The Role of Apical Instrumentation in Root Canal Treatment: A Review of the Literature

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Abstract

The issue of final apical preparation size remains controversial despite considerable clinical and in vitro research. The astute clinician must be aware of this research before choosing any instrumentation system because the informed clinician's decision must be guided by the best available evidenced-based information. This review article generated a Medline-based search strategy to disclose these studies and provides a critique and summary of the results.

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The most important objective of root canal therapy is to minimize the number of microorganisms and pathologic debris in root canal systems to prevent or treat apical periodontitis. This process of chemomechanical debridement, or cleaning of the root canal systems, has been described as the removal of all of the contents of the root canal systems before and during shaping. Grossman (1) described mechanical cleaning as the most important part of root canal therapy. Schilder (2) also considered cleaning and shaping as the foundation for successful endodontic therapy.

Thorough instrumentation of the apical region has long been considered to be an essential component in the cleaning and shaping process. It was discussed as a critical step as early as 1931 by Groove (3). Simon (4) later recognized the apical area as the critical zone for instrumentation. Other authors (5, 6) concluded that the last few millimeters that approach the apical foramen are critical in the instrumentation process. Mechanical instrumentation and irrigation are sound endodontic principles and essential components of successful endodontics (7, 8). Research has shown that mechanical instrumentation greatly reduces the number of microorganisms remaining in the root canal system. Mechanical instrumentation (9) has been shown to reduce bacterial count even without irrigants or dressings. A combination of mechanical instrumentation and irrigation (9, 10) further reduced the number of microorganisms by 100 to 1000 times. However, mechanical instrumentation with irrigation does not reliably disinfect an infected root canal system (11–14).

Manufacturers developed nickel-titanium rotary instrumentation systems to facilitate the cleaning and shaping process. They are popular because of their apparent ease of use and reduced number of instruments. However, Spangberg (6) noted that the strong emphasis on reducing the number of instruments and limiting apical preparations to small sizes does not produce clean apical preparations in diseased teeth. Given this controversial and important topic, we conducted a broad-based Medline search of the literature to characterize the major factors involved in apical canal instrumentation. Table 1 provides the Medline search strategy used to identify relevant articles for this review. A secondary search was then conducted using the references from the computer-generated list of articles. We have organized this review to cover the major factors impacting the selection of the final apical size, namely the anatomy of the apical constriction, apical canal diameter, apical instrumentation, and bacteria.

The Apical Constriction

The apical constriction (cementodentinal junction or CEJ) has long been advocated as the terminal end of instrumentation and obturation (3, 4). It is in theory the narrowest part of the canal and the location where the pulp ends and the periodontium begins. Ricucci (15) advocated instrumenting to the apical constriction because impingement outside this junction may delay wound healing or result in adverse effects on the outcome of endodontic therapy. Materials or medications extruded beyond the constriction may promote inflammation and a foreign body reaction. Ricucci and Langeland (16) showed that instrumentation and obturation to the apical constriction gave the best prognosis. A poorer prognosis was observed when obturating material extended beyond the apical constriction. A literature review by Wu et al. (17) agreed with the major findings of Ricucci and Langeland. However, it is worth noting that the apical constriction may not always be present or easily identifiable (4, 18).

