A clinical method to determine the optimal apical preparation size. Part I

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Objective. To establish a new approach for determination of the optimal apical preparation size (APS).
Study design. After preflaring 212 root canals from 80 extracted molars, electronic working length (WL) was measured to establish where the apical preparation size (APS) should be determined. Subsequently, nontapered, noncutting special instruments were used to reach WL. The diameter of the largest special instrument (SI) width that had to overcome some resistance to advance to WL was defined as d_{SI}. After sectioning the roots apically, the diameter of a potential rotary instrument was determined for each section, allowing a complete cutting of the root canal wall. The estimation of APS was related to d_{SI}.
Results. Theoretically, individual APS of d_{SI} + 0.60 mm yielded circumferential apical preparations in 98% of the cases. When shaping palatal/distal root canals of molars to d_{SI} + 0.40 mm, and mesiobuccal/mesiolingual/distobuccal root canals of molars to d_{SI} + 0.30 mm, complete preparations of root canal walls resulted in 78% (95% CI, 69%-87%) and 72% (95% CI, 65%-80%) of canals, respectively.
Conclusion. The described approach allowed evaluation of the APS for most root canals. Root canals should be shaped to larger sizes than normally recommended. **(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;102:686-91)**

In past decades, more and more attention has been focused on the form of the ideally instrumented root canal.[1] A parameter that has been addressed in only a few studies is the canal diameter to which the root canal should be enlarged, particularly in the most apical part.[2] This is surprising, as the studies of Kerekes and Tronstad[3-5] demonstrated that the apical diameter of root canals are larger than often assumed.

In infected teeth, microorganisms can be found in dentinal tubules adjacent to the root canal.[6] It is therefore recommended to remove the most heavily infected layer of dentine.[7] It was demonstrated that root canal debridement improved with progressively larger instrumentation, although no instrumentation technique ensured the elimination of all debris and bacteria.[8-11] The same is true for smear layer removal in the middle and apical third of the root canal.[12] In a recent clinical study, only apical instrumentation larger than normally recommended resulted in bacteria-free root canal samples.[13] The mesial canals of molars were shaped to size #60 and the canals of cuspids/bicuspids to size #80 using rotary LightSpeed instruments (Lightspeed Technology Inc., San Antonio, TX).

Unfortunately, the determination of the first file that binds in the apical part of the root canal does not allow a reliable prediction of the appropriate final instrument size required for complete apical enlargement. This is caused by interferences in the coronal and middle third of the root canal and may be overcome by preflaring.[14,15] Furthermore, many root canals have an oval or flat shape apically[7,16-18] that makes measuring the diameter of root canals difficult. Rotary NiTi instruments are becoming increasingly popular for the preparation of root canals. This technique may be helpful to better determine the apical preparation size. However, overpreparation should be avoided as it may result in apical perforation and weakening of the root.

The purpose of this study was to develop a method to determine the optimal apical preparation size (APS).

MATERIAL AND METHODS

Tooth selection

Included in the study were intact extracted maxillary and mandibular human molars with fully formed roots without any visible signs of external resorption. None

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of these teeth had prior root canal treatment. Eighty teeth with a total of 242 root canals were selected. Sixteen root canals had to be excluded due to obliteration, root fracture, or instrument fracture prior to measuring the apical canal diameter. The teeth were stored in 0.1% chlorhexidine.

Preparation of the teeth

Caries and restorations were removed when present. The cusps of the molars were leveled to provide a defined reference plane. Preoperative radiographs were taken to estimate the root canal length and to register the root canal curvature. The teeth were accessed and the pulp tissue removed. The root canals were negotiated with a size 06 hand file and irrigated with 1% sodium hypochlorite. The reference length of the root canal was measured by inserting a size 06 hand file into the root canal until the file tip was visible at the apical foramen. The distance between the tip of the file and the occlusal reference plane was defined as l_{ref}.

