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REVIEW ARTICLE

The effect of various in-vitro and ex-vivo parameters on irrigant flow and apical pressure using manual syringe needle irrigation: Systematic review

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KEYWORDS

Apical pressure;
Irrigant flow;
Root canal irrigation;
Syringe needle

Abstract *Background:* Fluid dynamics is a majorly neglected aspect to be studied in root canal irrigation. The fundamental rule to understand mechanics is to observe patterns of flow during the process. Thus, this work is conducted to do a systemic assessment of the in-vitro and ex-vivo based studies to evaluate the effect of various parameters on the irrigant flow and apical pressure on using a manual syringe needle for root canal irrigation.

Methods: The literature search was conducted through libraries such as PubMed (Medline), CINAHL, Embase, Scopus and other hand literature from Google Scholar, the British medical library etc. The systematic review was reported following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. As they include studies that were in-vitro and ex-vivo based, the risk of bias of the selected articles was assessed using a customized tool based on the previous literature and parameters evaluated in the studies included.

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Results: The literature search resulted in 101 items of which 19 records were included in this review. Results reported that multiple factors and parameters were assessed to evaluate the flow and apical pressures on using manual syringe needle irrigation.

Conclusions: Present systematic review gives insights in-depth about the irrigation dynamics of manual syringe needle irrigation. Besides, it is inconclusive to compile a single factor or a single parameter contributing to the enhanced irrigant flow and least apical pressures.

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1. Introduction

Endodontic therapy prognosis for a specific tooth depends on various factors that contribute to the clinical success (Chubb, 2019; Kim et al., 2018; Nocca et al., 2014). Negligence to one or the other aspect might lead to the failure of the treatment. The most studied and still neglected part of the endodontic treatment is the disinfection of the root canal space (Eckhardt et al., 2010; Teves et al., 2019). A three-dimensionally obturated root canal space is reciprocating three-dimensional disinfection and cleaning of the root canal system. When root canal irrigation is considered, various interesting factors such as needle type, needle design, needle placement, root canal preparation sizes, the taper of a root canal, facing of needle port (side vented needles), canal anastomosis, fluid flow rate, needle movement, frequency of needle movement, and needle gauge combine to dictate the enhanced cleaning and disinfection of root canal space (Haapasalo et al., 2014; Mohammadi et al., 2017).

Various dynamic mechanisms, such as cavitation, acoustic streaming and photoacoustic waves that occur during irrigant activation lead to enhanced cleaning (Dioguardi et al., 2018). When intricate mechanisms of root canal irrigation are to be understood, the fundamental rule is to observe flow patterns during the process. But it's impossible to perform the dynamic analysis on multiple parameters of root canal irrigation at various levels in a single in-vitro study design. Hence, observation of the irrigant simulated flow patterns and understanding different physical parameters involved in root canal irrigation strengthens our concept at the primary level to deliver the best therapeutic outcome. It's understood that an enhanced irrigant flow in root canal space requires a dynamic fluid movement. A static fluid will never create any forces on the root canal wall. Ultimately, the shear wall stress induced by the flowing liquid causes the dislodegement of tightly adhered bacterial biofilm along with the smear layer debris (Goode et al., 2013; Layton et al., 2015). However, canal disinfection is dependent on the irrigant's chemical action. Therefore the referred mechanical action is only partially responsible for the canal cleaning).

Various physical parameters such as flow velocity, flow patterns (Malki et al., 2012), the turbulence of the liquid and the turbulent forces created (Gulabivala et al., 2010), and wall shear stress (Goode et al., 2013) play a role in irrigation dynamics. Every physical parameter has its vital role, and they combine to cause dynamic forces in the crocked spaces of the the root canal. Although root canal irrigation is a dynamic combination of various factors that induce dislodging forces, the apical pressure developed during root canal irrigation safeguards the fundamental treatment aspect in a clinical scenario. So the dynamic forces should be under control and not cross the physical limit or physiological limit. Hence the present systematic review aimed at determining the effect of more relevant factors or parameters on irrigant flow and apical pressure on using a manual syringe needle for root canal irrigation.