TABLE 1. Medline search results

Set	Search Statement	# Citations
1	exp *Dental Cementum/ah (Anatomy & Histology)	78
2	exp *Dental Pulp Cavity/ah (Anatomy & Histology)	772
3	exp *Dental Pulp Cavity/mi (Microbiology)	386
4	exp DENTIN/mi (Microbiology)	409
5	exp *Periapical Periodontitis/mi (Microbiology)	199
6	exp *"Root Canal Therapy"/mt (Methods)	2160
7	exp *"Root Canal Preparation"/mt (Methods)	177
8	exp *"Root Canal Preparation"/is (Instrumentation)	544
9	exp "Root Canal Irrigants"/tu (Therapeutic Use)	282
10	exp *"Tooth Root"/ah (Anatomy & Histology)	612
11	1 or 2 or 3 of 4 or 5	1764
12	6 or 7 or 8 or 9 or 10	3377
13	11 and 12	470
14	limit 13 to (human and English language)	362
15	exp tooth apex/	603
16	14 and 15	67
17	11 and 15	91
18	12 and 15	269
19	17 or 18	290
20	limit 19 to (human and English language)	268
21	14 or 20	563
22	'apical'.ti	4583
23	(constriction or cleaning or enlargement or peridontitis).ti	6460
24	22 and 23	29
25	'one third'.ti	175
26	22 and 25	1
27	24 or 26	30
28	'root apices'.ti.	27
29	'root apexes'.ti.	2
30	27 or 28 or 29	59
31	limit 30 to (human and English language)	27
32	exp *BACTERIA/gd (Growth & Development)	19878
33	exp *Enterococcus faecalis/ip (Isolation & Purification)	214
34	exp Colony Count, Microbial/	12485
35	exp Histocytological Preparation Techniques/	150139
36	32 or 33 or 34 or 35	179916
37	11 or 12 or 30	4701
38	36 and 37	242
39	limit 38 to (human and English language)	187
40	21 or 31 or 39	723
41	exp epidemiologic methods/ or cohort studies/	2055862
42	40 and 41	295

Note that statements in brackets define prior search terms and were not used in the search (e.g. "Anatomy & Histology" defines the search term "ah").

Shape of the Apical Constriction

We have summarized the major findings on apical constriction studies in Table 2. The apical constriction has been carefully examined by a number of authors. Both Kuttler (19) and Mizutani et al. (20) showed irregularities in the shape of the cementodentinal junction. These shapes have been described as oval, long oval, ribbon shaped, or round (20). Drummer et al. (18) has shown the apical constriction to be irregular in a longitudinal direction as well. Twenty-five percent of the apical constrictions in teeth evaluated by Wu (21) had long oval shapes. In fact, the data demonstrated that the CEJ of most teeth were never completely round, but tended to be oval. Most (51–78%) of teeth examined by Mizutani et al. or Mauger et al. (20, 22) did not have a round apical constriction. It is apparent from the literature that the apical constriction is not uniformly round, but is generally either oval or irregular. Clinically, this means that the greatest diameter of the canal shape must be taken into consideration if this area is to be thoroughly debrided with root canal instruments.

Diameter of the Apical Constriction

As detailed in Table 2, a review of the literature discloses several articles that attempt to quantify the horizontal dimension of the apical constriction. This dimension varies tremendously within the canal. Kuttler's (19) classic study presented apical constriction dimensions for teeth from patients 25 yr and younger and 55 yr and older. Recognition of the role of continual deposition of cementum over life is a major contribution of this study and indicates that the astute clinician should consider patient age when planning endodontic treatment strategy. Green's (23) study reported that the apical constriction sizes for maxillary first bicuspids, maxillary molars, and mandibular molars. However, this study did not account for canal curvature when sectioning the root that could lead to an over-estimate of actual measurements. Kerekes and Tronstad (24–26) made morphometric measurements on anterior, premolar, and molar teeth and demonstrated a wide range of diameters in the apical constriction. Kasahara et al. (27) used transparent specimens to take his measurements and found that a #60 file adequately prepared the maxillary central incisor. Several other authors have reviewed this literature and developed similar conclusions (28–30). Stein and Corcoran (31) microscopically found a cementodentinal width of 0.189 mm for his 111 teeth. This study did not differentiate between individual types of teeth but rather are averaged for all the teeth in the sample. Mizutani et al. (20) examined 90 maxillary anterior teeth and summarized the cross-sectional area of the apical constriction. However, this study and others (22) did not appear to section the teeth perpendicular to the long axis of the canal at the level apical constriction and therefore, the measurements may not be accurate. Miyashita et al. (32) used transparent sections and demonstrated that the constriction of mandibular incisors were adequately debrided with a #40 file in 60% of the teeth. However, this study did not specifically evaluate the apical constriction but instead instrumented teeth at various distances (e.g. 0.5 mm) from the foramen.

