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Size of Master Apical File and Optimal Irrigation of the Apical Zone: A Systematic Review

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ABSTRACT

Introduction: To determine what would be the minimal apical diameter for optimal chemomechanical preparation in the root canal system in terms of debridement and/or irrigation delivery, in patients undergoing nonsurgical root canal treatment. **Methods and Materials**: Randomized controlled clinical trials, cohorts, cross-over studies from peer-reviewed journals published in English from January 1950 to June 2018 which reported outcome in terms of healing, microbial reduction and/or effectiveness of irrigation delivery to the apical third of the root canal system. Two reviewers conducted a comprehensive literature search. There were no disagreements between the two reviewers. The articles that met the inclusion criteria went through a predefined review process. **Results:** Due to the variety of methodologies and different techniques used to measure outcome for master apical file enlargement, it was not possible to standardize the research data and to perform meta-analysis. Twelve clinical articles were identified that met the inclusion criteria. **Conclusions**: The overall level of evidence on this topic was moderate (fair). From this systematic review, the majority of the studies collected and referred to recommend sizes higher than #30 as the minimal size in order to adequately prepare the apical region of the root canals. Only 2 out of 12 studies suggested the size #25 as acceptable. From this systematic review it may be concluded that a larger MAF preparation above size 30 aids chemomechanical action.

Keywords: Apical Size; Endodontics; Irrigation; Master Apical Size; Systematic Review

Introduction

The primary objective of nonsurgical root canal treatment is to eliminate microorganisms and pathologic debris from the root canal system [1] and to prevent its reinfection [2]. Gutierrez and Garcia [3] reported that root canal system is often improperly cleaned and shaped. It has also been reported that contemporary chemomechanical debridement techniques do not consistently eliminate bacteria during root canal treatment [4].

In a previous systematic review [5], the authors reported that, for teeth with necrotic pulps and periapical pathosis, enlargement of the apical root canal system would result in increased healing outcomes. The authors reported four articles on this subject with substantial differences between the studies. Against the backdrop of current clinical variability and the concurrent move towards an evidence-based practice, the authors then explored the effect of canal enlargement and microbial reduction for patients with a necrotic pulp and periapical pathosis [6]. In that systematic review, they reported seven articles on this clinical subject with substantial differences between them. Five articles concluded that root canal system enlargement reduced bioburden in the root canal system and two reported that there was no difference [5]. The results of that systematic review concluded that bioburden could not be eradicated by canal enlargement alone. A comprehensive search of the literature failed to reflect what was the current best available evidence used when making decisions about an optimal master apical file size (MAF) [7]. Thus, the question was asked again, in teeth requiring nonsurgical root canal treatment, what would be the optimal canal enlargement which would allow satisfactory irrigation of the root canal system.

The ideal clinical question to be answered in this context can be framed in terms of a PICO question (population [P], intervention [I], comparison [C], and outcome [O]), as follows: In teeth requiring primary nonsurgical root canal treatment, what is the best MAF size for optimal chemomechanical preparation to be effective in terms of debridement and/or irrigation delivery in the apical third of the root canal system?

Materials and Methods

The protocol for this systematic review was registered in the PROSPERO database (registration number CRD42015023350). The protocol for this systematic review was developed following established guidelines [8]. Also, a well-defined review question was developed by using the Patient Population, Intervention, Comparison, and Outcome (PICO) framework.

The AMSTAR checklist [9], the Oxford Systematic Review Appraisal Sheet [10], Critical Appraisal Skills Program [11], and the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system for grading evidence [12] were used to ensure the accuracy of this data analysis in this systematic review.

Formulating the review question

The following PICO framework was developed for a systematic review of the existing literature regarding apical enlargement and irrigation of root canal treatments: In teeth requiring primary nonsurgical root canal treatment, what is the best MAF size for optimal chemomechanical preparation to be effective in terms of debridement and/or irrigation delivery in the apical third of the root canal system?

Inclusion and exclusion criteria

The inclusion criteria for this review were:

1. Articles from peer-reviewed journals published in English from January 1950 to June 2018 which reported clinical outcome in terms of healing, microbial reduction and/or irrigation delivery to the apical third of the root canal system.
2. Similar pulpal and/or periapical status were compared in the investigation
3. The MAF size was given or could be calculated from the data
4. The comparison between different apical sizes and irrigation
5. The sample size was given in the study
6. The effect of enlargement and irrigation was measured
7. The results were given or could be calculated from the raw data
8. Exclusion criteria consisted of studies that did not meet the above inclusion criteria, animal studies; studies that used predetermined file sizes; studies that only discussed bacterial count for outcome assessment.

