbott 2005, Kirkevang *et al.* 2007). Micro-computed tomography is a non-destructive and highly accurate method to analyse root canal geometry. Furthermore, it offers the possibility to perform pre-scans to select teeth with similar root canal anatomy. In the current study, not only the analysis of root canal anatomy was of interest, but it was also attempted to gain information on how inserted root canal instruments were fitting in the apical region. The three-dimensional evaluation showed the real binding points of the instrument to the canal wall. This is not possible using conventional two-dimensional evaluations. Furthermore, it would appear that the volume filled by the instrument is clinically more important than a contact area in two

Table 4 Volume of canal, instrument and percentage of canal filled with the [initial apical file (IAF)] in the apical 2mm (mean ± SD)

	Mesiobuccal (n = 12)	Mesiopalatal (n = 12)	Distobuccal (n = 12)	Palatal (n = 12)
Canal volume	0.128 ± 0.037	0.094 ± 0.052	0.165 ± 0.061	0.322 ± 0.104
Instrument volume	0.048 ± 0.013	0.037 ± 0.011	0.058 ± 0.013	0.112 ± 0.036
Percentage filled	39.3 ± 10.1	46.8 ± 19.7	37.9 ± 11.1	38.0 ± 16.4

dimensions, because it more accurately reflects the mechanical debriding potential of a respective instrument.

K-type hand files were used in the present study. This was because these instruments are available in small sizes and are part of the standard set of instruments. Modified taper-less non-cutting instruments such as prototypes fabricated from LightSpeed files (LighSpeed Technology Inc., San Antonio, TX, USA) used in a previous study (Weiger *et al.* 2006) might give more accurate results regarding canal cross-section but do not exist in small sizes. Furthermore, their taper differs even more from the natural canal anatomy to that of a K-file.

The crown-down technique using rotary NiTi instruments was used, because it is considered the standard method prior to apical enlargement. It was originally described as the crown-down pressureless technique and underwent research scrutiny by Morgan & Montgomery (1984). One of the potential advantages of root canal preparation with early coronal flaring is the greater tactile awareness of the apical constriction (Saunders 2005). Determination of the first file to bind apically before and after preflaring was evaluated by different research groups using destructive laboratory techniques. A significant difference in file size before and after preflaring was found independently of the tooth type and the instruments used (Contreras *et al.* 2001, Tan & Messer 2002, Pecora *et al.* 2005, Ibelli *et al.* 2007, Silveira *et al.* 2008). From these studies, it could be concluded that coronal and midroot flaring offers substantial advantages for more accurate apical sizing.

Accurate determination of the working length is a crucial part of successful root canal treatment (Sjögren *et al.* 1990). The best place to end the preparation procedure is at the apical constriction, which is usually located at a distance between 0–3 mm from the radiographic apex (Kuttler 1955), keeping in mind that, in particular cases, the foramen could be found several millimetres short of the apex (Ricucci 1998). However, the topography of the apical constriction and the distance from the apex varies considerably (Dummer *et al.* 1984). Hitherto, most laboratory studies on root canal preparation were performed using a similar method for working length determination: a small hand file was inserted into the canal until the tip was just visible at the apex and then 0.5 or 1 mm was subtracted from this length. Simulating the clinical situation in the current study, the canal lengths were determined using an electronic apex locator (Root ZX). The method using an apex locator is more reliable than the radiographic method (Pratten & McDonald 1996). However, it has been shown in laboratory studies that in about 10% the position of the apical foramen could not be identified accurately to within ±0.5 mm (Shabahang *et al.* 1996, Welk *et al.* 2003).

According to the classification of canal cross-sections proposed by Jou *et al.* (2004) (round, oval, long oval and flattened), two- and three-dimensional evaluation 1-mm short of working length revealed that canal shapes were predominantly oval in the PAL canal. DB canals had mostly long oval or flattened shapes, whereas canal forms in MB1 and MB2 were found to be long oval in most specimens. Gani & Visvisian (1999) found comparable canal forms and distributions in cross-sections of maxillary molars 2 mm from the apex. In their study, age did not seem to affect the shape of the canals, and narrowing with age was statistically significant only for PAL and MB canals.

In 46 of the 48 evaluated canals, the IAF bound at two opposed canal walls in the segment between 0.3 and 2.3 mm coronally from working length. Only in two PAL canals, the firm contact between instrument and canal wall was not located in this area. Therefore, it could be concluded from three-dimensional evaluations that the operator's tactile sense to feel apical binding was correct in 95%. Based on the axial slices 1 mm coronally from working length, a double canal wall contact could be found in 65%. Previous studies evaluated the first binding instrument on root sections at 1 and/or 2 mm from WL (Gani & Visvisian 1999, Wu *et al.* 2002, Weiger *et al.* 2006). Wu *et al.* (2002) found that in 75% of the canals (mandibular premolars), the instrument (K-file or modified Lightspeed instrument with the largest diameter at the tip) had contact at one side of the wall only, in the other 25%, the instrument did not contact the wall at all (sections at WL level). In their study, the diameter of the instrument was smaller than the short diameter of the canal in 90% of the canals. In agreement with the current study, it was concluded that the first file to bind was an inadequate tool for apical sizing. Weiger *et al.* (2006) determined the optimal apical preparation size in maxillary and mandibular molars after sizing the root canals using special instruments with non-tapered, non-cutting shafts. Their calculations from root sections at 1 and 2 mm from the apex showed that apical enlargement to IAF + 0.60 mm was necessary to yield circumferential apical preparation in 98% of the cases. Furthermore, in 27% of the specimens, a smaller diameter was recorded at the 2-mm level compared to the 1-mm level, pointing to a multi-constricted apical anatomy. Based on the current three-dimensional data, it would appear that the overall misfit between instrument shape and root canal is the reason why apical sizing as performed here is of questionable clinical value. Future studies should investigate which file shape could offer a better initial apical fit. Potentially, this file should or could differ between different tooth types and canals. A further concern is the postoperative volume, or in other words, the ideal file shape to debride the apical area. As shown in a recent study, current instrument systems did not adequately debride apical aspects of root canals in maxillary molars (Paqué *et al.* 2009). Highly tapered instruments with a small tip performed worse in that regard than less tapered or variably tapered counterparts with a larger tip diameter. In this context, it should be noted that completely new approaches to instrument root canals such as the self-adjusting file system (SAF; ReDent Nova Inc., Tel Aviv, Israel) are about to appear on the market and should be taken into consideration.

In conclusion, two- and three-dimensional analysis of μCT scans revealed that whilst IAFs bound in the apical area, their fit was poor, because their shape does not correspond to maxillary molar canal anatomy.

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