Table 1 Characteristics of selected studies.

No	Study Type	Sample	Study objectives	Method of assessment	Outcomes	Ref
1	In vitro study (CFD based)	–	The effect of various apical preparation sizes on the irrigant flow and apical pressure is analyzed.	Root canal simulation	Velocity: • 30 gauge open needles have proven better compared to 30 gauge side vented needles. • 55 0.6% taper proved better as compared to other tapers.Shear stress: • 30 gauge side vented needles have proven better compared to 30 gauge open-ended needles. • 25 0.6% taper proved better as compared to other tapers.Apical pressure: • 30 gauge side vented needles induced the least apical pressures compared to 30 gauge open-ended needles. • 55 0.6% tapers were better with the least apical pressure values as compared to other tapers.	(C. Boutsioukis et al., 2010a)
2	In vitro study (CFD based)	–	The effect of various root canal tapers on the irrigant flow and apical pressures.	Root canal simulation	Velocity: • 30 gauge open-ended needles have proven better compared to 30 gauge side vented needles. • 60 0.2% taper proved better as compared to other tapers.Shear stress: • 30 gauge side vented needles have proven better compared to 30 gauge open-ended needles. • 30 0.2% taper proved better as compared to different tapers.Apical pressure: • 30 gauge side vented needles induced the least apical pressures compared to 30 gauge open-ended needles. • 60 0.2% taper was better with the least apical pressure values as compared to other tapers.	(C. Boutsioukis et al., 2010b)
3	In vitro study (CFD based)	–	The orientation of the side-vented needle opening on the irrigant flow and apical pressure.	Root canal simulation	• Shear stress was better when a 30 gauge side-vented needle with an open notch facing towards the lateral canal. • Apical pressure was least when the 30 gauge side vented needle was rotated 90 degrees clockwise. • Irrigant exchange was better when a 30 gauge side vented needle with an open notch rotated 270 degrees clockwise.	(Wang et al., 2015)
4	In vitro study (polycarbonate model-based)	–	Apical pressures were generated in separate and anastomosed canals using 30 gauge side vented needles at different flow rates.	Pressure sensing and signal transduction	• Compared to separate canal models, anastomosis models induced the least apical pressures. • When different flow rates were compared, 1.5 ml/min induced the least apical pressures. • When different needle placements were considered, the least apical pressures were induced, when a needle was placed 3 mm from the canal.	(Huang et al., 2017)

(continued on next page)

Table 1 (*continued*)

No	Study Type	Sample	Study objectives	Method of assessment	Outcomes	Ref
5	In vitro study (CFD based)	–	The effect of frequency of needle movement on the irrigant flow and apical pressures.	Root canal simulation	• Stationary needles during irrigation proved to induce more velocity compared to other types. • Needle movements frequently during irrigation proved to induce more velocity compared to others. • The needle kept in motion with an amplitude of 3 mm at a frequency of 1 Hz, generated the least apical pressures compared to others.	(Hu et al., 2019)
6	Ex-vivo study (Based on the testing system)	–	The effect of needle type, gauge and needle design on the irrigant flow.	Data acquisition frompressure & displacement transducers	• Among the groups compared, 30 gauge side vented needles required more duration for irrigation. • When the volume of irrigant delivered is compared, 27 gauge needles were proved better to others. • The average flow of irrigant was higher with 25 gauge side vented needles compared to others. • Both maximum (intra barrel) pressures and average pressure recorded during irrigation was higher with 30 gauge side vented needles.	(Boutsioukis et al., 2007)
7	In vitro study (CFD based)	–	The effects of various fluid flow rates on irrigant exchange and flow.	Root canal simulation	• Both the inlet velocity and turbulence quantities were recorded higher at flow rates of 0.79 ml/sec for 30 gauge side vented needles.	(Boutsioukis et al., 2009)
8	In vitro study (CFD based)	–	The effect of needle insertion depth on the irrigant flow and apical pressures.	Root canal simulation	• When velocity magnitude is compared, 30 gauge open-ended needles proved beneficial at all depths compared to 30 gauge side vented needles. • When wall shear stress is compared, 30 gauge side vented needles proved better than 30 Gauge open-ended needles at all depths. • When mean apical pressures were compared, 30 Gauge Side vented needles induced the least apical pressure values at all depths compared to 30 gauge open-ended needles.	(Christos Boutsioukis et al., 2010a)
9	In vitro study (CFD based)	–	The effect of needle design on the irrigant flow.	Root canal simulation	• When maximum wall shear stress was compared, syringe irrigation with a side vented needle proved better than syringe irrigation with an open-ended needle. • When velocity magnitude and intensity of turbulence is compared, syringe needle irrigation with an open-ended needle proved better.	(Chen et al., 2014)
10	Ex-vivo study (CFD Based)	–	The effect of needle design and needle placement on the irrigant flow and apical pressure.	Root canal simulation	• When fluid velocity is compared, 27 Gauge notched open-ended needle proved better compared to other groups. • When different volume flow rates are compared, varied results were obtained in different comparisons made.	(Šnjarić et al., 2012)