Finally, the working length (l_{WL}) was determined by a size 06 hand file connected to an electronic apex locator (Root ZX, Morita, Tokyo, Japan). For this purpose, each molar was placed in a wet environment as described by Weiger et al.[19]

Flaring of the coronal and middle third of the root canals was done with rotary 6% tapered NiTi instruments (HERO 642, MicroMega, Besançon, France) by using a crown-down approach to eliminate all interferences in the coronal part of the root canal. The sequence of instruments was as follows: (1) mesiobuccal, mesiolingual and distobuccal canals: Gates-Glidden burs, size 2-3, for the cervical thirds, followed by 6% tapered HERO 20 for the middle thirds; (2) distal and palatal canals: Gates-Glidden burs, size 2-4, for the cervical thirds, followed by a 6% tapered HERO size 20 and size 30 for the middle thirds; and (3) HERO instruments, used in a circumferential fashion, in oval canals. The root canals were intermittently irrigated with 1% sodium hypochlorite. The apical thirds (about 4 mm) were left unprepared.

Sizing of root canals

After the preflaring was completed, special instruments (SIs) specifically designed to measure the apical canal diameter were used. The special instruments have nontapered, noncutting shafts that allow for better access in the apical region without binding in remote areas of the root canal (Fig. 1). The SIs are available in various diameters and made of either stainless steel (size 08, 10, 12.5, 15, and 17.5) or nickel-titanium (size 20, 25, 30, 35, 40, and 45). They were inserted passively into the root canal, starting with a special instrument size 08, until l_{WL} was reached. Care was taken to avoid any force during the measurements. The largest SI with which some resistance had to be overcome to reach l_{WL} was recorded within the range of 1 mm. The diameter of this instrument (d_{SI}) was related to anatomical parameters determined microscopically.

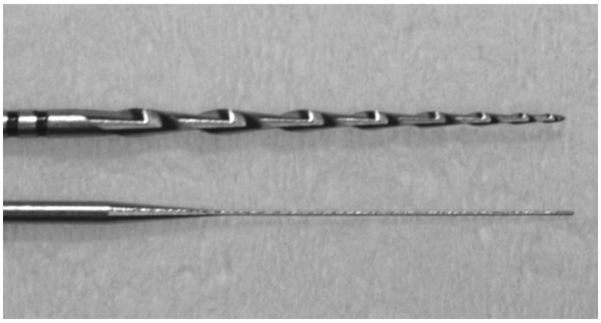

Fig. 1. Instrument specifically designed to gauge the apical canal diameter compared to a rotary file with a 0.04 mm taper.

Microscopic analysis

The roots were carefully sectioned at 1 mm and 2 mm from the apex by a rotating diamond disk positioned perpendicularly to the root canal and prepared for microscopic analysis. Each cross section (1-mm level and 2-mm level) was rinsed with saline and then stained with a fuchsin solution to highlight the contours of the root canal. All cross sections were examined under the light microscope at ×14.4 magnification (Makroskop, Leica, Benzheim, Germany) and photographed. The slides were projected on a screen, and 1 examiner determined which diameter of a potential instrument would completely cut the inner layer of the root canal dentin wall. Assuming that the axis of a rotating instrument was located in the center of the root canal, the largest diameter of the cross section was measured in oval or flat root canals and defined as optimum APS (Fig. 2). In a nearly circular root canal, optimum APS was defined when at least 0.1 mm of the canal-wall dentin could be removed.

Statistical analysis

For each level, d_{SI} (diameter of SI) was related to APS. To provide the basis for an equation, $y = d_{SI} + x$ was set with "x" as the correction factor for each type of root canal. The variable y was calculated for $x = 0.3$ mm, 0.4 mm, 0.5 mm, and 0.6 mm. The frequency of cases resulting in a complete apical preparation ($y \geq$ APS) was computed with the 95% confidence interval (CI) for each type of root canal. Overlapping confidence intervals indicate that there is a statistically significant difference.