Search methodology

Cochrane Oral Health Group's Trials Register (to June 2018), the Cochrane Central Register of Controlled Trials (CENTRAL) (The Cochrane Library 2018), MEDLINE *via* OVID (to June 2018), EMBASE *via* OVID (to June 2018), the meta Register of Controlled Trials (to June 2018), the electronic MEDLINE, Embase, and PubMed databases were searched. Additionally, the bibliography of all relevant articles, the grey literature and textbooks were manually searched. Based on inclusion and exclusion criteria, two reviewers independently selected the relevant articles. In the case of any disagreement over inclusion or exclusion of a particular article, the authors would come together to discuss the divergence and then agree on the final outcome. To answer the clinically relevant question, a four-step method of evidence-based analysis was applied: Step 1, a search for the clinical evidence regarding the apical size in electronic databases, and bibliographies of all relevant articles and review articles were both electronically and hand searched; Step 2, appraisal and selection of papers according to study validity and clinical importance; Step 3, collection and analysis of the published evidence; and Step 4, determining the clinical applicability of the results.

Using the PICO formatted question, methodological medical subject heading (MeSH) terms were generated to make the search strategy more sensitive in identification of studies. These terms included: *Apical Size, Apical Diameter, Root Preparation, Root Apex, Tooth Apex, Determining Apical Size, Master Apical Size, Apical Histology,* and *Apical Canal Enlargement and Irrigation.* Studies that met the above inclusion criteria underwent critical analysis.

Extracted data included the size of the population in the group; the number of dropouts or withdrawals, if reported; a description of the materials and methods with a detailed assessment of the size of the apical enlargement; and the outcome variables used to measure the effectiveness of the apical enlargement.

Quality assessment

Quality assessment of randomized clinical trials and observational studies was performed using the CONsolidated Standards Of Reporting Trials (CONSORT) statement criteria [13] and the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) statement criteria [14], respectively. The Newcastle-Ottawa risk of bias for each of the included studies was reported as: low, moderate, or high (good/fair/poor) [15]. The threshold for the Newcastle-Ottawa Scales was as follows: 6-9 (good) low risk of bias, 3-5 (fair) moderate risk of bias, or 0-2 (poor) high risk of bias.

Table 1. Excluded Articles [16]

Studies	Reason for exclusion
Xu K *et al.*	Laboratory study [17]
Arslan H *et al.*	Canals were instrumented to predetermined size 40 [18]
Vinhorte MC *et al.*	Different size(s) were not compared [19]
Gianluca P *et al.*	Laboratory study [20]
Akhlaghi *et al.*	Laboratory study [21]
Akhlaghi *et al.*	Laboratory study [22]
Rocas *et al.*	Discussed different tapers with similar apical size [23]
Chen J *et al.*	The enlargement of root canal diameter brought on increase of stress of root canal wall [24]
Merino *et al.*	Canals were all instrumented to size 30 [25]
Paiva SS *et al.*	Different size(s) were not compared [26]
Psimma *et al.*	Canal enlargement and irrigation extrusion [27]
Sarno MU *et al.*	Canals instrumented to 40/0.04 [28]
Marinho *et al.*	Laboratory study [29]
Krajczár K *et al.*	Laboratory study [30]
De Gregorio *et al.*	Laboratory study [31]
Elayouti *et al.*	Canal enlargement led to removal of dentin [32]
Borges MF *et al.*	Canal enlargement and apical extrusion [33]
Arvaniti IS & Khabbaz MG	Different tapers were measured with size 30 [34]
Mitchell RP *et al.*	Apical extrusion and canal enlargement [35]
Boutsioukis C *et al.*	Simulated root canals [36]
Brunson *et al.*	Laboratory study [37]
Shin *et al.*	Laboratory study [38]
Fornari *et al.*	Laboratory study [39]
Mitchell RP *et al.*	Size and extrusion of irrigants [35]
Siqueira JF Jr *et al.*	Canals were instrumented to predetermined size without comparison [40]
Huang *et al.*	Laboratory study [16]
Garcez *et al.*	Laboratory study [41]
Aydin C *et al.*	0.02 vs. 0.04 taper to predetermined size 30 [42]
Mickel AK *et al.*	It is unclear how the apical 1/3 of the canals were instrumented with 0.04 taper files to ascertain size prior to enlargement of the canals [43]
Khademi *et al.*	Laboratory study [44]
Jodway B & Hülsmann M.	Compared root preparation with different instruments [45]
Versluis A *et al.*	The enlargement of canal brought stress concentrations on roots with round configuration [46]
Bartha T *et al.*	Apical enlargement using hand instrumentation and light speed and apical preparation [47]
Lam PP *et al.*	Apical enlargement with light speed did not increase fracture susceptibility [48]
Lee SJ *et al.*	Used plastic simulated teeth, 20/0.04, 0.06, 0.08 [49]
Albrecht *et al.*	Laboratory study [50]
Usman *et al.*	Laboratory study [51]
Hülsmann M *et al.*	Both groups were prepared to apical size 45 [52]
Sabins RA *et al.*	All canals were prepared to size 30 and flared to 60 [53]
Hoskinson *et al.*	Different pulpal and periapical conditions were grouped together, and the exact number of teeth with the MAF sizes and taper were not provided [54]
Rollison *et al.*	Laboratory study [55]
Coldero *et al.*	Laboratory study [56]
Tan *et al.*	Laboratory study [57]
Peters *et al.*	Laboratory study [58]
Siqueira *et al.*	Laboratory study [40]
Sjogren *et al.*	Predetermined instrumentation to size 40 [59]
Parris *et al.*	It was unclear what were the sizes of MAF [60]
Yared & Dagher.	Canal enlargement and extrusion [61]
de Souza *et al.*	Animal study [62]
Bystrom, *et al.*	MAF was not discussed [63]
Benatti *et al.*	Animal study [64]
Chow TW	Artificial canals [65]
Bystrom *et al.*	MAF was not discussed [66]
Kerekes & Tronstad	Different pulpal and periapical status were grouped together [67]
Ram Z	Quantitative results were not provided [68]
Strindberg LZ	Quantitative results were not provided. It was unclear how instrumentation was performed [69]