Table 1 (*continued*)

No	Study Type	Sample	Study objectives	Method of assessment	Outcomes	Ref
					• When the placement of the needle is compared, maximum fluid velocity was observed, when the needle was placed at 95% of working length. • When fluid pressure is analyzed, 27 gauge close-ended side vented needles are shown to induce lower pressure values than others. • When different flow rates are analyzed, 0.05 ml/sec generated the least flow rates in all the groups compared. • When the needle placement is compared, minimum pressure values were observed when the needle was placed 25% of working length.	
11	In vitro study (CFD based)	–	The effect of various needle designs on the irrigant flow and apical pressures.	Root canal simulation	• When velocity magnitude is compared, 30 Gauge bevelled open-ended needles were better compared to others. • When wall shear stress is compared, 30 Gauge multi vented closed-ended needle proved better. • When mean apical pressures were compared, 30 Gauge multi vented closed-ended needle yielded the least pressure values compared to others.	(Christos Boutsioukis et al., 2010b)
12	Ex-vivo study (Based on thermal image analysis)	7	The effect of needle gauge and needle placements on the irrigant flow.	Fluid flow recording using a camera of the thermal image analysis system	• When different needle designs were compared, 27 Gauge needle designs have shown a better irrigant flow in different preparations than others. • When depth to apex canal size is assessed, Needle placed 3 mm from the root apex showed positive irrigant flow in all groups compared to other compared variables.	(Hsieh et al., 2007)
13	In vitro study (Based on root canal model)	–	The effect of needle gauge and design on the irrigant flow and apical pressures at different evaluated flow rates.	Root canal simulation	• When irrigant flow was assessed in terms of dye clearance, 30gauge open-ended needles proved better to others. • When different flow rates on dye clearance were assessed, max clearance was observed at 4 ml/min in all the groups compared. • 30 gauge side vented needles elicited the least pressures when placed 3 mm and 1 mm from the apex. • When different flow rates were compared, 1 ml/min induced the least apical pressures compared to other groups.	(Park et al., 2013)
14	In vitro study (CFD Based)	–	The effect of needle tip design on irrigant flow and apical pressures at different needle placements.	Root canal simulation	• When wall-flow velocity is compared, 27 gauge side vented closed-ended needle proved better compared to other groups.	(Shen et al., 2010)

(*continued on next page*)

Table 1 (*continued*)

