CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Preparation requirements to effective irrigation of the canal system

Rita Viviana Ferreira da Silva

Dissertação conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)

Gandra, 24 de julho de 2022

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Rita Viviana Ferreira da Silva

Dissertação conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)

Preparation prerequisites to ensure effective irrigation of the canal system

Trabalho realizado sob a Orientação do Dr. Valter Fernandes e Co-Orientação do Dr.Luis Caetano

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Declaração de integridade

Eu, **Rita Viviana Ferreira da Silva**, declaro ter atuado com absoluta integridade na elaboração deste trabalho. Confirmo que em todo o trabalho conducente à sua elaboração não recorri a qualquer forma de falsificação de resultados ou à prática de plágio (ato pelo qual um indivíduo, mesmo por omissão, assume a autoria do trabalho intelectual pertencente a outrem, na sua totalidade ou em partes dele). Mais declaro que todas as frases que retirei de trabalhos anteriores pertencentes a outros autores foram referenciadas ou redigidas com novas palavras, tendo neste caso colocado a citação da fonte bibliográfica.

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Declaração do Orientador

Eu, Válter Raul da Cunha Fernandes, com a categoria profissional de Monitor Clínico do Instituto Universitário de Ciências da Saúde, tendo assumido o papel de Orientador da dissertação intitulada "Pré-requisitos da preparação para garantir uma irrigação eficaz do sistema de canais", da Aluna do Mestrado Integrado em Medicina Dentária, "**Rita Viviana Ferreira da Silva"**, declaro que sou de parecer favorável para que a Dissertação possa ser depositada para análise do Arguente nomeado para o efeito para a Admissão a provas públicas conducentes à obtenção do Grau de Mestre.

AGRADECIMENTOS

Começo por agradecer aos meus pais, Rui e Manuela, que incansavelmente estiverem presentes neste meu percurso académico e me proporcionam tudo isto. A eles devo-lhes tudo, são os melhores.

Aos meus irmãos Ruben e Rui Jorge e cunhada Inês que sempre torceram para o meu sucesso.

À minha binómia Joana que sempre me encorajou, nunca me deixou desistir e me acompanhou em todas as intermináveis épocas de exames.

Por último, mas não menos importante a todos os colegas que acompanharam esta caminhada e fizeram dela mais bonita.

RESUMO

Na endodontia um dos passos mais importantes é a limpeza e a desinfeção dos sistemas de canais para prevenir e tratar a periodontite apical. Para que tal seja possível é necessário realizar adequadamente algumas etapas, nomeadamente, cavidade de acesso, instrumentação e irrigação. O objetivo principal deste estudo foi realizar uma revisão integrativa sobre os requisitos necessários para assegurar uma correta irrigação dos canais radiculares.

Foi realizada pesquisa eletrónica na base de dados PubMed, utilizando combinações de palavras-chave e abrangendo artigos entre 2012 e 2022 de idioma Inglês.

Dos 22 artigos selecionados, 5 abordam os tipos de cavidades de acesso e a sua influência na irrigação, 5 estudos analisaram as diferentes técnicas de instrumentação 5 estudam os efeitos do tamanho e conicidade da preparação, 5 analisam os diferentes tipos de irrigantes e 2 as diferentes técnicas de irrigação.

Com esta revisão sistemática integrativa pudemos concluir que as cavidades endodônticas tradicionais são mais vantajosas do que as cavidades de acesso conservadoras que todas as técnicas de instrumentação são eficazes desde que sejam bem executadas, que a conicidade do canal tem mais influencia na preparação do que o tamanho, que nenhum irrigante consegue satisfazer todos os requisitos de forma independente e portanto, a sua combinação obtém melhores resultados e por último concluímos que a combinação do irrigante com ultrassom melhora o efeito antibacteriano e permite obter canais mais limpos.

PALAVRAS-CHAVE- Endodontia, irrigação, canal radicular, redução bacteriana, instrumentação, tamanho e conicidade

ABSTRACT

In endodontics one of the most important steps is cleaning and disinfection of the canal systems to prevent and treat apical periodontitis. For this to be possible it is necessary to properly perform some steps namely, access cavity, instrumentation and irrigation. The main aim of this study was to conduct an integrative review on the necessary requisites to ensure proper irrigation of root canals.

An electronic search was performed in the PubMed database, using combinations of the keywords and covering articles between 2012 and 2022 in English.

Of the 22 selected studies, 5 investigated the types of access cavities and their influence on irrigation, 5 studies analyzed the different instrumentation techniques 5 studied the effects of preparation size & taper, 5 analyze the different types of irrigants and 2 the different irrigation techniques.

With this integrative systematic review we could conclude that TEC is more advantageous than CEC, that all instrumentation techniques are effective as long as they are well performed, that the taper of the canal has more influence on the preparation than the size, that no single irrigant can satisfy all requisites independently and therefore their combination obtains better results, and finally we concluded that the combination of irrigant with ultrasound improves the antibacterial effect and allows to obtain cleaner canals.

Key Words- Endodontics, irrigation, root canal, bacterial reduction, instrumentation, size and taper

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Table of contents

1 Introduction 1

2 Objectives and hypotheses 3

3 3. Method 4

3.1 Information sources and search strategy 4

3.2 Study selection and data collection process 4

4 Results 6

5 Discussion 20

5.1. Access cavity 21

5.2. Instrumentation technique 22

5.3. Size and Taper 23

5.4 Irrigants 24

5.4.1 Irrigants types and actions 24

5.4.2 Irrigation techniques 27

6 Limits 31

7 Conclusion 32

Index of figures and graphs

Figure 1- Prisma flow of the search strategy……5
Figure 2 - Distribution by types of studies……6
Figure 3- Representative access cavity image……..21
Figure 4- Representative instrumentation image……..22
Figure 5- Representative size & taper image……23
Figure 6- Representative size & taper image……30

List of acronyms and abbreviations

PTD- photodynamic therapy

CEC- conservative endodontic cavity

UEC- ultraconservative endodontic cavity

TAC- truss-access-cavity

UCW- untouched canal wall

OM- operative microscope

AHTD- accumulation of hard-tissue debris

RPT- remaining pulp tissues

SNI: syringe and needle irrigation

UAI: ultrasonic activated irrigation

MAF- master apical file

DB- disto-buccal

NaOCl- sodium hypochlorite

EDTA- ethylenediaminetetraacetic acid

CHX- chlorhexidine gluconate

PCA- parachloroaniline

CA- citric acid

MA- maleic acid

CTR- cetrimide

PPI- positive pressure irrigation

NPI- negative pressure irrigation

RC- root canal

RCS- root canal system

PSI- passive sonic irrigation

PUI- passive ultrasonic irrigation

1 Introduction

The objective of root canal treatment is to prevent or treat apical periodontitis and the success depends on the eradication of microbes from the root-canal system and prevention of reinfection. (1)

The elimination or reduction of bacterial contamination is the main goal of endodontic treatment. This goal is reached with appropriate chemo mechanical preparation, and by preserving as much tooth structure and the original canal geometry as possible (1)

The purpose is to reduce bacterial contamination as much as possible with minimum mechanical preparation and proper chemical disinfection. Preparations with larger instruments results in more volume of irrigation reaching the apical region. On the other hand, larger instruments are less flexible and do not stay centered in the canal. That could be an issue on curved canals, which results in unnecessary dentin removal on one side of the canal, leaving untouched dentin on the other side of the canal walls. (2,3)

Disinfection of the complex root canal system at the apical portion of the root canal remains the most critical therapeutic measure to treat apical periodontitis. The difficulty on the removal of bacterial debris from the apical portion has been attributed to the inadequate flushing of irrigants. Variations in the shape and the diameters of the apical root canal space, affects the dynamics of irrigant flow and subsequently the disinfection and dissolution effects of irrigation (4)

Irrigation is a key part of successful root canal treatment as it fulfils several important mechanical, chemical and (micro) biological function. Irrigation has several desired functions as: mechanical washing action (helps remove debris); reduce instruments friction during preparation (lubricant), facilitate dentin removal (lubricant), dissolve inorganic tissue (dentin), penetrate to canal periphery, dissolve organic matter (dentin collagen, pulp tissue, biofilm), kill bacteria and yeasts (also in biofilm),do not irritate or damage vital periapical tissue, no caustic or cytotoxic effects, do not weaken tooth structure. Irrigation is also the only way to impact those areas of the root canal wall not touched by mechanical instrumentation. (5)

Nowadays, sodium hypochlorite (NaOCl) is the most used irrigant in endodontics, but there are also other solutions, such as ethylenediaminetetraacetic acid (EDTA), chlorhexidine (CHX), citric acid, maleic acid and Q MIX. There are also many options to increase the efficacy of the irrigants as sonic and ultrasonic irrigation, warming and agitation.