Ghani and Visvisian sectioned root apices 2 mm from their apical foramen in 40 maxillary molars (33). He showed differences in the anatomical shape of the apices and differences among age groups. Unfortunately, Ghani's study sample size was too small for each age group and inconclusive because teeth were not sectioned at the exact cementodentinal junction. Wu et al. (21) horizontally sectioned 180 teeth at various distances from the apex. Their study showed the apical constriction diameters for each group of teeth. Ponce and Fernandez (34) studied the cementodentinal junction in 18 anterior teeth and presented the diameters of the apical constrictions at the cementodentinal canal junction. He found apical constriction diameters ranging from 29 to 35 mm. Unfortunately, Ponce's sample size was limited.

The literature has shown a number of studies concerning the apical constriction dimensions. There have been several comprehensive studies (19, 21, 24–26) that have investigated the diameters of the apical constriction. Other studies are confined to a limited age group or sample size. Because the anatomy in this region is so complex and variable, most studies do not reflect the true horizontal dimensions of this region of the canal (35). More thorough studies about the shape and size of the apical constriction are needed.

Instrumentation

Over the years, many ways have been advocated for the ideal mechanical preparation of root canal systems based in large part upon obturation philosophy. In 1932, Jasper (36) believed that gutta-percha could be easily extruded from the canal and, therefore, advocated a gradual taper to the root canal to accommodate silver points. Years later, grossly tapered preparations were advocated by Berg (37). The canals were enlarged to quite large sizes to accommodate large heated

TABLE 2. Maxillary apical constriction diameters

	Kuttler 268 teeth 1955	Green 110 teeth 1956	Tronstad 220 teeth 1977	Kasahara 510 teeth 1990	Stein 111 teeth 1990	Sabala Review 1991	Tronstad Suggested 1991	Mizutani 90 teeth1992	Miyashita 1085 teeth1997	Gutmann Suggested1997	Mauger 100 teeth 1998	Ghanai 40 teeth 1999	Wu 180 teeth 2000	Ponce 18 teeth 2003
Centrals	25–35		45	60	19	80	70–90	42		35–60			35	30
Laterals	25–35		60		19	80	60–80	37		25–40			45	30
Cuspids	25–35		45		19	80	50–70	38		30–50			35	35
1st Bi's	25–35	20	50		19	60	35–90			25–40			40	
1 canal			70			60							30	
2 canals			20											
3 canals														
2nd Bi's	25–35				19		35–90			25–40				
1 canal			70			80							40	
2 canals			35			45–60							30	
Molars	25–35				19									
MB root		25				45	35–60			25–40			45	
1 canal			60									30–40	20	
2 canals			40									25–35	20	
DB root		25	40			45	35–60			25–40		20–50	25	
Pal root		35	40			60	80–100			25–40		40–55	35	

MANDIBULAR APICAL CONSTRICTION DIAMETERS

	Kuttler	Green	Tronstad	Kasahara	Stein	Sabala	Tronstad	Mizutani	Miyashita	Gutmann	Mauger	Ghanai	Wu	Ponce
Centrals	25–35		70		19	60	35–70		40	25–40	50		40	
Laterals	25–35		70		19	60	35–70		40	25–40	50		40	
Cuspids	25–35		70		19	80	50–70			30–50			50	
1st Bi's	25–35		35				35–70			30–50				
1 canal					19	80							35	
2 canals						45–60							25	
2nd Bi's	25–35		40				35–70			30–50				
1 canal					19	80							35	
2 canals						45–60							25	
Molars	25–35													
M root		25	60		19	45	35–45			25–40			40	
D root		30	60			60	40–80			25–40			50	

Data are presented as ISO file size.

pluggers that were used to condense warm gutta-percha. In 1956, Seidler (38) described a technique for instrumentation that would create round tapered canals with minimal opening at the apex. Schilder (39, 40) later described his instrumentation process for an ideal preparation for thermoplasticized obturation. He thought the canal should have a larger diameter at the coronal orifice with a gradual decreasing taper towards the apical constriction that had the smallest diameter. This large diameter was needed for obturation utilizing his warm vertical technique. Buchanan (41) advocated avoiding aggressive apical instrumentation with a minimally tapered canal. He believed that in this type of shaped canal during the obturation process, the cone of gutta-percha would move apically and tighten the seal. Also, there was less chance of apical extrusion. However, many of these opinions were not supported by experimental research. Indeed, many of these instrumentation techniques were designed for the obturation phase of endodontic therapy and were not developed for optimal chemomechanical debridement of infected root canal systems.