No	Study Type	Sample	Study objectives	Method of assessment	Outcomes	Ref
					• When apical pressures were evaluated, the side vented closed-ended needle induced the least apical pressures compared to other groups. • When needle placement is compared, wall-flow velocity was higher in all the groups, when the needle was placed 3 mm from the apex. • When the effect of needle placement on apical pressures is evaluated, the least apical pressures were recorded in all the groups, when the needle was placed 5 mm from the apex.	
15	In vitro study (Based on periapical pressure assessment model)	–	The needle gauge and needle design on the generated apical pressures at different flow rates were evaluated.	Pressure determination in the closed root canal system	• When both apical fluid pressure and apical pressure is compared, 30 gauge side vented closed-ended needles(Max-i-probe), proved to induce the least apical fluid pressures compared to 30 Gauge non-bevelled open-ended needle (NaviTip). • When different flow rates are analyzed, 0.5 ml/min induced the least apical pressure and apical fluid pressure in both the compared groups.	(Khan et al., 2013)
16	Ex-vivo Study (CFD Based)	5	The effect of needle designs on irrigant flow and apical pressures at different needle placements.	Root canal simulation	• The side vented demonstrated lower positive pressures and high shear stress. • A front vented needle was associated with higher apical pressures when used 1 mm short of the working length. • The notched needle has shown the lowest shear stress among the types compared.	(Loroño et al., 2020)
17	Ex-vivo Study (Periapical pressure assessment model)	12	The effect of needle design on the generated apical pressures.	Apical pressure assessment set-up	• Canal Type and needle of choice have influenced the generated apical pressures. • Closed-ended needles generated less apical pressures than open-ended needle types.	(Ordinola-Zapata et al., 2021)
18	Ex-vivo Study (Periapical pressure assessment model)	–	The different apical preparation sizes on the generated apical pressures.	Pressure assessment using apparatus	• With increasing apical sizes, the apical pressures reduced in syringe needle irrigation (30-Gauge side vented)	(Chen et al., 2021)
19	Ex-vivo Study (CFD Based)	60	The effect of root canal taper, apical preparation sizes on the irrigant flow and apical pressures at different needle placements.	Root canal simulation	• 30 sized 0.06 tapered proved efficient irrigant flow and induced the least apical pressures at all needle placements assessed.	(Sujith et al., 2021)

CFD – Computational Fluid Dynamic Analysis.

Study Question

- Population- Studies compared the simulated root canal canals of extracted human teeth or root canal models.
- Intervention/Comparision- Invitro or ex-vivo studies comparing the manual syringe needle irrigation.
- Outcome- Assessment of irrigant flow and apical pressure.

2. Materials and methods

2.1. Literature search

The literature search was conducted in May 2021 including medical libraries such as PubMed (Medline), Cumulative Index to Nursing and Allied Health Literature (CINAHL), EMBASE, Scopus and Google Scholar. Later, a hand search was conducted from independent peer-review journals such as the Journal of Endodontics, Scientific Reports, International Endodontic Journal, Journal of Conservative Dentistry, Australian Endodontic Journal, Dentistry and oral medicine archives. The systematic review followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (PRISMA, 2015). A search was carried out using multiple search terms and keywords including "root canal", "canal models", "virtual canal models", "extracted teeth", "extracted human teeth", "manual syringe needle", "manual needle", "irrigation", "in-vitro studies", and "ex-vivo studies" or by combining the words between them. Later, we applied the boolean operator "AND" to report the following search strings in PubMed, Scopus and CINAHL: "in-vitro and ex-vivo parameters 'AND' effects of apical pressure using manual syringe irrigation".

2.2. Inclusion and exclusion criteria

Studies or other material sources that were published before 2006 were excluded from our study because our study aimed to cover the latest studies that highlight different in-vitro and ex-vivo parameters on apical pressures and challenges associated with manual syringe irrigation. The papers on in-vitro and ex-vivo with various parameters involved in root canal irrigation are considered. Studies with the simulated root canals or extracted human teeth or root canal models are included. Interventions with comparing the manual syringe needle irrigation and assessment of irrigant flow and apical pressure were also included. Besides, studies with no english, clinical trials, animal studies, and studies comparing the irrigant extrusion are excluded.