A variety of instruments and techniques in combination with disinfecting irrigation solutions and intracanal medications have been proposed for the chemo-mechanical preparation of infected root canals. The cleaning and shaping efficiency of root canal instruments, aim to achieve a well-tapered root canal form, sufficient for the required irrigant flow in the whole canal and allow an optimal obturation. (6,7)

2 Objectives and hypotheses

The main aim of this study was to perform an integrative review on the preparation requeriments to ensure effective irrigation of the root canal system (*RCS*).

The null hypothesis was preparation of RCS does not affect their irrigation.

3 3. Method

3.1 Information sources and search strategy

A literature search was performed on PubMed (via National Library of Medicine) considering such database includes the major articles in the field of dentistry and biomaterials The following combination of search terms were applied in this study: "*irrigation*" AND "*apical diameter*" AND "*size and taper*" AND "*endodontics*" AND "*root canal preparation*" AND *"endodontic cavity"*. The inclusion criteria involved articles published in the English language, from 2012 to 2022. The eligibility inclusion criteria used for articles searched also involved: in vitro studies; meta-analyses; randomized controlled trials and prospective cohort. The exclusion criteria were the following: papers without abstract, systematic reviews, bibliography reviews, thesis and dissertations; articles whose title/or abstract do not fit the theme; all papers in a foreign language (not in the English language) and where the full text was not available. Also, a hand-search was performed on the references list of all primary sources and eligible studies of the systematic review for additional relevant publications. Studies based on publication date were not restricted during the search process.

3.2 Study selection and data collection process

The articles retrieved by the search process were evaluated in three steps. Studies were primarily scanned for relevance by title, and the abstracts of those were not excluded at this stage were assessed. The author (RS) analyzed the titles and abstracts of the retrieved, potentially relevant articles meeting the inclusion criteria. The total of articles was compiled for each combination of key terms and therefore the duplicates were removed using Mendeley citation manager. The second step comprised the evaluation of the abstracts and non-excluded articles, according to the eligibility criteria on the abstract review. A preliminary evaluation of the abstracts was carried out to establish whether the articles met the purpose of the study. Selected articles were individually read and analyzed concerning the purpose of this study. At last, the eligible articles received a study nomenclature label, combining first author names and year of publication. The following variables were collected for this review: authors' names, publication year,

aims, type of study, study design, post type, composite core material, type of analysis and main outcomes.

4 Results

The literature search identified a total of 363 articles in PubMed, as shown in Fig.1. Duplicates were removed, and titles and abstracts of 254 articles were independently evaluated. A total of 223 articles were excluded because they did not meet the inclusion criteria. The remaining 31 potentially relevant studies were then evaluated. Of those studies, 9 were excluded because they did not provide comprehensive data considering the purpose of the present study. Thus, 22 studies were included in this review.

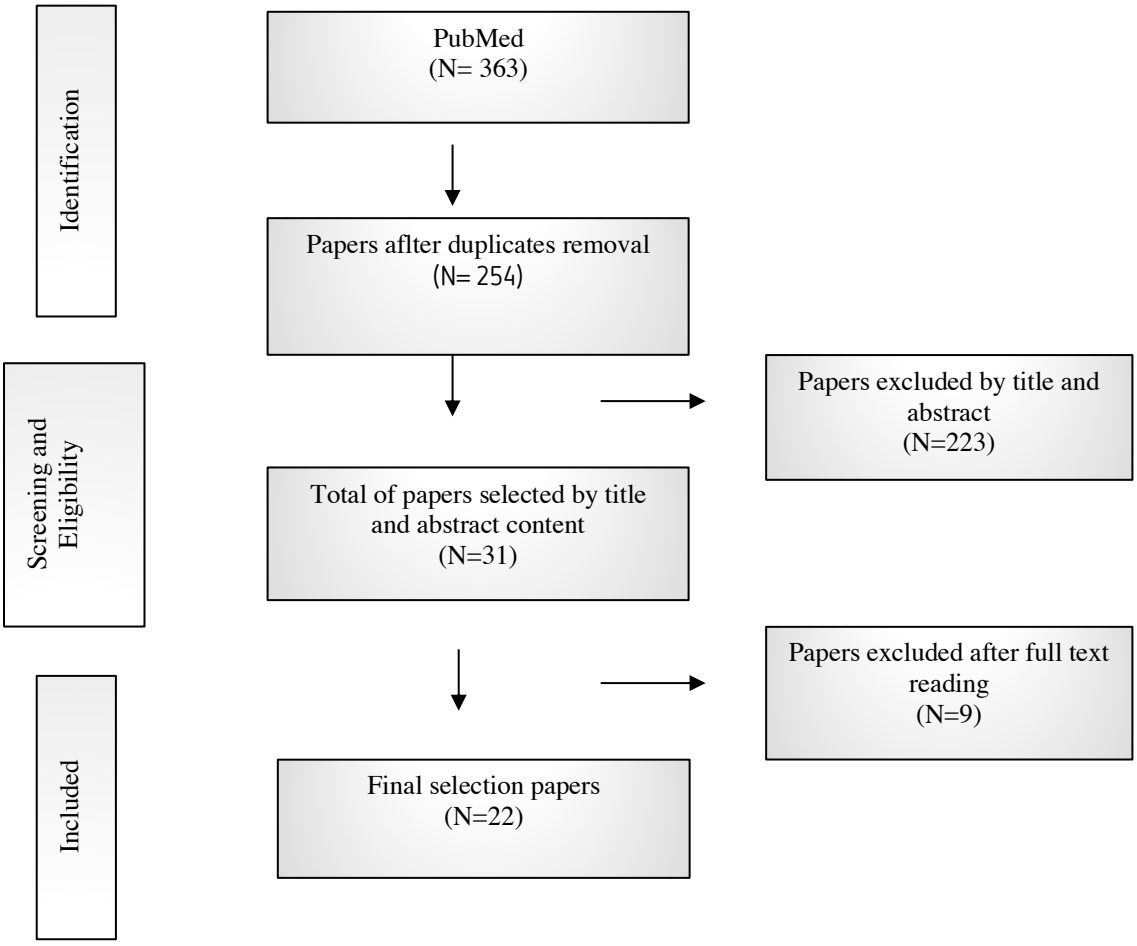

Figure 1- Prisma flow of the search strategy

Of the 22 selected articles, there are 9 experimental studies, 5 *in vitro* studies, 3 *ex vivo* studies, 2 comparative studies, 1 clinical study,1 *in vivo* study and 1 research study.

Of the 22 studies, 5 studied the types of access cavities and which one was the most advantageous, 5 studied the different types of instrumentation techniques 5 studied the differences of size & taper on the RCS, 5 the types of irrigants and 2 the irrigation techniques.

The most relevant results were found in each study were subsequently extracted and organized in a table in order to provide a more dynamic, interactive and structed analysis.