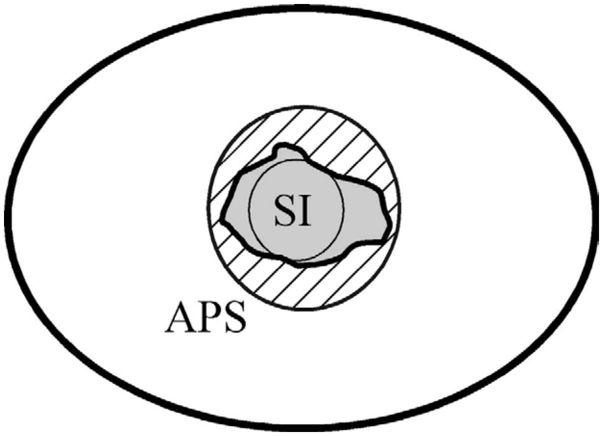

Fig. 2. Root canal section with the outline of the original root canal, the cross section of the SI, and a rotating instrument with APS.

RESULTS

A total of 226 root canals were prepared for apical sizing. Fourteen root canals were excluded due to either a common apical foramen or the inability to passively insert the SI into the apical region. In the remaining 212 root canals, the SI was protruded to the most apical part of the root canals. Finally, the parameter APS was related to d_{SI} in 210 root canals of mandibular and maxillary molars. The cross sections of 2 cases were not suitable for microscopic analysis.

In 191 root canals (90%), it was possible to apply a SI with a diameter of 0.15 mm (No. 15) or larger (Table I). The mean distance between the tip of the SI and the apical reference point that was electronically determined by the apex locator was 0.51 mm. In other words, the SI reached l_{WL} within the range of 1.0 mm in 86% of the measurements (Table II).

The variability of APS for an emphasis-placed d_{SI} is demonstrated in Fig. 3. The mean values for APS are emphasis-placed in Table III. The frequency of complete apical preparation ($y \geq$ APS) is shown to increase with a larger correction factor x (Table IV). As expected, APS at the 2-mm level was in 73% of the analyzed cross sections larger compared to APS measured at the 1-mm level. The mean difference was 0.18 mm (95 % CI, 0.14-0.21 mm).

For instance, an APS of d_{SI} + 0.4 mm in distal or palatal root canals would result in a complete instrumentation in 78% (95% CI, 69%-87%). Similar results were achieved for the smaller mesiobuccal, distobuccal, and distolingual root canals when shaping them apically to d_{SI} + 0.3 mm (72%; 95% CI, 65%-80%). Theoretically, an apical enlargement to d_{SI} + 0.6 mm would allow for complete cutting of canal walls in 205 out of the 210 examined root canals (98%; Table IV).

DISCUSSION

The large sample size used in this study compensated for the anatomical variations and yields reliable, representative results.

Although there is some controversy about the size of the APS, its importance is significant when considering the best possible debridement of infected root canals.[2,20] As the first apical binding file (FABF) may not reflect the apical diameter for reasons of interferences in the root canal or an oval canal, dentin is probably not removed from the entire circumference of the canal wall simply by using the conventional rule of enlarging the root canal with instruments 3 sizes larger than the FABF.

To determine the appropriate final diameter needed for complete apical enlargement, preflaring of the coronal and middle thirds has been recommended prior to determining the initial file that binds.[14,15] It facilitates the FABF, allowing it to reach the apical region. In the present study, the root canals were preflared, but instead of conventional files, cylindrical, nontapered instruments were used for apical sizing. This special design allows the instrument to easily bypass any interference in the root canal that might lead to premature binding.

Unlike other experimental studies[15,21] that determined working length by subtracting 1 mm of the length of a small file whose tip was just visible at the apical foramen, in this study the working length was established by an apex locator in an early phase of the root canal preparation. This procedure reflected the clinical situation. In the majority of the measurements, the SI could be protruded to the electronically determined end point of the preparation, or short of it. In some cases, however, it is theoretically possible that the SI has actually not reached the level of apical sectioning. In about 90% of root canals, a SI with a diameter of 0.15 mm or larger reached the most apical part of the root canal, which was in agreement with the results of other studies.[14,15]

Determining root canal diameters prior to root canal instrumentation requires cross sections that are perpendicular to a tangent that meets a defined point of the curvature, as done in the present study. When the cutting plane is chosen only vertical to the root axis, then a round root canal appears oval in a cross section from the curved part of the root. In these cases, the extent of the geometric distortion depends, in the end, on the actual root canal curvature. As a result, d_{prep} would be inaccurate to define the APS. The cross section at the 2-mm level provided additional information about the apical topography. In 27% of the specimens, a smaller diameter was recorded at the 2-mm