Table 2. Summary of the main characteristics of included studies

Study	State/ Country	Funding source	Study design	Random allocation	Population characteristics	N (sample size)	Sampling method
Rodrigues [70]	Rio de Janeiro, Brazil	NA	Clinical	Yes	Necrotic with apical periodontitis	43	DNA extract for microbial sampling
Marinho *et al.* [29]	São Paulo, Brazil	NA	Clinical study	Yes	Necrotic pulp, single rooted canals with periapical pathosis	31	Polymerase chain reaction (16S recombinant DNA) and limulus amebocyte lysate assay
Saini *et al.* [71]	Haryana, India	NA	Clinical study	Yes	Necrotic pulp with periapical lesion	167, 5 interventions	12-month follow-up, PAI radiographic and clinical evaluations
Souza *et al.* [72]	São Paulo, Brazil	NA	Clinical study	NA	Necrotic pulp with periapical lesion	43	24-month follow-up, radiographic evaluation
McGurkin-Smith *et al.* [73]	Chapel Hill, NC, US	NA	Clinical study (1 exp. group and 3 interventions: S1, S2, SC)	NA	Apical periodontitis & necrotic pulps	31	Bacterial samples taken upon access (S1), after instrumentation and strict irrigation protocol (S2), & following >1 week of Ca(OH)2 (SC)
Nair *et al.* [2]	Zurich, SW	NA	Clinical study (2 exp. groups using necrotic pulps of M roots of mandibular 1st molars. MB canals instrumented using SS hand files to 0.25 & ML canals with NiTi to 0.40), Apical ⅓ of D root of 4 mandibular 1st molars with necrotic pulps & apical periodontitis used as positive controls, apical ⅓ of 3 clinically healthy mandibular 1st bicuspid roots served as negative controls	NA	Apical periodontitis & necrotic pulps	16	After treatment, apical portion of root of each tooth was surgically removed; specimens fixed, decalcified, subdivided in horizontal plane, embedded in plastic, processed, and evaluated by correlative light and transmission electron microscopy for presence of microorganisms
Card *et al.* [74]	Chapel Hill, NC, USA	Funded in part by grant from Steven Senia, LightSpeed Tech.	Clinical study (1 exp. group and 3 interventions), 5 teeth served as negative controls	NA	Apical periodontitis & necrotic pulps	40	Bacterial sampling performed upon access & after each of two consecutive instrumentations. First instrumentation used 0.04 taper ProFile rotary files & 1% NaOCl irrigation; second used LightSpeed files and 1% NaOCl irrigation for further enlargement of apical ⅓
Shuping *et al.* [75]	Chapel Hill, NC, USA	NA	Clinical study (1 exp. group and 5 interventions), 5 teeth served as negative controls.	NA	Apical periodontitis & necrotic pulps	42	Canals sampled before treatment, during & after instrumentation, & after treatment with Ca(OH)2 & samples incubated anaerobically for 7 days at 37°C. Bacteria from each