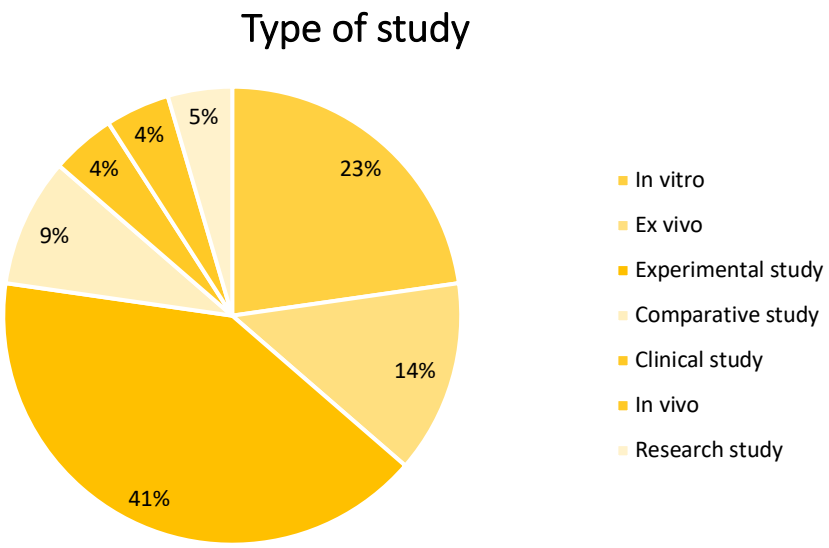

Figure 2 – Distribution by types of studies

The major findings are drawn as follow:

- Conservative endodontic access does not offer advantages when compared with traditional endodontic cavity since compromises disinfection and the location of the canals, produces more accumulation of debris and leaves more untouched areas. (8–10)

- The different instrumentation techniques can reduce bacterial counts to a similar level. None of the techniques can reduce 100% of bacterial counts without proper irrigation. (11–13)Canals with high prevalence of isthmuses and protrusions, using multifile rotary system may be prefers over reciprocating files.(14)

- Increase the size of RC produces cleaner canals, decreasing the number of bacteria (1) when the irrigation is performed with a syringe and needle but when the irrigation is performed ultrasonically small and large preparations has the same results. (15) Increase the taper had better results regarding the reduction of bacteria (16)

- NaOCl is the most used irrigant. EDTA is the most used irrigant for reducing smear layer. (17) Maleic acid is more efficient than EDTA to reduce smear layer. (18) Irrigants have better results when combined.(19)

- Sonic irrigation can achieve better results when compared to ultrasonic irrigation. The combination of instrumentation with ultrasound allows to get cleaner canals. (20,21)

Author (year)	Study design/Methods	Population	Objective	Results	Conclusion
Alimadadi (2021) (1)	*In vitro* study	A total of 126 extracted human mandibular molars	Assess the effect of apical size and taper on the efficacy of root canal disinfection with LED photodynamic therapy (PDT) as an adjunct to irrigation with sodium hypochlorite.	% Reduction of colony counts compared to control group: Group 25/4% NaOCl 98,48% NaOCl + PDT 96,46% Group 25/6% NaOCl 98,25% NaOCl + PDT 99,56% Group 30/6% NaOCl 99,44% NaOCl + PDT 99,98%	Increasing the apical size and conduction of PDT as an adjunct to sodium hypochlorite irrigation significantly decreased the number of residual bacteria in the root canal system.
Vieira (2020) (8)	*Ex vivo* study	Mandibular incisors with oval-shaped canals.	Compare root canal disinfection and shaping in teeth with contracted or conventional endodontic cavities	% Bacterial counts CEC > TEC Unprepared areas CEC= TEC	The findings showed that disinfection was significantly compromised after root canal preparation of teeth with contracted endodontic cavities
Barbosa (2020) (9)	Experimental study	Thirty extracted intact mandibular molars	Assess the impact of conservative endodontic access cavities (CEC) and truss-access cavities (TAC) during root canal treatment	S1- first sample collection S2- second collection, instrumented with Reciproc Blue R25 S3- third collection, instrumented with Reciproc Blue R40 S4- fourth collection, after final irrigation Microbial counting S1 to S2 – significant reduction in 3 groups (TEC, CEC, TAC) S2 to S3- significant reduction in 3 groups S3 to S4- no differences found Inter-group microbial counting S1: TEC=CEC=TAC S2: TAC > CEC TAC > TEC	CEC did not offer any advantage in comparison to TEC in any of the parameters considered. Furthermore, CEC were associated with larger percentages of unprepared canal surface area and larger volume of remaining root filling material within the pulp chamber.

				TEC = CEC S3: CEC > TAC CEC > TEC TAC = TEC S4: TEC=CEC=TAC % Microbial reduction CEC > TEC % Unprepared areas CEC > TEC CEC = TAC TEC = TAC	
Silva (2020) (10)	Experimental study	Twenty extracted intact 2-rooted maxillary premolars	Evaluate the influence of ultraconservative endodontic cavities (UEC)	% Untouched canal area UEC= TEC % AHTD after instrumentation UEC >TEC Void found in root fillings UEC= TEC % Root filling remnants in the pulp chamber after instrumentation UEC > TEC Time required to access and prepare root canals UEC= 47 ± 1O min TEC= 40 ± 13 min Time to fill the RC and clean the pulp chamber UEC= 37± 8 min TEC= 30 ± 5 min Total time required to perform RC treatment UEC= 84 ± 13 min TEC= 70 ± 15 min	There was no true benefit associated with ultraconservative endodontic cavities. UEC resulted in more AHTD remaining inside the root canals. UEC did not influence the quality of root fillings; however, UEC made the cleaning procedure of the pulp chamber more difficult, thus increasing the total time required to perform root canal treatment. Moreover, UEC were not associated with an increase in fracture resistance of root filled 2-rooted maxillary premolars
Machado (2013) (11)	Comparative study	Sixty distobuccal root canals of maxillary molars	Compare the bacterial reduction achieved with reciprocating and rotary systems during root canal preparation	S1 (initial) ▪ G1 (WaveOne) 6.58± 0.30 ▪ G2 (Reciproc R25) 6.66 ± 0.30	All systems tested reduced bacterial counts to a similar level.

				▪ G3 (ProTaper system) 6.66 ± 0.26 ▪ G4 (MTwo system) 6.67 ± 0.20 ▪ G5 (Manual) 6.50 ± 0.32 S2 (immediate after instrumentation) ▪ G1 (WaveOne) 5.03 ± 0.79 ▪ G2 (Reciproc R25) 4.94 ± 0.37 ▪ G3 (ProTaper system) 5.21± 0.45 ▪ G4 (MTwo system) 5.01 ± 0.21 ▪ G5 (Manual) 5.29 ± 0.35 S3 (after 7 days) ▪ G1 (WaveOne) 5.42 ± 0.51 ▪ G2 (Reciproc R25) 5.31 ± 0.46 ▪ G3 (ProTaper system) 5.61 ± 0.37 ▪ G4 (MTwo system) 5.35 ± 0.27 ▪ G5 (Manual) 5.53 ± 0.30	
Machado (2017) (12)	Experimental study	Sixty distobuccal root canals of maxillary molars	Evaluate the bacterial reduction promoted by ProTaper Next and Twisted File by comparing to ProTaper Universal and manual technique.	S1 (initial) ▪ G1 (ProTpaer Next) 7.41 ± 0.03 ▪ G2 (Twisted File) 7.41 ± 0.03 ▪ G3 (ProTaper Universal) 7.32 ± 0.01 ▪ G4 (Manual) 7.31 ± 0.01 S2 (immediate after instrumentation) ▪ G1 (ProTpaer Next) 5.62 ± 0.28 ▪ G2 (Twisted File) 5.46 ± 0.27 ▪ G3 (ProTaper Universal) 6.06 ± 0.05 ▪ G4 (Manual) 6.11 ± 0.11 S3 (after 7 days) ▪ G1 (ProTaper Next) 6.15 ± 0.07 ▪ G2 (Twisted File) 6.11 ± 0.06 ▪ G3 (ProTaper Universal) 6.38 ± 0.03 ▪ G4 (Manual) 6.37 ± 0.03	ProTaper Next and Twisted File promote a higher bacterial reduction than Protaper Universal and manual techr4nique.