Table I. Number of root canals allowing the SI with a diameter d_{SI} to protrude to working length

	Lower molars			*Upper molars*		
d_{SI}	*dis*	*mb*	*mL*	*pal*	*mb*	*db*
0.06 mm	—	—	—	—	—	—
0.08 mm	—	1	1	—	—	—
0.10 mm	—	3	1	—	—	—
0.125 mm	—	3	4	—	4	4
0.15 mm	4	9	11	2	9	8
0.175 mm	8	7	8	2	8	3
0.20 mm	17	9	7	8	6	7
0.25 mm	5	3	1	11	5	5
0.30 mm	8	1	—	3	3	2
0.35 mm	—	—	—	6	1	—
0.40 mm	—	—	—	3	—	—
0.45 mm	1	—	—	—	—	—
∑	43	36	33	35	36	29
mean d_{SI}	0.22 mm	0.17 mm	0.16 mm	0.26 mm	0.19 mm	0.18 mm

dis, distal; *mb*, mesiobuccal; *mL*, mesiolingual; *pal*, palatal; *db*, distobuccal.

Table II. Number of measurements related to the distance d between the tip of the SI and the electronically determined apical reference point

	Lower molar			*Upper molar*		
d	*dis*	*mb*	*mL*	*pal*	*mb*	*db*
0-1.0 mm	42	31	28	31	27	24
1.5-3.0 mm	1	5	5	4	9	5
mean (mm)	0.27	0.53	0.70	0.39	0.70	0.53

dis, distal; *mb*, mesiobuccal; *mL*, mesiolingual; *pal*, palatal; *db*, distobuccal.

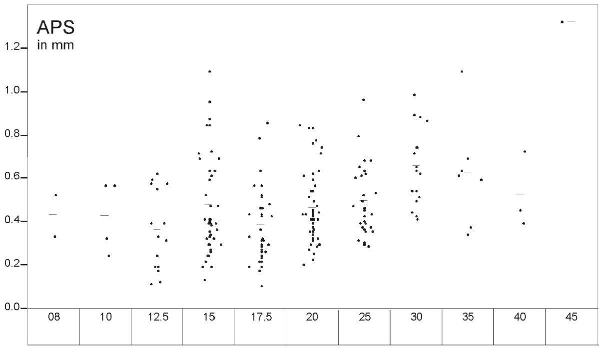

Fig. 3. The individual values for APS representing the minimum apical preparation size in relationship to d_{SI} (1 mm level). The bars represent mean values.

level compared to the 1-mm level, pointing to a multiconstricted apical anatomy.[22]

As cross sections of root canals of molars tend to deviate from the circular form,[3-5,16] it is necessary to enlarge the canal to file sizes larger than d_{SI}. For adequate debridement, it is recommended that a root canal be shaped at least 3 sizes beyond the FABF. Wu et al.[21] reported this rule not to hold true in incisors with oval root canals. In long oval canals, a hybrid technique combining rotary instruments with Hedström files, used in a circumferential manner, was proposed to improve the preparation results in a buccolingual direction.[23] In a curved root canal, however, circumferential filing can only be achieved in the straight portion of the canal. The root canal curvature controls the direction of the file and avoids a sufficient preparation of the apical part of the canal. In the apical region, root canals tend toward a rounder cross section as the long diameter of oval canals decreases apically.[17] In most cases, this may allow a wider enlargement with suitable flexible NiTi rotary instruments.

In the present study, an APS of d_{SI} + 0.3 mm (6 file sizes) for mesiobuccal (upper molars), distobuccal, and mesiolingual root canals would make complete apical preparation possible in 70%-90% of the cases. For palatal, distal, and mesiobuccal (lower molars) root canals, an APS of d_{SI} + 0.4 mm (8 file sizes) would be required to achieve complete cutting of the inner layers of the dentin walls in 69%-89% of the cases. When there is no SI available and no individual apical sizing

Table III. Mean values for APS representing the minimum apical preparation size

	Lower molar			Upper molar		
APS	*dis*	*mb*	*mL*	*pal*	*mb*	*db*
Mean	0.53	0.48	0.46	0.52	0.48	0.37
95% Cl	0.45-0.60	0.42-0.54	0.40-0.52	0.46-0.58	0.40-0.47	0.32-0.43

dis, distal; *mb*, mesiobuccal; *mL*, mesiolingual; *pal*, palatal; *db*, distobuccal; *CI,* confidence interval.