Shaping and Enlargement of Root Canal Systems

The literature has also shown that root canal systems need to be enlarged sufficiently to remove debris and to allow proper irrigation to the apical third of the canal. Research has shown that canals need to be enlarged to at least #35 file for adequate irrigation to reach the apical third (42). Ram (43) concluded that canals need to be enlarged to a #40 file size so that maximum irrigation is in contact with the apical debris. When smaller files were used, debris was not flushed out by irrigation. Chow (44) demonstrated that the canal system had to be instrumented to at least #40 file for proper irrigation. Shuping et al. (45) and Siqueira et al. (46) later confirmed the findings that larger file sizes are needed to allow the irrigating solution to reach the apex.

Larger instrumentation sizes not only allow proper irrigation but also significantly decrease remaining bacteria in the canal system. Orstavik et al. (11) demonstrated that instrumentation with a #45 file decreased the bacterial growth by 10-fold. Dalton et al. (47) also showed with increasing file size, there was an increasing reduction of bacteria. His sampling was only significant between bacteria sampling before and after first instrumentation. This study was replicated by Sjogren et al. (48) who reported that a #40 file decreased bacteria better than smaller sized files. Opposing these findings was the study of Yared and Dagher (49) who reported that a #25 file was as efficient as a #40 file for reducing residual microorganisms.

Apical Enlargement

The apical portion of the root canal system can retain microorganisms that could potentially cause periradicular inflammation and therefore treatment interventions that maximize removal of pathogens should be indicated in the treatment of infected root canal systems (50). Nair et al. (51) found even after long term therapy, apical microflora can play a significant role in endodontic treatment failures. It is then necessary to remove this heavily infected dentin when instrumenting the canal.

Guidelines or standards for apical preparation were espoused by Weine (52). He advocated enlarging the apical part of the root canal to three sizes larger than where the first file bound. But other authors (35, 53–55) have concluded that it is questionable whether filing three sizes larger than the first file that binds will adequately remove dentin circumferentially in the canal. Buchanan (56–61) has advocated minimal apical preparation (e.g. #20 or #25) based on his clinical opinions. He proposed that enlarging the canal size would cause apical transportation or zips. These techniques focus more on minimal apical preparation for the prevention of iatrogenic instrumentation, yet are based primarily upon clinical impressions.

Parris et al. (62) evaluated apical clearing, a technique involving the rotation of the final largest file at working length following irrigation and drying of the canal systems. Apical clearing effectively removed debris remaining on the walls in the apical third. Wu and Wesselink (63) showed instrumentation to a #45 file size in molars reduced the number of remaining bacteria. Sequeira (64) and Wu (63) demonstrated that although there was bacterial reduction during apical enlargement, complete debridement was not possible. Another group of authors (65) instrumented mandibular canines/bicuspids to size #80 and the mesial roots of mandibular molars to a size #60 and demonstrated an 81 to 100% reduction in remaining bacteria. Rollison et al. (66) showed larger file sizes to a #50 produced greater reduction in remaining bacteria than those instrumented with a #35 file. His in vitro study with *Enterococcus faecalis* also used selected canals and curvatures. Tan and Messer (67) compared hand versus rotary files using specific criteria for apical enlargement. Their results also conclude that no technique was totally effective in cleaning the apical canal space. They concluded that larger instrumentation was beneficial in reducing the debris in the apical third of the canal. Recently, Usman et al. (68) also showed that larger instrumentation files cleaned the apical third of the canal better than smaller instrument size. Contrary to the above studies, Coldero et al. (69) reported that there was no difference in intracanal bacterial reduction with and without apical enlargement. Chemomechanical preparation of the coronal aspect allowed NaOCl to reach the apical part of the canal and thus aid in eliminating *E. faecalis* without apical enlargement. However, in their study, there was minimal difference in the apical instrumentation sizes between groups. Taken together, virtually all of the above studies provide a strong consensus that larger apical preparation sizes produces a greater reduction in remaining bacteria and dentinal debris as compared to smaller apical preparation sizes.