							sample quantified & log10 values used for calculations & comparisons
Dalton *et al.* [76]	Chapel Hill, NC, US	Supported in part by grant from American Association of Endodontists Foundation	Clinical study (2 exp. groups and 4 interventions). Five teeth served as negative controls	Yes	Apical periodontitis & necrotic pulps	48	Canals sampled before, during, & after instrumentation, samples incubated anaerobically for 7 days at 37°C, colony-forming unit numbers calculated, & log transformation performed to normalize counts
Yared and Dagher [77]	Beirut, Lebanon	NA	Clinical study (2 exp. groups and 3 interventions)	NA	Apical periodontitis & necrotic pulps	60	60 single-rooted teeth used. Half prepared to size 25 file and other half to size 40 file. Root canals dressed with Ca(OH)2 for 1 week Sample 1 collected from uninstrumented canal, & Sample 2 collected after cleaning and shaping & final irrigation with 1% NaOCl Canals dried and filled with aqueous Ca(OH)2, & after 1 week, post Ca(OH)2 dressing sample (Sample 3) taken from canals
Orstavik *et al.* [78]	Haslum, Norway	NA	Clinical Study (2 exp. groups and 3 interventions)	NA	Apical periodontitis and necrotic pulps	23	Samples subjected to standardized 2-appt regimen of extensive apical reaming in absence of antimicrobial agents & 1-week dressing with $Ca(OH)_2$ Bacteriological samples taken from root canal at the start, & apical samples at the end of each sitting: uninstrumented canals (sample I), files 20-25 used with saline as irrigant (sample R1), working length not discussed, canals increased in size until dry white dentin visible with size 35-80. Four to 5 mm of tip of last 2 sizes of reamers cut off (sample D1 and D2); canals were with $Ca(OH)_2$ & sealed for 1 week. At 2nd apt Sample R2 taken; canals enlarged 2 ISO sizes following largest reamer used at first sitting; tips of these 2 reamers cut off for bacteriological testing (D3 and D4)
Salzgeber & Brilliant [79]	Columbus, OH	NA	Clinical study (2 groups and 3 interventions)		Vital pulps and necrotic pulps	19 in each group	A radiopaque material was used as an irrigant to delineate apical penetration *in vivo*

Table 3. Summary of the results of the included studies per Newcastle-Ottawa quality assessment

Study	Interventions/Selection	Primary outcomes/ Assessment and follow-up	Results of intragroup comparison/ Comparability	Results of intergroup comparison	Score	Risk of bias
Rodrigues [70]	2 groups for retreatment (*n*=22, 2.5% NaOCl; 21=saline); samples were taken before, during and after instrumentation (3 stars)	Levels of total bacteria and streptococci (2 stars)	Irrigation was not as important as chemomechanical preparation (2 stars)	No significant difference. Canals were instrumented to 35 (4 canals) and 50 (39 canals)	7/9	Low
Marinho *et al.* [29]	3 groups with root canal preparation (*n*=10 per group): GI: 2.5% NaOCl , GII: 2% chlorhexidine gel, and GIII (control group): saline solution; samples were taken by using paper points before (s1) and after root canal instrumentation (s2), subsequently to 17% EDTA (s3), after 30 days of intracanal medication (Ca[OH]2+saline solution) (s4), and before root canal obturation (s5) (3 stars)	Reduction of proinflammatory cells and endotoxin (2 stars)	Irrigation was not as important as chemomechanical preparation (2 stars)	After instrumenting to size 40/0.04, the difference in the endotoxin reduction was not significant	7/9	Low
Saini *et al.* [71]	5, 2-5 sizes larger than the First Binding Apical File (FBAF) (3 stars)	12-month follow-up PAI radiographic and clinical evaluations (3 stars)	The groups were comparable (2 stars)	The proportion of successfully healed cases increased with an increase in the apical preparation size with 48%, 71.43%, 80%, 84.61%, and 92% (2-6 sizes larger) FBAF respectively	8/9	Low
Souza *et al.* [72]	Two groups, 2 sizes larger than the first binding file (*n*=40) and 3 sizes larger than the first binding file (*n*=40) (3 stars)	Radiographic only (1 star)	The groups were comparable (1 star)	22 out of 24 (91.67%) Group I and 17 of 19 patients (89.47%) in Group II healed; no significant differences (*P*>.05)	5/9	Moderate
McGurkin-Smith *et al.* [73]	Canal instrumented to a SS 15 to 20 file & placed within 1 mm of estimated working length. Apical flutes cut off & placed into liquid dental transport media (LDT). Canals instrumented with predetermined final Profile GT file size and 5.25% NaOCl. Hand-file two sizes larger than last GT file placed and irrigated with EDTA and 5.25% NaOCl (S2). $Ca(OH)_2$ placed for 1 week, canal then irrigated with saline and final sample (SC) taken. Canals further instrumented to larger apical diameter and obturated, but no further samples taken (3 stars)	GT protocol significantly reduced bacteria in canals but failed to render canal bacteria-free in more than half of cases. $Ca(OH)_2$ significantly further reduced bacteria. MAF size not identified (2 stars)	At S1, 93.55% harbored bacteria; at S2, 52.72% of the cases sampled bacteria. At SC, 14% of cases cultured bacteria. McNemar test showed significant reduction (*P*<0.0009) in Bacteria between S1 and S2; this was also true between S2 and SC (*P*<0.0019) (1 star)	Larger apical size removed more bacteria than smaller apical size	6/9	Low
Nair *et al.* [2]	MB roots of mandibular 1st molars instrumented to size 25 and ML roots	Table III details no differences in microbial reduction between the	Comparable groups (2 stars)	Size 25 and 40 rendered the same results	6/9	Low