Cavalli (2017) (13)	Clinical study	Thirty single root canals with primary endodontic infection	Correlate the microbiological profile and levels of endotoxins found in primary endodontic infection with the presence of clinical features and to evaluate the removal of microorganisms and endotoxins using rotary, reciprocating, and hybrid systems for biomechanical preparation	Reduction of endotoxins MTwo > Genius > Reciproc – no statistical differences	Signs and symptoms were correlated with microorganisms. Endodontic treatment was effective in reducing bacteria and endotoxins but was not capable of completely removing them from the root canal.
Robinson (2013) (14)	Comparative study	Teeth were selected for instrumentation using reciprocating or rotary instruments (n = 19).	Compare the 3 dimensional distribution, quantity,and density of remaining inorganic debris in the mesial root of mandibular molars after instrumentation.	G1 (WaveOne) – reciprocating system G2 (ProTaper universal) – rotary system % Of canal wall converted into debris ProTaper > WaveOne % Of debris remaining in the canal ProTaper < WaveOne	In canals with a high prevalence of isthmuses and protrusions, using multifile rotary systems may be prefered over reciprocating files because it can yield cleaner canals with less debris accumulation.
Lee (2019) (15)	*Ex vivo* study	Mandibular premolars with round (n = 48) and oval (n = 48) root canals .	Examine the debridement of round and oval root canals prepared to two apical sizes with and without ultrasonically activated irrigation.	% RPT ▪ Preparation size } significant impact ▪ Irrigation technique } ▪ Root canal shape- not significant impact ▪ SNI > UAI ▪ Preparation size 20 > Preparation size 40 – SNI ▪ Preparation size 20 = Preparation size 40 — UAI % Root canal area untouched ▪ Preparation size } significant impact ▪ Root canal shape } ▪ Irrigation technique } No significant impact ▪ % Area untouched } ▪ Oval canals > round canals – in size 20 ▪ Oval canals > round canals – in size 40	Root canals prepared to a larger size (40) were cleaner than those prepared to a smaller size (20), when irrigation was performed with a syringe and needle. When the irrigant was ultrasonically activated, smaller preparations resulted in canals that were as clean as larger preparations.

Paraskevopoulou (2016) (16)	Experimental study	25 mandibular incisors	Investigate the influence of taper on intracanal bacterial reduction.	CFU- Pre-op ▪ Control = 43222 ▪ P.saline = 42916 ▪ NaOCl + EDTA = 41216 CFU- Pos-op taper 4% ▪ Control = 36976 ▪ P.saline = 2455 ▪ NaOCl + EDTA = 512 CFU- Pos-op taper 8% ▪ Control = 30330 ▪ P.saline = 379 ▪ NaOCl = 67	Chemomechanical instrumentation was more efficient at reducing E. faecalis when the taper of root canals increased from 4% to 8% and NaOCl plus EDTA led to a greater intracanal bacterial reduction than saline, regardless of the taper achieved.
Alegre (2017) (17)	*Ex-vivo* study	20 premolars	Determine the concentrations of irrigating solutions and the residual content of parachloroaniline (PCA) formed after endodontic irrigation, using 5% NaOCl, 0.9% NaCl, 10% EDTA and 2% CHX 2%.	% Decrease NaOCl concentration ▪ F1: 5% to 3,4% ▪ F2: 5% to 3,6% ▪ F3: 5% to 3,7% ▪ F4: 5% to 3,8% NaOCl concentration ▪ After use of 0,9% Nacl ○ F5: 0.007% ○ F6: 0.003% ○ F7: 0.001% ▪ After use of 0,9% Nacl ○ F8: 0.0011% ○ F9: 0.0009% ○ F10: 0.0006% % Decrease of EDTA ▪ F8: 10% to 8,9% EDTA concentration after 0,9% Nacl ▪ F9: 0.013% ▪ F10: 0.006% ▪ F11: 0.002% % Decrease of CHX concentration ▪ F12: 2% to 1,85% ▪ F13: 2% to 1,80% PCA concentration	During endodontic irrigation the concentration of 5% NaOCl decreases significantly in the first 4 phases and the concentrations of EDTA and CHX also decrease. There is PCA training in the last stages of the procedure.

				▪ F12: 0.0007% F13: 0.0005%	
Varghese (2017) (18)	*In-vitro* study	Thirty single-rooted anterior teeth	Evaluate the demineralization effect of a chelating agent, maleic acid (MA) when used as a root bio modifier on the cemental surface.	Removal of smear layer at 1 and 3 min ▪ CA = EDTA ▪ MA > EDTA ▪ MA > CA Quantification of smear layer in 1 min ▪ CA o 9 specimens: no smear layer o 6 specimens: moderate smear layer ▪ EDTA o 5 specimens: no smear layer o 10 specimens: moderate smear layer ▪ MA o 4 specimens: no smear layer o 11 specimens: moderate smear layer Quantification of smear layer in 3 min ▪ CA o 9 specimens: no smear layer o 6 specimens: moderate smear layer ▪ EDTA o 5 specimens: no smear layer o 10 specimens: moderate smear layer ▪ MA o 12 specimens: no smear layer o 3 specimens: moderate smear layer	MA removed smear layer effectively compared to EDTA and CA. Considering its beneficial qualities such as low toxicity, chemical adherence to hydroxyapatite, fibroblast attachment, etc., could provide enhanced results in terms of regeneration.
Neauhaus (2016) (20)	Experimental study	8 groups of single or dual microbial species	Compare a novel passive sonic irrigation (PSI) device (6000 Hz) with PUI and manual irrigation (MI) with respect to their efficiency in removing different endodontic microorganisms from curved and straight root canals.	Experiment 1 (tested the irrigation effect alone using 0,9 sodium chloride in a short-term infection model.) Ex: *E.faecalis* CFU after irrigation ▪ Control = 6.47 CFU ▪ MI = 4.68 CFU ▪ PUI = 3.84 CFU ▪ PSI = 2.97 CFU	PSI at 6000 Hz might be at least equal to PUI with respect to reduction of the microbial load in curved and straight root canals.

				The curvature (straight or curved RC) ▪ PSI > PUI Experiment 2 (tested the additional effect of activation using 1,5% NaOCl as a irrigant in a long-term infection model) ▪ PSI & PUI o effective against *E.faecalis* and *C.albicans* immediately after the treatment o after 3 days, 50% samples positive time points 0,3,5 and 7 days PSI= PUI	
Xia (2020) (22)	In *vitro* study	Forty extracted intact human first premolars	Compare the percentage of dentin removed, instrumentation efficacy, root canal filling and load at fracture between CEC, and TEC on root canal therapy in premolars.	% Dentin removed CEC < TEC UCW (untouched canal wall) CEC > TEC Canal surfaces and volume CEC = TEC Increased sectional area from apical foramen in premolars with 2 roots CEC > TEC Deviation of the central point after instrumentation CEC > TEC	The instrumentation efficacy and the percentage of filling material did not significantly differ between CECs and TECs in premolars.
Rover (2017) (23)	Experimental study	Thirty extracted intact maxillary first molars	Assess the influence CECs on root canal detection, instrumentation efficacy, and fracture resistance assessed in maxillary molars. TECs were used as a reference for comparison.	DETECTION OF ROOT CANALS Stage 1 (detection without magnification) TEC = 11 CEC= 4 Stage 2 (detection with magnification 16x) TEC= 12 CEC= 5 Stage 3 (detection with magnification 16x + ultrasonic tips) TEC = 13 CEC=12 After stage 3 TEC= 2	The results did not show benefits associated with CECs. This access modality in maxillary molars resulted in less root canal detection when no ultrasonic troughing associated to an OM was used and did not increase fracture resistance.

				CEC= 3 % OF NONINSTRUMENTED CANAL AREAS CEC= 27,4% ± 8,5% TEC =25,8% ± 9,7% %AHTD TEC= 1,3% ± 1,4% CEC= 0,9% ± 0,6%	
Neto (2012) (24)	Experimental study	Twenty-four human single-rooted canine teeth	Assess the effectiveness of three systems of mechanical preparation to reduce Enterococcus faecalis within root canals.	Mean % redution of *Enterococcus faecalis* after instrumentation G1: ProTaper rotary = 75.61% G2: ProTaper manual = 83.44% G3: K-files manual = 92.48%	All the three instrumentation systems reduced E. faecalis counts to a similar degree.
Akhlaghi (2013) (25)	*In vitro* study	Eighty-nine human mandibular first molars with curved MB canals	Evaluate the effect of size and taper MAF in reducing bacteria from the apical third of the curved canals	Size/ taper of MAF & Quantity of bacteria ▪ Control group: 700 ▪ G1 (25/0.04): 177.53 ▪ G2 (25/0.06): 167 ▪ G3 (30/0.04): 166 ▪ G4 (30/0.06): 165.69 ▪ G5 (35/0.04): 163.76 ▪ G6 (35/0.06): 163.76	MAF #25/0.04 had no significant difference compared to other groups with greater apical size/taper; all groups could effectively reduce intra-canal bacteria.
Srirekha (2017) (26)	*In vivo* study	120 human mandibular teeth indicated for root canal treatment was selected for the study.	Determine the effect of apical preparation size and taper using two different needles on the irrigant penetration into the apical part of root canals.	Irrigant penetration depth between 30 4% & 35 4% ▪ Flat ended needles ○ 30 4% = 3.39 ○ 35 4% = 2.99 ▪ Side vented needles ○ 30 4% = 4.68 ○ 35 4 % = 3.71 Irrigant penetration depth between 30 4% & 30 6% ▪ Flat ended needles ○ 30 4% = 1.62 ○ 30 6% = 1.02 ▪ Side vented needles ○ 30 4% = 3.28 ○ 30 6% = 2.47 Irrigant penetration depth between two needles in	Concluded that an apical preparation size of 30 and 6% preparation taper in DB canal of mandibular molars allow adequate irrigation penetration in the apical third with flat open-ended needles performing better than side vented needles.