Table IV. Frequency of apical preparation sizes resulting in complete cutting of the dentinal wall in relationship to the correction factor x that is added to d_{SI} (1-mm level)

Lower molar	Distal				Mesiobuccal				Mesiolingual			
x (in mm)	0.30	0.40	0.50	0.60	0.30	0.40	0.50	0.60	0.30	0.40	0.50	0.60
Incomplete	23 (55%)	13 (31%)	7 (17%)	1 (2%)	15 (42%)	10 (28%)	6 (17%)	3 (8%)	11 (34%)	9 (28%)	3 (9%)	2 (6%)
Complete	19 (45%)	29 (69%)	35 (83%)	41 (98%)	21 (58%)	26 (72%)	30 (83%)	33 (92%)	21 (66%)	23 (72%)	29 (91%)	30 (94%)
Upper molar	**Palatal**				**Mesiobuccal**				**Distobuccal**			
x (in mm)	0.30	0.40	0.50	0.60	0.30	0.40	0.50	0.60	0.30	0.40	0.50	0.s60
Incomplete	14 (40%)	4 (11%)	3 (9%)	2 (6%)	11 (30%)	10 (28%)	7 (19%)	5 (14%)	3 (10%)	3 (10%)	1 (3%)	0 (0%)
Complete	21 (60%)	31 (89%)	32 (91%)	33 (94%)	25 (70%)	26 (72%)	29 (81%)	31 (86%)	26 (90%)	26 (90%)	28 (97%)	29 (100%)

possible, clinicians should strive for an average APS of 45-50 for mesiolingual, mesiobuccal, and distobuccal root canals and 60 to 65 for distal and palatal root canals. When the apical diameter is measured by a conventionally tapered file, as done in some experimental studies,[11,12] the APS should be at least 6-8 file sizes larger than the FABF. These observations are well in line with the findings of Tronstad[24] and Senia.[2] In the guidelines for LightSpeed instruments, Senia suggested an APS larger than commonly recommended.[2] Smaller APS, for example, size 25 or 30 in mesiobuccal root canals, leads in almost every root canal treatment to an underpreparation of the apical region. The microscopic observations made in the present study largely agreed with those of Kerekes and Tronstad,[3-5] published more than 25 years ago. They clearly demonstrated that the largest apical diameter of the root canal frequently exceeded the diameter of the master apical file normally used at that time.

Due to a wide range of individual variation, there is no guarantee that an extensive apical enlargement will result in complete cutting of the canal walls. Although flexible rotary NiTi instruments like LightSpeed instruments allow the preparation of curved root canals to a large diameter, irrigation and the use of an intracanal dressing like calcium hydroxide may overcome these anatomical variations. This is particularly true for areas not accessible for instruments in case of an existing infection.[25] In lower molars, communications between the mesiobuccal and the mesiolingual root canals render debridement difficult. A recent study demonstrated that an APS of 60 led to negative bacterial samples in already all infected mesiobuccal root canals in molars, apart from those cases in which intercanal communications were suspected.[13] Finally, an extensive enlargement may also improve the efficacy of irrigating solutions. Irrigants may reach the apical region more easily and display their antimicrobial potential more effectively.[26] Furthermore, there seems to be a rather slight risk of weakening the root and apical perforation as long as the flexible NiTi instrument remains centered in the canal and transportation is avoided. Enlarging the apical part of the mesiobuccal root canal from size 30 to 50 only results in removal of a total of 0.1 mm of the canal wall.

CONCLUSIONS

The described technique allowed evaluation of the APS in clinical situations for most root canals in molar teeth. Root canals should be shaped to larger sizes than normally recommended, particularly in infected cases. By rule of thumb, APS should be at least 6 (mesiobuccal, mesiolingual, and distobuccal root canal) and 8 file sizes (distal and palatal root canal) larger than FABF when no SI is available.

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