	instrumented to size 40. Irrigation with 5.25% NaOCl and 17% EDTA. After obturation, apical portion of the root of each tooth surgically removed. Specimens fixed, decalcified, subdivided in horizontal plane, embedded in plastic, processed, and evaluated by correlative light and transmission electron microscopy (3 stars).	two canals. 14 of the 16 root canals revealed residual intracanal infection after instrumentation, antimicrobial irrigation, & obturation. Microbes located in inaccessible recesses & diverticula of main canals, intercanal isthmus, & accessory canals, mostly biofilms (1 star)				
Card *et al.* [74]	Sample 1: size 10 to 20 to within 1 mm of estimated WL. Working length established within 1 mm of apex; sample 2: canals instrumented to predetermined size. Mandibular M canals instrumented to 0.465 mm and single-rooted teeth instrumented to 0.599 mm. Dilacerated molars were instrumented to 0.36. S3: Final instrumentation performed with LightSpeed. Molar sizes ranged from 0.565-0.65 mm and bicuspid/cuspid canals ranged from 0.8-1.0. Irrigation with 1% NaOCl (3 stars)	100% of cuspid/bicuspid canals and 81.5% of molar canals rendered bacteria-free after first instrumentation (2 stars)	Significant difference between S1 and S3, and S1 and S2. No statistically significant difference between S2 and S3. Authors concluded that a high percentage of the infected root canals from mandibular cuspids, bicuspids and molar mesial roots will no longer harbor cultivatable bacteria when instrumented to sizes above 60, their statistical analysis (the difference between S2 and S3) did not show that (P=0.0617) (1 star)	Larger apical size rendered more bacterial-free apical portion	6/9	Low
Shuping *et al.* [75]	Sample 1: initial, Pre-instrumentation sample. Sample 2: Sample after initial instrumentation to working length with size 0.216-0.360 mm depending on canal. Sample 3: sample during instrumentation and irrigation with 1.25% NaOCl with size larger than at S2 ranging from 0.279 to 0.465 mm. Sample 4: sample after final instrumentation. Canals instrumented to predetermined size one size larger than size instrumented at S3 (0.360-0.600 mm). S5: after one week of medication with $Ca(OH)_2$ (3 stars)	NaOCl irrigation with rotary instrumentation is important step in reduction of bacteria during endodontic treatment specifically after S3 (0.279-0.465), (2 stars)	Statistically significant decrease in bacteria from S1 to S4. Statistically significant decrease in bacteria between S4 & S5 (1 star)	Compared the results with previous study (Dalton *et al.* 1998): Only after S3 were bacteria reduced in the NaOCl study compared with saline study. Addition of irrigating with NaOCl resulted in better antibacterial effect when instrumentation exceeded size 30 to 35	6/9	Low
Dalton *et al.* [76]	Sample 1: Size 15 to 20 K-file used to determine working length & minimally disrupt canal contents. S2: Sample after	Similar and uniform reduction with progressive filing, regardless of technique (P<0.0001)	All mean bacterial samples (S2, S3 and S4) significantly lower than S1 means, regardless of file type. No statistically	Comparable groups	6/9	Low