				▪ 30 4% o Flat ended= 3.36 o Side vented= 4.68 ▪ 35 4% o Flat ended= 2.99 o Side vented= 3.71 Irrigant penetration depth between two needles in ▪ 30 4% o Flat ended= 1.62 o Side vented= 3.28 ▪ 30 6% o Flat ended= 1.02 o Side vented= 2.47	
Ferrer (2015) (27)	Research study	72 specimens were divided into 5 experimental groups according to the final irrigation regime used	Determine the residual antimicrobial activity of several final irrigation protocols with 7% maleic acid (MA) alone and combined with chlorhexidine (CHR), cetrimide (CTR) or both, in root canals infected with *enterococcus faecalis*	% Grown samples at 60 days ▪ G1: 2.5% NaOCl = 100% ▪ G2: 7% MA = 91,7% ▪ G3: 7% MA + 0.2% CTR = 58,3% ▪ G4: 7% MA + 2% CHR = 41,7% ▪ G5: 7% MA + 0.2% CTR + 2% CHR = 33,3%	Final irrigating solutions of 7% MA combined with 2% CHX or 2% CHX + 0.2% CTR were found to effectively improve antimicrobial root canal disinfection
Stojicic (2012) (28)	Experimental study	*Enterococcus faecalis* and mixed plaque bacteria were exposed to QMiX, 2% chlorhexidine (CHX), MTAD and 1% sodium hypochlorite (NaOCl)	Assess in a laboratory experimental model the efficacy of a novel root canal irrigant, QMix, against Enterococcus faecalis and mixed plaque bacteria in planktonic phase and biofilms. In addition, its ability to remove smear layer was examined.	Direct exposure teste ▪ QMix, 1 % NaOCl } 100% kill *E.faecalis* after 5 seconds ▪ 2% CHX, MTAD } Not eliminate 100% *E.faecalis* after 3 min ▪ QMIX, 2% CHX } The fastest killers; MTAD, 1% NaOCl } Killed mixed plaque bacteria Biofilm ▪ QMIX 2X > NaOCl ▪ QMIX 4X > CHX	QMiX and NaOCl demonstrated superior activity against planktonic and biofilm bacteria as compared to 2% CHX and MTAD. As in smear layer removal, QMiX was comparable to 17% EDTA.

				▪ QMIX 12X > MTAD ▪ 2% NaOCl = QMIX ▪ MTAD- least effective Smear layer removal ▪ QMIX = EDTA (in 5 min) ▪ QMIX- 0.88 } Open tubules after ▪ EDTA- 0.85 } smear layer removal	
Widjiastuti (2018) (29)	Experimental study	27 extracted single-root mandibular premolars	Analyze the differences between irrigant replacement in the positive and negative pressure irrigation systems regarding root canal cleaning efficacy.	The mean of distance between the apical end and the peak of the irrigation solution discharged from the irrigation needle: ▪ Control= 2.209 ▪ T1 (PPI) = 0.041 ▪ T2 (NPI) = 0.068 -Score 1 (no smear layer in RC wall and the dentin tubuli were all open) -Score 2 (thin smear layer and some dentin tubulini were open) -Score 3 (homogeneous smear layer covering the walls of RC, no smear layer on the surface of RC and most tubes were covered with smear plug -Score 4 (homogeneous smear layer covered all the walls of the root canal, no open dentin tubule) -Score 5 (thick smear layer covering the entire wall of the root canal Score of root canal sanitation in each group: ▪ Control o Score 1 =0% o Score 2 =0% o Score 3 =11.11% o Score 4 =88.89% ▪ T1 o Score 1 =0% o Score 2 =0% o Score 3 =77.78% o Score 4 =22.22% ▪ T2 o Score 1 =0% o Score 2 =66.67%	The irrigation solution exchange of the NPI system is more capable of reaching the apical end compared to the PPI system, resulting in a higher sanitation level in the apical third of the root canal.

				○ Score 3 =33.33% ○ Score 4 =0%	
Kalyoncuoglu (2016) (30)	*In vitro* study	90 single-rooted mandibular premolar	Evaluate and compare the antifungal efficacy of QMix 2in1, 5.25% NaOCl, 2% CHX, and 17% EDTA as a final rinse against Candida albicans (C. albicans).	Mean number of *Candida albicans* ▪ NaOCl = 0 ▪ QMix 2in1 = 0 ▪ CHX = 0 ▪ EDTA= 2790 (NaOCl = QMix 2in1 = CHX) > EDTA	QMix 2in1 proved to be effective against C. albicans when used as a final rinse. According to the findings of the present study, QMix 2in1 may be recommended as an alternative final rinse solution.

5 Discussion

The present integrative review reported the major results of relevant previous studies taking into account the types of access cavities the different instrumentations and irrigation techniques the types of irrigants and size & taper and their influence on RCS irrigation.

Thus, the null hypothesis tested was rejected. A detailed discussion is provided as follow.

Schilder described 5 mechanical and 4 biological objectives for successful root canal therapy. (31)

The mechanical objectives are:

1. The root canal preparation should develop a continuously tapering cone. This shape mimics the natural canal shape
2. Making the preparation in multiple planes which introduces the concept of "flow". This objective preserves the natural curve of the canal
3. Making the canal narrower apically and widest coronally. To create a continuous taper up to apical third which creates the resistance form to hold gutta-percha in the canal.
4. Avoid transportation of the foramen. There should be gentle enlargement of the foramen while maintaining its position
5. Keep the apical foramen as small as possible. Since over-enlargement of the apical opening contributes to number of iatrogenic problems. Doubling the file size apically increases the surface area of foramen for four folds.

The biological objectives are:

1. Confinement of instrumentation within the root canals only.
2. Ensure not to force necrotic or instrumentation debris beyond the apical foramen.
3. Optimum debridement of the root canal shape
4. Creation of sufficient space for intra-canal medicaments

5.1. Access cavity

A very important initial phase for the endodontic treatment is the preparation of the access cavity, with adequate shape and size to allow the detection of all canal orifices, reducing the risk of canals not being located, increase the effectiveness of root instrumentation, eliminate anatomical interferences and avoid intraoperative iatrogenic complications. (8)

In order to minimize the loss of tooth structure, increase mechanical stability, and fracture resistance of endodontically treated teeth, keeping them in function for longer, the CEC (conservative endodontic cavity) inspired by the minimally invasive technique was developed as an alternative to TEC. (8,10)

However, some authors suggest that CEC may have a negative influence on RCS preparation and potentially interfere with endodontic treatment success as it results in a larger noninstrumented canal area compared to TEC. (8–10,22,23). Whereas one author concludes that there is no significative difference on the percentage of noninstrumented area between CEC and TEC. (23)

Similarly, other problems have been reported regarding this technique, such as difficulty in locating root canals due to the presence of the pulp chamber ceiling (23) and significantly compromised disinfection. (8,23)

In addition, some authors report that CEC requires more time to fill the RC and clean the pulp chamber as well as to perform the RC treatment. (10) CEC also increase sectional area from apical foramen and increase the deviation of central point after instrumentation.(22)

TAC (truss-access-cavity) is a type of conservative cavity that separates individual cavities in multirooted teeth to maximize dentin preservation between them. *Barbosa et al*. (9) concluded that this type of access does not offer any advantage compared to TEC.