2.3. Risk assessment

After document search, duplicate records are removed by reading the title and abstract. By applying inclusion and exclusion criteria rest of the papers were passed to evaluate risk assessment. The risk of bias was carried out by a customized tool by taking previous in vitro based systematic review literature in endodontics into consideration(Căpută et al., 2019;

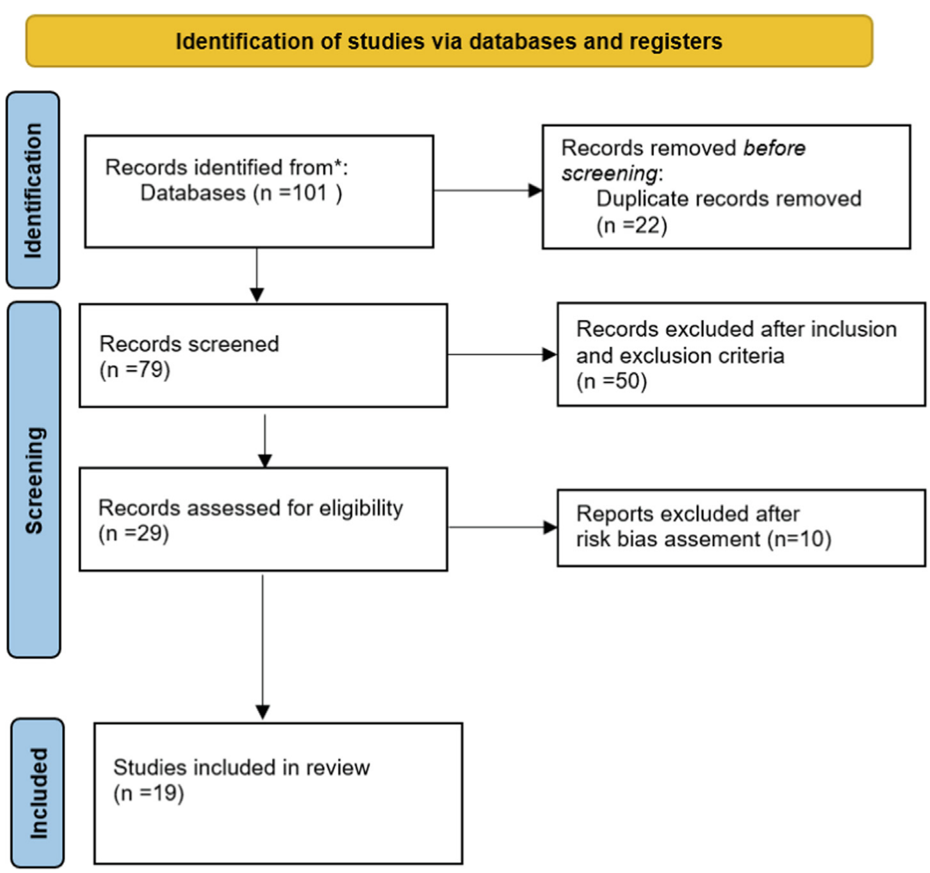

Fig. 1 Systematic review process with an explanation from PRISMA flow diagram.

Neelakantan et al., 2018). The study was assessed to have a high risk if it did not record a ''yes'' in three or more four main categories. Moderate if two out of four categories did not record a ''yes'' and low if adequate sample justification, randomization and assessor blinding were followed with appropriate study design.

3. Results

3.1. Search outcomes

The search identified 101 publications after the removal of duplicated studies 79 were to remain for further consideration. By applying inclusion and exclusion criteria, 29 items of left to conduct the risk assessment. During the risk assessment, all authors agreed to consider 19 papers and to do the final review (Fig. 1). No work from hand search literature is eligible for all criteria for inclusion. All the included studies have shown a high risk of bias, as they have mentioned details only on the stadardization of the preparation and root canal geometry after instrumentation. (Sujith et al., 2021), was also considered to have a high risk of bias, even after sample justification, as the study was unclear on the randomization and assessor blinding (Ref Fig. 2).