Are there other ways to instrument the root canal system? In 1995, Lussi et al. (70) described a noninstrumentation technology (NIT) for cleansing and obturating the canal system. This technology utilizes alternating pressure fields to produce hydrodynamic turbulence that perfuses sodium hypochlorite into minute ramifications of the canal system. After cleaning the canal with NIT, it is obturated using a low pressure vacuum to aspirate sealer into the canal system (71) and dentinal tubules. Lussi (72, 73) also showed that a combination of mechanical instrumentation, NIT for cleansing, and obturation using sealer and a gutta-percha cone resulted in less leakage. However, Attin et al. (74) evaluated the quality of canal debridement with NIT. They showed that 75 to 79% of the middle and apical areas contained significant amount of remaining organic debris and concluded that NIT stills needs further refinement before clinical use.

Longitudinal Studies Concerning Instrumentation

Longitudinal studies have been conducted over the years. These studies have evaluted the influence of various aspects of endodontic therapy on clinical success. Strindberg's study (75) followed 254 patients for up to 10 yr. His results showed that small apical preparations had greater success using the instrumentation and obturation techniques of the 1950s. Hoskinson and colleagues reported a retrospective study (76) evaluating two protocols with similar final apical preparation sizes (#20–30), but different obturation techniques. The results indicated similar success rates with both protocols. Kerekes and Tronstad (77) studied 333 patients that were treated with a standardized technique. His results concluded that larger file sizes did not have better results than smaller file sizes. The Toronto study (78) also concluded there was no difference in success when it came to apical enlargement. However, this study did not quantify the master apical sizes and nickel titanium rotary files were not generally used in this study.

Microorganisms in dentinal tubules

Table 3 summaries the in vitro and in vivo studies evaluating bacterial infection in dentinal tubules. Sufficient evidence exists to demonstrate that instrumentation and irrigation (9, 10, 66–68) of root canals does not always remove all of the microorganisms. Bacteria are able to penetrate dentinal tubules in vitro and in vivo. Deeply embedded bacteria are shielded from instrumentation and irrigation, making their removal or eradication difficult.

In Vitro Studies

Akpata and Blechaman (79) showed that when the number of bacteria in a canal increased, their depth of penetration in dentinal tubules also increased. Haapasalo and Orstavik (80) used bovine teeth and showed that *E. faecalis* may heavily invade dentinal tubules up to 400 μm. Orstavik and Haapasalo (81) found that *E. faecalis* and *Streptococcus sanguis* invaded dentinal tubules 300 to 400 μm within 2 to 3 wk. Siqueira et al. (82) demonstrated that *E. faecalis*, *Propionibacterium acnes*, and *Actinomyces israelii* heavily invaded tubules. They also observed that *Porphyromonas gingivalis* penetrated deeply in tubules. Peters et al., (83) reported that *E. faecalis* penetrated tubules further than *A. israelii* and that penetration was even greater for both bacteria in the absence of smear layer. Perez et al. (84), using bovine teeth, demonstrated that *S. sanguis* penetrated 792 μm into the tubules. In a follow up study, Perez et al. (85) demonstrated that *S. sanguis* migrated into dentinal tubules but *A. naeslundi* and *Prevotella intermedia* did not migrate. Instead, they aggregated and formed clus-