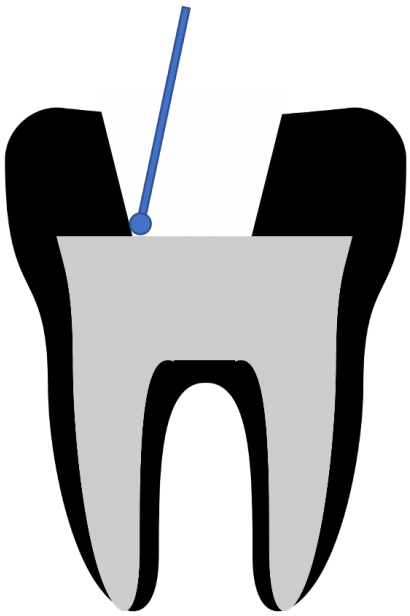

Figure 3 – Representative access cavity image

5.2. Instrumentation technique

After the access to the pulp chamber, and the location of the canals holes, the instrumentation of the RCS begins, the mechanical removal of the vital and/or necrotic tissue and microbial biofilm, enables the optimal flow of chemical irrigants, favoring a clean, debrided environment and the disinfection of the RCS.(15)

When comparing three instrumentation systems (rotary, reciprocating and manual) studies report that no significant differences are found regarding bacterial reduction during canal preparation since they obtained similar results.(11,24)

In opposition, studies show that with rotary systems there is a greater bacterial reduction (12) that they produce cleaner canals with less debris accumulation.(14)

Robinson et al(14) also concluded thar rotary system produces a bigger percentage of canal wall converted in debris.

In contrast, *Daiana Cavalli et al. 2017* (13)argues that when using hybrid systems there is a more effective removal of microorganisms and endotoxins because there is a higher frequency of irrigation during biomechanical preparation due to the use of a greater number of instruments compared to other systems.

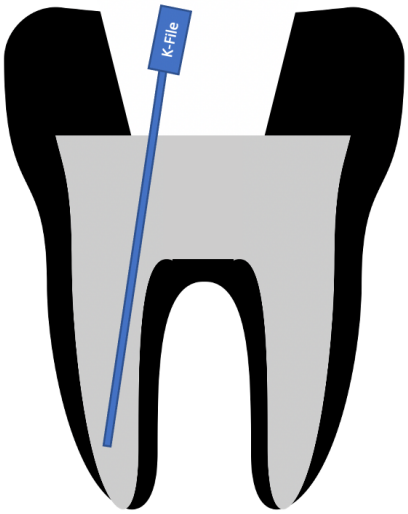

Figure 4 – Representative instrumentation image

5.3. Size and Taper

The taper usually is expressed as the amount that the file diameter increases each millimeter along its working surface from the tip toward the file handle. For example, a size #25 file with a.0.2 taper would have a 0,27 mm diameter 1 mm from the tip, a 0,29 mm diameter 2 mm from the tip. Instruments can have constant or variable taper. (31)

Akhlaghi et al.(25) evaluated the effect of size and taper of apical preparation in reducing intra-canal bacteria and reported that apical preparations of mesiobucal canals to size 25/4% had no significant difference with other sizes (35/6%, 35/4%, 30/6%, 30/4% and 25/6%) and the bacterial count equally and efficiently decreased in all groups. These results were similar to *Alimadadi et al*. (26)results.

Lee et al.(15) concluded that size 20 preparations increase the RPT when compared with size 40 preparations.

On the other hand, other authors state that increased taper results in a more efficient and deeper penetration of the irrigant solution into the apical region and a decrease in the number of residual bacteria(16).

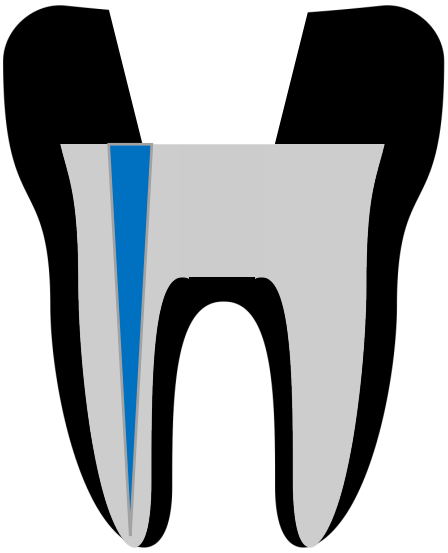

Figure 5- Representative size & taper image

5.4 Irrigants

Irrigation is a key part successful root treatment.

It has several functions, which may vary according to the irrigant used: it reduces friction between the instrument and dentine, improves the cutting effectiveness of the files, dissolves tissue, cools the file and tooth, and furthermore, it has a washing effect and antimicrobial/antibiofilm effect.

Irrigation is also the only way to impact those areas of the root canal wall not touched by mechanical instrumentation. (5)

5.4.1 Irrigants types and actions

5.4.1.1 Sodium Hypochlorite

NaOCl is the most commonly used irrigant solution (32) because of its antibacterial capacity and the ability to dissolve necrotic tissue, vital pulp tissue, and organic components of dentin and biofilms in a faster manner.(33)

NaOCl solution is frequently used as a disinfectant or a bleaching agent. It is the irrigant of choice in endodontics, owing to its efficacy against pathogenic organisms and pulp digestion and satisfies most of the preferred characteristics stated earlier.(32)

Estrela (34) reported that the mechanisms of action operate through three different mechanisms:

- Saponification, as an organic solvent that degrades fatty acids and transforms them into fatty acid salts (soap) and glycerol (alcohol), reducing the surface tension of the remaining solution
- Neutralization of amino acids by forming water and salt
- Combination between chlorine and protein amino groups forming chloramines. Chloramines impede cell metabolism and is a strong oxidant that inhibes essential bacterial enzymes by irreversible oxidation of sulfhydryl group.

Alimadadi et al.(1)concluded that the effect of NaCOl can be enhanced by using PDT as adjunct.

Alegre et al (17) showed the instrumentation the concentration of sodium hypochlorite decreases due to effect on the canal preparation.

Regarding to the percentage of bacteria *E.Faecalis* that are killed, the 1% NaOCl kill at 100%.(28) and regarding to the percentage of bacteria *C.Albicans* it has also been proved that the 5,25% NaOCl was able to eliminate 100% of them. (30)

5.4.1.2 Chlorhexidine gluconate

CHX was developed in the United Kingdom and first marketed as an antiseptic cream. It has been used for general disinfection purposes and the treatment of skin, eye, and throat infections in both humans and animals.(35)

It has been used as an irrigant and medicament in endodontics for more than a decade(36)

It has a broad spectrum of action on Gram positive and Gram-negative bacteria and yeasts. It is useful as an adjuvant in endodontics, used in the concentration of 2%, as an irrigant or drug, due to its substantivity and broad antibacterial spectrum (17)

Chlorhexidine exhibits an antifungal activity against *C.albicans* of 100%. (30)

Ferrer et al (19) concluded that the use of CHX mixed with maleic acid or cetrimide can be recommended for final irrigation protocols.

The interaction between CHX and root canal dentin after intracanal use decreases the percentage of chlorhexidine on RC.(17)

5.4.1.3 EDTA (Ethylenediaminetetraacetic acid)

EDTA is a fluid substance with a neutral pH of 7.3, which can be found in concentrations from 10 to 17% and is most effective at 17%.

This solution is intended to demineralize the dentin and eliminate the inorganic tissue, the Smear Layer.

EDTA, used usually in concentration of 17%, dissolves the inorganic portion of dentine and smear layer by chelation and is recommended for use after NaOCl to complete smear removal.(28)

It has a small antibacterial effect on some species of microorganisms such as alpha-hemolytic Streptococcus and Staphilococcus aureus, but in return has a high antimycotic effect.(37)

5.4.1.4 Citric acid

Citric acid is a chemical solution that helps instrumentation and is used as a descaling agent to remove the smear layer, formed during instrumentation of the root canals, which can retain microorganisms and impede adhesion of the cement obturated. (38).

Varghese concluded that citric acid at pH 1, for 2-3 minutes resulted in optimal cementogenesis in open apex and *semear layer* removal.

The authors demonstrated that citric acid causes better demineralization effect compared to EDTA. (18)

5.4.1.5 Maleic acid

Maleic acid is an organic acid, which was proposed as an alternative solution to EDTA due to its ability to eliminate the *smear layer*.