	initial instrumentation to working length with size 0.216 to 0.360 mm depending on canal. Sample 3: intermediate sample during instrumentation & irrigation with saline with size larger than at S2 ranging from 0.279 to 0.465 mm. Sample 4: sample after final instrumentation. Canals instrumented to one size larger than size instrumented at S3, 0.360 to 0.600 mm (3 stars)	No detectable difference in CFU after NiTi rotary or SS hand instrumentation (P=0.42). Neither technique could predictably render canals free of bacteria (2 stars)	significant difference detected between S2 and S3 means (P=0.07). Statistically significant reduction detected between S2 and S4 means (P=0.0006) & between S3 and S4 means (P=0.01) (1 star)			
Yared & Dagher [77]	Sample 1: uninstrumented canal. Sample 2: Irrigation with 1% NaOCl. Group A instrumented to size 25 and Group B instrumented to size 40. Sample 3: After1 week of $Ca(OH)_2$ (3 stars)	No statistically significant difference between size 25 and 40 file groups after instrumentation & after 1-week $Ca(OH)_2$ (2 stars)	No statistically significant difference between size 25 and 40 groups regarding Sample 2 and Sample 3 (1 stars)	Comparable groups	6/9	Low
Orstavik *et al.* [78]	Sample I: uninstrumented root canal. Sample R1: reamers up to size 20 to 25 used with saline as irrigation. D1 and D2: Further instrumentation of apical part with reamers of increasing sizes performed until white dentin visible. Size of final reamer ranged from 35 to 80. Four to 5 mm of the tips of last two sizes of reamers cut off for Samples D1 and D2. R2: After a week of $Ca(OH)_2$, medicament removed by alternate rinsing with saline & 0.5% citric acid. D3 and D4: Canals re-instrumented with reamers of next two sizes following largest reamer used at first sitting (3 stars)	Instrumentation to larger size files more efficiently reduced bacterial flora (Table 1 in Orstavik *et al.* 1991). All root canals but one showed growth at start of treatment. Dentin samples positive in 14 of 23 teeth at end of first appt. Eight of 23 canals had detectable growth at start of 2nd appointment, but in sufficient numbers for quantification in only one root canal. Subsequent dentin samples negative at 2nd appointment (2 stars)	Instrumentation to larger size files more efficiently reduced bacterial flora (Table 1 in Orstavik *et al.* 1991). Less quantifiable growth of bacteria from D4 to D3, from D3 to R2, from R2 to D2, from D2 to D1, from D1 to R,1 & from R1 to I within an individual root canal system (1 star)	Extensive apical reaming and 1-wk of $Ca(OH)_2$ reduced bacterial growth. Canals initially instrumented to reamer sizes 35 or 40 tended to harbor bacteria more frequently and in greater mean numbers than canals which had been instrumented to greater than size 40 at the first appointment (Figure 2 published in Orstavik *et al.* 1991). The difference at the second appointment in bacterial reduction was not significant. (P=0.06). Two roots with evidence of infection in dentin at 2nd appt both instrumented to size 40	6/9	Low
Salzgeber & Brilliant [79]	19 canals with vital pulps and 19 with necrotic pulps were instrumented to size: A) access opening, B) 30, C) 35, D) 45, E) above 45; irrigated with radiopaque irrigant and exposed to radiograph (A-E) and irrigation with Hypaque 50% (2 stars)	The solution reached the apex of necrotic canals size 35 and reached the apex of vital pulps size 45 and above (1 star)	Enlargement increased solution penetration. From size (30 to size 35, 45, above), vital canals demonstrated (47, 79, 94.7, 100%) of solution in the apical 1/3, respectively. In necrotic canals: from size (30 to 35) 58% and 100% penetration in apical 1/3 was reported (2 stars)	At size 30, solution reached all the necrotic canals and 79% of vital canals.	5/9	Moderate

Table 4. Profile of outcome data by potential prognostic factors by the included studies

Author	Sample Size (N)	Methodology	Canal Size Preferred	Patency	Irrigation	Taper of the Canal	Delivery Device	Tooth Type	JBI Score*	NOS Score+
Rodrigues *et al.* [70]	43	Microbial sampling	35	NA	2.5% NaOCl and saline	0.04	NaviTip, 3 mm short of WL	Postoperative periodontitis	6	7
Marinho *et al.* **[29]**	31	Microbial sampling	40	NA	3 groups (NaOCl, CHX, saline)	0.04	27-G needle	Single rooted necrotic with periapical lesion	6	7
Saini *et al.* [71]	129	PAI and Clinical	>30	Size 10 0.5-1.0 mm beyond apex	5 mL of 17% EDTA and 3% NaOCl (5 mL), $Ca(OH)_2$ with CHX	0.02	27-G needle 1-2 mm from apex	Necrotic pulp and periapical lesion	6	8
Souza *et al.* [72]	80	Radiographic	NA	NA	2 mL 2.5% NaOCl, 2 mL 17% EDTA, $Ca(OH)_2$	0.02	5-mL Plastic Syringe 10pk and capillary tip, 5-mm from apex	Necrotic pulp and periapical lesion	5	5
McGurkin-Smith *et al.* [73]	31	Microbial sampling	45-90	NA	5.25% NaOCl, EDTA and Ca(OH)2	0.08-0.12	28-Gauge Double D needle	Necrotic pulp and periapical lesion	5	6
Nair *et al.* [2]	16	Histological examination	25	NA	5.25% NaOCl and 17% EDTA	0.02	NA	Necrotic pulp and periapical lesions, Mandibular mesial root	5	6
Card *et al.* [74]	40	Microbial sampling	36-59	NA	1% NaOCl, $Ca(OH)_2$	0.04	28-Gauge Double D needle	Necrotic pulp and periapical lesion[78]	5	6
Shuping *et al.* [75]	42	Microbial sampling	35-	NA	1.25% NaOCl	0.04	28-Gauge Double D needle	Necrotic pulp and periapical lesion	5	6
Dalton *et al.* [76]	48	Microbial sampling	35 to 60	NA	Saline, $Ca(OH)_2$	0.02, 0.04	30-Gauge Maxi Probe	Necrotic pulp and periapical lesion	6	6
Yared & Dagher [77]	60	Microbial sampling	25	NA	1% NaOCl, $Ca(OH)_2$	0.02	NA	Necrotic pulp and periapical lesion	5	6
Orstavik *et al.* [78]	23	Microbial sampling	35-	NA	Saline, $Ca(OH)_2$	0.02	30-gauge needle	Necrotic pulp and periapical lesion	5	6
Salzgeber & Brilliant [79]	38	Radiopaque irrigant	35-	NA	Hypaque	0.02	23-gauge needle	Two groups: (19) necrotic pulps, (19) vital pulps	5	5