TABLE 3. Dentinal tubule infection

Author	Year	In Vivo/ Vitro	Method of Determination	Teeth Used	Depth of Penetration
Matsuo	2003	Vivo	Immunohisto	40	70% had bacteria in tubules up to cementum *Fusobacterium*, *Eubacterium alactolyticum*, *E. nodatum*, *Lactobacillus casei*, *Peptostretoccous micros*
Weiger	2002	Vitro	Fluorescent photomicroscope	24	*S. sanguis* *E. faecalis* up to 150 μm
Siqueira	2002	Vivo	SE	15	300 μm cocci & rods
Peters & Wesselink	2001	Vivo	Light	25	375 μm *Fusobacterium*, *P. intermedia*, *P. gingivalis*, *A. israeli*
Peters & Wesselink	2000	Vitro	Light	Bovine	Up to 2000 μm *E. faecalis*, *A. israeli*
Berkiten	2000	Vitro	SE	28	*P intermedia* 26 μm *S. sanguis* 383 μm
Waltimo	2000	Vitro	Light	Human	Yeasts 60 μm
Siqueira	1996	Vitro	SE	Bovine	Heavy penetration *P. endodontalis*, *Fusobacterium nucleatum*, *A. israelii*, *P. gingivalis*, *Propionibacterium acnes*, *E. faecalis*
Love	1996	Vivo	Light	Human	200 μm in cervical & mid root 60 μm in apical *S. gordonii*
Perez	1996	Vitro	SE	Bovine	1300 μm *S. sanguis*
Sen	1995	Vivo	SE	Human	10–150 μm Cocci, rods
Nagoka	1995	Vivo	SE	Human	2100 μm
Perez	1993	Vitro	Light microscopy & SE	Bovine	*S. Sanguis*, *P. intermedia*, *A. naeslundi*
Perez	1993	Vitro	Light microscopy & SE	Bovine	792 μm *S. Sanguis*
Orstavik	1990	Vitro	SE	Bovine	600–1350 μm *S. sanguis*, *E. faecalis*, *E. coli*, *P. aeraginosa*
Ando & Hoshino	1990	Vivo	Light microscopy	Human	500–2000 μm *Lactobacillus*, *Streptococcus*, *Propionibacterium*, *Peptococcus*
Haapasalo & Orstavik	1987	Vitro	SE	Bovine	300–400 μm *E. faecalis*
Armitage	1983	Vivo	Light microscopy	Human	Half way up DC junction
Akpata	1982	Vitro	Light microscopy	Human	>Half way through tubules *S. sanguis* *E. faecalis*

ters on canal walls. Perez et al. (86) demonstrated that in the absence of a smear layer *S. Sanguis*, remained viable after 14 days. Studies on human teeth showed *S. sanguis* can penetrate tubules up to 382 μm, but *P. intermedia* only penetrated tubules by 26 *u*m (87). Yeasts have even been shown to penetrate the tubules up to 60 μm (88).

In Vivo Studies

Although in vitro studies are important from many perspectives, clinical research provides a gold standard for evaluating the effect of instrumentation on remaining bacteria. Armitage et al. (89) found bacteria in dentinal tubules one-half the distance to the cementodentinal junction. Ando and Hoshino (90) demonstrated the presence of bacteria 500 to 2000 μm in tubules in teeth with heavily decayed crowns. Nagaoka et al. (91) showed that vital teeth are more resistant to tubular invasion but, as time progressed, both vital and nonvital teeth showed greater depths of penetration. The maximum depth of penetration was 2100 *u*m for non vital teeth. Sen et al. (92) found yeasts as well as bacteria in dentinal tubules, at depths from 10 to 150 μm. Love (93) studied regional variation of tubular penetration. He found heavy bacterial invasion and deeper penetration (up to 200 μm) at the cervical and mid-root levels. At the apical level, he found contamination and more superficial invasion (up to 60 *u*m). However, in a study by Peters et al. (93), half of the teeth with apical periodontitis demonstrated bacteria deep in the tubules that in some cases penetrated nearly to the cementum layer. Siqueira et al. (94) demonstrated the presence of bacteria up to 300 μm in the dentinal tubules. Matsuo et al. (95) showed that 70% of the tubules had bacteria in them, some located as far as the cementum. Love and Jenkinson (96) postulated that in vivo conditions may stimulate bacteria and promote intratubular growth in dentinal tubules. They proposed that symbiotic relationships with other bacteria allow the invasion of other groups of bacteria to more easily invade the dentinal tubules.