It also has a very low toxic action and a higher eradication of the *E.Faecalis* biofilm compared to EDTA or citric acid. (19)

Varghese (18) observed that maleic acid was efficient on the elimination of *smear layer*

5.4.1.6 Q MiX

Q-MiX Dentsply is a new endodontic irrigation product for smear layer removal. It contains EDTA 17%, CHX 2% and detergents. It is a ready-to-use solution without manipulation.

The authors demonstrated in their study that irrigation with Q-mix is effective against Enterococcus faecalis, biofilm and effective in its ability to remove the smear layer.(28)

Authors demonstrated in their studies that Q MiX 2-in-1 has the same efficacy as NaOCl 5.25% and CHX 2%, with one small difference: Q-mix removes more bacteria in 1 minute than the other solutions mentioned.

As for the removal of the smear layer, it removes more in less time, compared to EDTA 17% (30)

5.4.2 Irrigation techniques

5.4.2.1 Conventional passive irrigation

Manual irrigation system using needles is still widely accepted by both general practitioners and endodontics. In this technique the dispensing of an irrigant into a canal through needles/cannulas of variable gauges, either passively or with agitation. The agitation might be achieved by moving the needle up and down the canal space. The design of these needles can be closed-ended or side-vented channels. (39)

The size and design of the needle/cannula tip has a great impact on the flow rate and speed of irrigation as well as on the penetration depth of the irrigant. We can divide

the various types of needles into two groups: open-ended needle and closed-ended needle (40).

5.4.2.2 Dynamic manual irrigation

Dynamic manual irrigation is a simple and economical technique, consist on the repeated insertion of a well-adjusted Guta-percha cone to the working length of a pre-instrumented canal.

The Guta-percha cone produces an hydrodynamic effect that improves the displacement and exchange of irrigants in the apical third.

The cone moves into the canal with back-and-forth movements along the canal length up to 0-2 mm from the apex.(41)

5.4.2.3 Negative pressure irrigation (NPI)

The irrigation system creates negative pressure at the tip of the needle.

The irrigation solution is placed in the coronal zone and suction at the tip of the irrigation needle in the apical part creates a current flow downward toward the apex. That is, the apical negative pressure, can only happen when the needle (cannula) is used to aspirate irrigation solutions from the apical constriction of the root canal, creating rapid and turbulent currents towards the end of the needle (29,42)

Authors concluded that NPI system is more capable of reaching the apical end compared to PPI system, resulting in a higher sanitation level in a third apical area of the RC. (29)

5.4.2.4 Positive pressure irrigation (PPI)

The first administration system of irrigant into the root canal was a needle connected to a syringe, now called positive pressure irrigation (PP).

The basic concept and clinical goal is to apply the irrigating solution throughout the root canal and at the same time generate a hydrodynamic flow to facilitate the elimination of debris through the canal orifice. It aims to avoid accumulation and obstruction by the debris produced during instrumentation, particularly in the apical third,

which cause mechanical blockage and facilitate the growth of microorganisms and the formation of biofilms.

It is the most traditional technique and is considered the "gold standard" for endodontic irrigation.

5.4.2.5 Sonic irrigation

Sonic activation has proven to be an effective method to disinfect the root canal system. Most real systems have smooth plastic tips of different sizes, activated with sonic frequency by a handpiece that operates at a frequency of 1-6 kHz.

Sonic irrigation works by generating an oscillation pattern at one end of the handpiece. In the insertion zone of the disposable tip with the handpiece is the zone of minimum amplitude of oscillation while in the free tip the vibration is maximum.

The authors demonstrated that this vibration method is effective in debridement of the root canal. (21)

One of the most commonly used sonic instruments is the EndoActivator (Dentsply, Tulsa) (20). It is a handpiece that uses disposable polyamide tips to activate the solution and thus prevent active cutting of the root canal walls or opening of the apical constriction. Because sonic irrigation has a low frequency, it can work more safely. (42)

Neuhaus et al. (20) concluded that PSI (passive sonic irrigation) at 6000 Hz might be at least equal to PUI (passive ultrasonic irrigation) with respect to reduction of the microbial load in curved and straight root canals.

5.4.2.6 Ultra-sonic irrigation

The use of ultrasonic irrigation is an indispensable step to improve RCS disinfection. The frequency range used in the ultrasonic unit is between 25000 Hz and 40000 Hz. (43)

The effectiveness of ultrasound in irrigation is determined by its ability to produce cavitation and acoustic transmission. Cavitation is the formation of small bubbles that implode rapidly, producing a shock wave that removes the biofilm. Meanwhile, acoustic

transmission produces shear forces that will help extract debris from the instrumented canal.(43)

Ultrasonic irrigation is activated and therefore produces greater oscillations at the tip compared to sonic irrigation. (21)

The authors demonstrated that ultrasound-activated irrigation increases the efficacy of NaCl.(20)

In curved canal roots, ultrasound instruments are less likely to oscillate freely.

It has also been shown that even in straight canal roots, they come into contact with the walls in at least 20% of the working time.

Furthermore, although ultrasonic irrigation instruments generally have a non-cutting shape, as they are made of a metal alloy stronger than the root dentin, their prolonged use promotes the risk of altering the morphology of the root canal (44)

Figure 6 – Representative irrigation image

6 Limits

This systematic integrative review has some limitations. The limitation of the language may have contributed to the loss of some potentially relevant articles. However, the English language is irrefutably the universal language of science and most of the articles found throughout the research were in that language. Thus, we consider this parameter the least problematic and conditioning.

The search methodology may have excluded relevant articles because we used a single database (PubMed). This problem was minimized when searching the bibliographic references of the selected studies.

7 Conclusion

Within the limitations of this study, the following concluded remarks can be drawn as follow:

- TEC offer many advantages when compared to CEC.
- All instrumentations techniques can achieve good results as long as they are well executed.
- The taper has more influence on the treatment of RC than the size.
- NaOCl the most widely used irrigant in endodontics but no irrigant has all the requisites for a good irrigant and therefore their combination is the best option.
- The combination with ultrasound improves the antibacterial effect and allows to obtain cleaner canals.

8. References

1. Alimadadi H, Asnaashari M, Naseri M, Yadegari Z. Effect of Apical Size and Taper on the Efficacy of Root Canal Disinfection With LED Photodynamic Therapy as an Adjunct to Irrigation With Sodium Hypochlorite. Journal of Lasers in Medical Sciences. 2021;12(1):1–8.
2. Siqueira JF, Lima KC, Magalh~es FAC, Lopes HP, de Uzeda M. Mechanical Reduction of the Bacterial Population in the Root Canal by Three Instrumentation Techniques. Vol. 25. 1999.
3. Card SJ, Sigurdsson A, Ørstavik D, Trope M. The Effectiveness of Increased Apical Enlargement in Reducing Intracanal Bacteria. 2002.
4. Haapasalo M, Shen Y, Qian W, Gao Y. Irrigation in Endodontics. Vol. 54, Dental Clinics of North America. 2010. p. 291–312.
5. Haapasalo M, Shen Y, Wang Z, Gao Y. Irrigation in endodontics. British Dental Journal. 2014 Mar 21;216(6):299–303.
6. Scha« E, Vlassis & M. Comparative investigation of two rotary nickel^titanium instruments: ProTaper versus RaCe. Part 2. Cleaning effectiveness and shaping ability in severely curved root canals of extracted teeth.
7. Guelzow A, Stamm O, Martus P, Kielbassa & AM. Comparative study of six rotary nickel-titanium systems and hand instrumentation for root canal preparation.
8. Vieira GCS, Pérez AR, Alves FRF, Provenzano JC, Mdala I, Siqueira JF, et al. Impact of Contracted Endodontic Cavities on Root Canal Disinfection and Shaping. Journal of Endodontics. 2020 May 1;46(5):655–61.
9. Barbosa AFA, Silva EJNL, Coelho BP, Ferreira CMA, Lima CO, Sassone LM. The influence of endodontic access cavity design on the efficacy of canal instrumentation, microbial reduction, root canal filling and fracture resistance in mandibular molars. International Endodontic Journal. 2020 Dec 1;53(12):1666–79.
10. Silva AA, Belladonna FG, Rover G, Lopes RT, Moreira EJL, De-Deus G, et al. Does ultraconservative access affect the efficacy of root canal treatment and the fracture resistance of two-rooted maxillary premolars? International Endodontic Journal. 2020 Feb 1;53(2):265–75.
11. Machado MEL, Nabeshima CK, Leonardo MFP, Reis FAS, Britto MLB, Cai S. Influence of reciprocating single-file and rotary instrumentation on bacterial reduction on infected root canals. International Endodontic Journal. 2013 Nov;46(11):1083–7.
12. Machado ME de L, Nabeshima CK, Caballero-Flores H, Elmadjian-Filho M, Duarte MAH, Odinola-Zapata R, et al. Instrument design may influence bacterial reduction during root canal preparation. Brazilian Dental Journal. 2017 Sep 1;28(5):587–91.
13. Cavalli D, Toia CC, Flores Orozco EI, Khoury RD, Cardoso FG da R, Alves MC, et al. Effectiveness in the Removal of Endotoxins and Microbiological Profile in Primary Endodontic Infections Using 3 Different Instrumentation Systems: A Randomized Clinical Study. Journal of Endodontics. 2017 Aug 1;43(8):1237–45.
14. Robinson JP, Lumley PJ, Cooper PR, Grover LM, Walmsley AD. Reciprocating root canal technique induces greater debris accumulation than a continuous rotary technique as assessed by 3-dimensional micro-computed tomography. Journal of Endodontics. 2013 Aug;39(8):1067–70.