**JBI (Joanna Briggs Institute) - http://joannabriggs.org/research/critical-appraisal-tools.html; + NOS (Newcastle Ottawa Scale) - https://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0078156/*

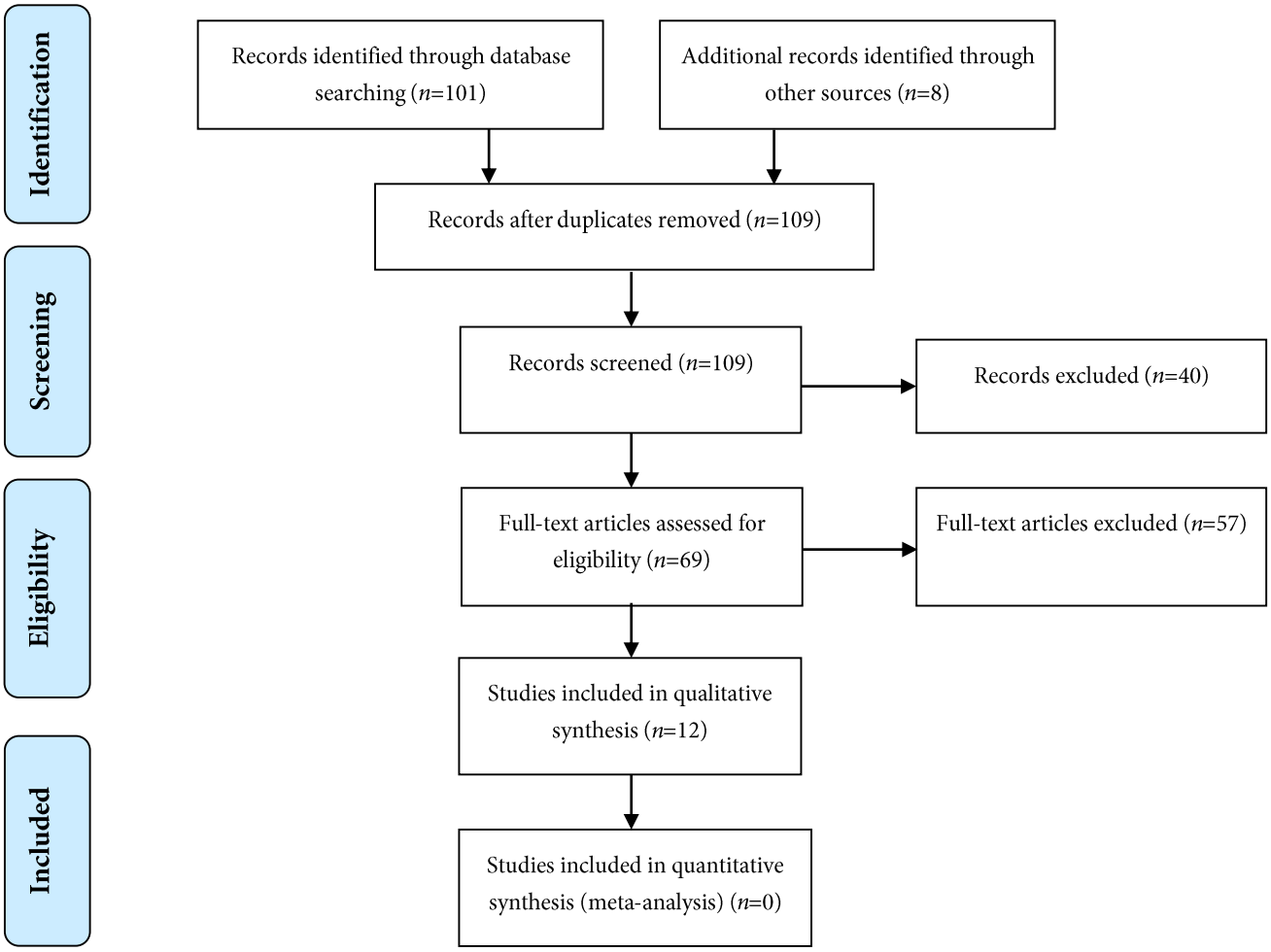

Figure 1. PRISMA flow diagram Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009)22

Results

Due to variety of methodologies and different techniques used to measure outcome for apical enlargement, it was not possible to standardize the research data and to apply meta-analysis. Figure 1 details the flow of the research strategy.