Studies involving bacterial penetration of dentinal tubules have to cope with some technical shortcomings. Studies with bovine teeth have been questioned because their tubules have wider diameters than human tubules (85). Studies that involve grinding may destroy certain species of bacteria (97). Others, using stains, do not identify gram negative bacteria (98). Whereas others are limited in their identification of specific bacteria (99).

New molecular techniques are being developed to better identify and quantify bacteria (94, 95, 97) in human dental tubules. The primary advantage of these molecular techniques is greater sensitivity and specificity.

Fate of the Bacteria in Tubules

Despite the recognized experimental limitations, it is clear that bacteria invade the tubules at variable distances. Should there be a reason for concern? Love and Jenkinson (96) concluded that bacteria left in dentinal tubules may cause infections following root canal therapy. Oguntebi (97) also concluded that bacteria in the tubules can contribute to failure of endodontic therapy. But, Peters et al. (99) concluded that some bacteria superficially located in the tubules do not survive instrumentation and those that remain deeper in the tubules may be subsequently inactivated or of an insufficient number to cause pathology. However, in a later study, Peters et al. (100) concluded that bacteria still present in the deeper levels of the tubules were of sufficient numbers that they could possibly lead to recurrent infections.

Intracanal medications have long been advocated to promote disinfection or eradication of microorganisms in dentinal tubules. Various agents (101–106) have been used to disinfect the tubules up to 220 μm. These various agents or solutions were not effective on all types of bacteria. Weiger et al. (107) studied the vitality of bacteria in infected human dentin tubules after treatment with an intracanal medication. They found, under selected conditions, viable *S. Sanguis* and *E. faecalis* even after treatment with calcium hydroxide.

Conclusion

The ultimate goal of root canal instrumentation is to eradicate bacteria from the root canal system (108–110). The ability to thoroughly clean and shape the anatomic complexities of the canal system is the primary determinant for endodontic success (4). Longitudinal studies have shown instrumentation to larger files sizes doesn't contribute significantly to the enhanced statistical success for endodontic therapy. However, these studies are often retrospective or have other factors (e.g. sample size) (75, 76, 78). Moreover, many of these studies do not specifically evaluate the impact of a significant enlargement of the canal or of apical region with regards to clinical success. More specific studies support the general conclusion that larger apical preparation reduces the bacterial count (63–67). They have also shown that larger apical sizes yield cleaner canals that may promote further success. Failing to clean canals, especially in the apical region, can result in treatment failure (50, 51).

Yet, despite its importance, the number of comprehensive studies dealing with the anatomy and diameter of the apical region is limited (19, 21, 24–26). The clinical philosophy that apical preparation sizes should be kept as small as possible, rather than as large as required, disregards existing scientific literature and appears to be based primarily upon clinical opinion (56–61).

Better microbial removal and more effective irrigation occurs when canals are instrumented to larger apical sizes (42–46). Although bacteria may remain viable in dentinal tubules (107) proper instrumentation and adequate irrigation (11, 43, 44) significantly reduces bacteria from the canal (9, 10) and the dentinal tubules (102–105). The scientific evidence of a high success rate when proper cleaning is obtained before obturation gives credence to the importance of good apical cleaning.

Clinicians desire easier and faster endodontic therapy (6). Dental manufacturers are suggesting that this is attainable with rotary instruments. However, in their desire to make instrumentation "easy," some are suggesting apical enlargement to only a size #20, #25, or #30, giving the erroneous impression that apical canal diameters are more or less the same small size. A review of the literature indicates that the apical constriction and the 3 to 4 mm of the canal coronal to it are larger than the size advocated by some manufacturers (Table 2).

As endodontists, we should be careful to adopt the best available evidence for supporting clinical treatment plans. Ignoring science for the sake of speed and simplicity may place the final outcome for our patients in jeopardy. Moreover, because the apical dimensions of root canals range from very large to very small, we should seek instruments and techniques that can help the clinician determine when instrumentation to the correct apical size has been achieved. Although much has been discussed in this area, additional research is clearly warranted.

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