15. Lee OYS, Khan K, Li KY, Shetty H, Abiad RS, Cheung GSP, et al. Influence of apical preparation size and irrigation technique on root canal debridement: a histological analysis of round and oval root canals. International Endodontic Journal. 2019;52(9):1366–76.
16. Paraskevopoulou MTh, Khabbaz MG. Influence of Taper of Root Canal Shape on the Intracanal Bacterial Reduction. The Open Dentistry Journal. 2016 Nov 3;10(1):568–74.
17. Alegre O, Yévenes I, Parada J, Maggiolo S, Fernández E. Determination of residual parachloroaniline produced by endodontic treatment after the use of 5% sodium hypochlorite and 2% chlorhexidine combined: an ex-vivo study. Revista clínica de periodoncia, implantología y rehabilitación oral. 2017 Dec;10(3):145–8.
18. Varghese J, Ballal N. An in vitro study to evaluate the demineralizing effect of maleic acid and cell attachment on cemental surface. Saudi Endodontic Journal. 2017 Jan 1;7(1):23–8.
19. Ferrer-Luque CM, González-Castillo S, Ruiz-Linares M, Arias-Moliz MT, Rodríguez-Archilla A, Baca P. Antimicrobial residual effects of irrigation regimens with maleic acid in infected root canals. Journal of Biological Research-Thessaloniki. 2015 Dec;22(1).
20. Neuhaus KW, Liebi M, Stauffacher S, Eick S, Lussi A. Antibacterial Efficacy of a New Sonic Irrigation Device for Root Canal Disinfection. Journal of Endodontics. 2016 Dec 1;42(12):1799–803.
21. Mohammadi Z, Shalavi S, Giardino L, Palazzi F, Asgary S. Impact of ultrasonic activation on the effectiveness of sodium hypochlorite: A review. Vol. 10, Iranian Endodontic Journal. Iranian Association of Endodontics; 2015. p. 216–20.
22. Xia J, Wang W, Li Z, Lin B, Zhang Q, Jiang Q, et al. Impacts of contracted endodontic cavities compared to traditional endodontic cavities in premolars. BMC Oral Health. 2020 Sep 7;20(1).
23. Rover G, Belladonna FG, Bortoluzzi EA, De-Deus G, Silva EJNL, Teixeira CS. Influence of Access Cavity Design on Root Canal Detection, Instrumentation Efficacy, and Fracture Resistance Assessed in Maxillary Molars. Journal of Endodontics. 2017 Oct 1;43(10):1657–62.
24. Matos Neto M, Santos SSF, Leão MVP, Habitante SM, Rodrigues JRDD, Jorge AOC. Effectiveness of three instrumentation systems to remove Enterococcus faecalis from root canals. International Endodontic Journal. 2012 May;45(5):435–8.
25. The Effect of Size and Taper of Apical Preparation in Reducing Intra-Canal Bacteria: A Quantitative SEM Study. Vol. 9, IEJ Iranian Endodontic Journal. 2014.
26. Effect of Apical Preparation Size and Taper on Irrigant Penetration in Apical Third of Root Canal using Two Different Endodontic Needles: An In Vivo Study. 2017.
27. Ferrer-Luque CM, González-Castillo S, Ruiz-Linares M, Arias-Moliz MT, Rodríguez-Archilla A, Baca P. Antimicrobial residual effects of irrigation regimens with maleic acid in infected root canals. Journal of Biological Research-Thessaloniki. 2015 Dec;22(1).
28. Stojicic S, Shen Y, Qian W, Johnson B, Haapasalo M. Antibacterial and smear layer removal ability of a novel irrigant, QMiX. International Endodontic Journal. 2012 Apr;45(4):363–71.

29. Widjiastuti I, Rudyanto D, Yuanita T, Bramantoro T, Widodo WA. Cleaning efficacy of root canal irrigation with positive and negative pressure system. Iranian Endodontic Journal. 2018 Jun 1;13(3):398–402.
30. Kalyoncuoglu E, Tunc E, Ozer S, Keskin C, Bilgin K, Birinci A. Evaluation of antifungal efficacy of QMix 2in1 as a final irrigant: An in vitro study. Nigerian Journal of Clinical Practice. 2016 Nov 1;19(6):807–10.
31. Berman LH, Hargreaves KM. Instructions for online access [Internet]. Available from: http://ebooks.elsevier.com
32. Sodium hypochlorite in endodontics: an update review. 2008;
33. Steve Senia E, James Marshall P, Rosen S. The solvent action of sodium hypochlorite on pulp tissue of extracted teeth.
34. Estrela C, Estrela CRA, Luis Barbin E, César J, Spanó E, Marchesan MA, et al. Mechanism of action of sodium hypochlorite 113. Braz Dent J. 2002;13(2):113–7.
35. Fardal O, Turnbull RS. A review of the literature on use of chlorhexidine in dentistry. Vol. 112, Journal of the American Dental Association (1939). 1986. p. 863–9.
36. Mohammadi Z, Abbott P v. The properties and applications of chlorhexidine in endodontics. Vol. 42, International Endodontic Journal. 2009. p. 288–302.
37. Mohammadi Z, Shalavi S, Jafarzadeh H. Ethylenediaminetetraacetic acid in endodontics. European Journal of Dentistry. 2013;7(5 SUPPL.).
38. Ruddle C. Endodontic disinfection: Tsunami irrigation. Vol. 5, Saudi Endodontic Journal. Medknow Publications; 2015. p. 1–12.
39. Elumalai DrD, Kumar DrA, K Tewari DrR, K Mishra DrS, Iftekhar DrH, Alam DrS, et al. Newer Endodontic irrigation devices: An update. IOSR Journal of Dental and Medical Sciences [Internet]. 2014;13(6):04–8. Available from: http://www.iosrjournals.org/iosr-jdms/papers/Vol13-issue6/Version-5/B013650408.pdf
40. Pasricha SK, Makkar S, Gupta P. Pressure alteration techniques in endodontics-a review of literature. Vol. 9, Journal of Clinical and Diagnostic Research. Journal of Clinical and Diagnostic Research; 2015. p. ZE01–6.
41. Mohammadi Z, Yaripour S, Shalavi S, Palazzi F, Asgary S. Root Canal Irrigants and Dentin Bonding: An Update. IEJ Iranian Endodontic Journal. 2017;12(2):131–6.
42. Endodontics Modern Endodontic Principles Part 4: Irrigation.
43. Plotino G, Cortese T, Grande NM, Leonardi DP, di Giorgio G, Testarelli L, et al. New technologies to improve root canal disinfection. Vol. 27, Brazilian Dental Journal. Associacao Brasileira de Divulgacao Cientifica; 2016. p. 3–8.
44. Boutsioukis C, Verhaagen B, Walmsley AD, Versluis M, van der Sluis LWM. Measurement and visualization of file-to-wall contact during ultrasonically activated irrigation in simulated canals. International Endodontic Journal. 2013 Nov;46(11):1046–55.