A total of 57 articles were excluded for the reasons given in Table 1. These articles are listed in Table 1 [16-26, 29-58, 60-66, 68, 69, 80-86].

The list of included articles after electronic and hand searching included 12 clinical studies that reported on irrigation delivery with apical enlargement and are reported in Table 2 [29, 70-79, 87].

Though some laboratory studies reported adverse events associated with canal enlargement such as file separation [57, 58], canal transportation [57] and perforation [57], no clinical studies reported any adverse events.

Table 3 details the primary outcome in each study as the effect of apical enlargement and irrigation in the root canal system as measured using microbiological sampling and/or irrigation delivery to the apical third of the canal(s). Table 4 details the minimal size preparation for irrigation delivery. The overall quality of evidence was moderate (fair). Ten clinical studies recommended that an apical size above 30 would allow irrigants to reach the apical third of the canal [70-72, 74-76, 78, 79, 88, 89], and two clinical studies recommended size 25 [77, 87] .

Discussion

The results of this current systematic review confirmed that more evidence-based research in this area is needed. Though variable morphologies demand different approaches to cleaning and shaping the root canal system, the question in this systematic review was what would be the minimum apical size for optimal irrigation of the root canal system. The overall level of evidence on this topic was moderate (fair). From this systematic review, it may be concluded that the majority of the studies collected and referred to recommend sizes higher than #30 as the minimal size in order to adequately prepare the apical region of the root canal systems.

A recent study by Marinho *et al.* [89] did not compare size 30 to size 40, but reported that at size 40 significant reduction in endotoxins was observed.

However, size is only one parameter in nonsurgical root canal treatment but, as reported in this current systematic review, it is an important factor. Other factors to consider would be the antimicrobial solution [75], delivery system [90], canal configuration (isthmus, curvature, *etc.*) [74], pulpal status [79], intracanal medicament [78], patency [91], taper [50], and differences in methodological analysis. For these reasons, the studies were not comparable to perform a meta-analysis.

Various irrigating devices, techniques, irrigating needle sizes and types were used in the included studies. Those identified include a 28-Gauge Double D needle (Beutlich Pharmaceuticals LP, Waukegan, IL, USA); a 30-Gauge Maxi Probe needle (Dentsply Rinn, Elgin, IL, USA); 23-, 24-, 27-, 28-, and 30-gauge needles; an EndoVac Master Delivery Tip (SybronEndo, Orange, CA, USA); a Navitip needle (Ultradent Products, South Jordan, UT, USA); and negative pressure through use of a macro-cannula. Moreover, some of the included studies did not identify what irrigation technique/equipment has been used in their investigation [29, 57, 77, 78, 87].

A 26-gauge needle corresponds to outer diameter size of 0.40 mm, a 27-gauge is 0.36 mm [92], and a 30-gauge needle corresponds to 0.31 mm [93].

Kahn *et al.* [90] reported that, in root canal systems instrumented to size 30 and size 35, the 27-gauge notch-tip needle was found to be highly effective but the needle must be placed close to the working length. In that study, a Maxi Probe needle was highly effective in delivering irrigation at sizes 20-35 without the stipulation of having to place the end of the needle close to the working length.

The EndoActivator (Advanced Endodontics, Santa Barbara, CA, USA) is a new type of irrigation device that is based on sonic vibration (up to 10000 cpm) of a plastic tip in the root canal [94]. EndoVac (SybronEndo, Orange, CA, USA) is an apical negative pressure irrigation system which was developed as a means to irrigate and remove debris at the apex without forcing irrigation solution into the periapical area [95]. The claim that EndoVac [96] or EndoActivator [97] are superior to traditional irrigation with 27-gauge side-vented needle have not been supported in randomized clinical trials [96, 97].

We suggest that the future studies on this topic should be consistent in their methodologies and reports in the following items: the file size(s); the type(s) of teeth used, and, if there are various types of teeth, how the MAF was determined and adapted to the morphology of that particular root; the type of irrigation solution used as well as the concentration; the size and type(s) of irrigation needle(s) used and how far the needle penetrated the root canal system, and the volume of irrigation solution used in the groups.

Conclusion

The results of this current systematic review confirmed that more evidence-based research in this area is needed. No single apical size accomplished all the tasks required for root canal system disinfection. Detailed understanding of the characteristic of action of various solutions, canal morphology, and irrigation delivery instruments and methodologies are important for optimal success. From this systematic review it may be concluded that a larger MAF preparation above size 30 aids chemomechanical action.

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