3.2. Study characteristics

A total of 19 studies were included in the present systematic review Table 1. These studies were further classified into two groups including 12 invitro studies (Boutsioukis et al., 2007; C. Boutsioukis et al., 2010a, 2010b; Huang et al., 2017; Wang et al., 2015), (Christos Boutsioukis et al., 2010a; Chen et al., 2014; Hu et al., 2019), (Christos Boutsioukis et al., 2010b), (Khan et al., 2013; Park et al., 2013; Shen et al., 2010), and 7 ex-vivo (Boutsioukis et al., 2009), (Šnjarić et al., 2012), (Hsieh et al., 2007), (Chen et al., 2021; Loroño et al., 2020; Ordinola-Zapata et al., 2021; Sujith et al., 2021) type. In which, 15 have comprehensively assessed on flow rates (C. Boutsioukis et al., 2010a, 2010b; Wang et al., 2015), (Boutsioukis et al., 2009; Christos Boutsioukis et al., 2010a, 2010b; Chen et al., 2014; Hsieh et al., 2007; Hu et al., 2019; Huang et al., 2017; Park et al., 2013; Shen et al., 2010; Šnjarić et al., 2012), (Loroño et al., 2020), (Sujith et al., 2021) and 15 discussed on the apical pressure (Boutsioukis et al., 2007; C. Boutsioukis et al., 2010a, 2010b; Huang et al., 2017; Wang et al., 2015), (Christos Christos Boutsioukis et al., 2010a), (Boutsioukis et al., 2010b; Hsieh et al., 2007; Park et al., 2013; Shen et al., 2010; Šnjarić et al., 2012), (Chen et al., 2021; Loroño et al., 2020; Ordinola-Zapata et al., 2021; Sujith et al., 2021). Besides, 11 were assessed based on computational fluid dynamic analysis methods (C. Boutsioukis et al., 2010a, 2010b; Wang et al., 2015), (Huang et al., 2017), (Christos Boutsioukis et al., 2010a, 2010b; Chen et al., 2014; Šnjarić et al., 2012), (Shen et al., 2010), (Loroño et al., 2020), (Sujith et al., 2021). Some studies reported usage of thermal image analysis (Hsieh et al., 2007), polycarbonate model (Boutsioukis et al., 2007), testing system (Boutsioukis et al., 2009), root canal model (Park et al., 2013), and three studies analyzed based on periapical pressure assessment models (Khan et al., 2013), (Chen et al., 2021; Ordinola-Zapata et al., 2021).

Whereas country distribution, six from Greece (C. Boutsioukis et al., 2010a, 2010b),(Boutsioukis et al., 2010c, d) (Boutsioukis et al., 2009; Christos Boutsioukis et al., 2010a; Hu et al., 2019), (Christos Boutsioukis et al., 2010b); four from China (Boutsioukis et al., 2007; Chen et al., 2021; Huang et al., 2017; Wang et al., 2015); three from Canada (Chen et al., 2014; Park et al., 2013; Shen et al., 2010); and two from Spain were (Loroño et al., 2020) (Ordinola-Zapata et al., 2021) reported. Rest was from Croatia (Šnjarić et al., 2012), Taiwan (Hsieh et al., 2007), Georgia (Khan et al., 2013), the USA (Chen et al., 2021) and India (Sujith et al., 2021). The detailed characteristics of all papers further investigated based on study type, objective, method of investigation, and outcomes are summarized in Supplementary material 1.

3.3. Description of the included studies based on the evaluated parameters

The parameters assessed in the included studies were irrigant flow pattern, velocity magnitude, wall shear stress, streaming velocity, apical pressure, irrigant replacement, irrigant exchange, irrigant delivery volume, intra barrel pressure, duration of irrigation, and intensity turbulence and irrigant flow. Factors assessed were needle type, needle design, needle placement, root canal preparation sizes, the taper of a root canal, facing of needle port (side vented needles), canal anastomosis, fluid flow rate, needle movement, frequency of needle movement, and needle gauge. Types of models and software used to assess the irrigant flow rates and apical pressures varied from one study to another. The model type or software used or the included studies differed. The complete study results were variable, and we cannot conclude a single parameter contributing to the enhanced irrigant flow and least apical pressures.

Although the method of evaluation for most of the included studies was similar, multiple parameters and factors were assessed in the included studies, considered for this review. So, in this section, we tried to give compiled data on the assessed factors and parameters that had a variation on the irrigant flow and apical pressures.

- Final preparartion size

Boutskioskis et al. has evaluated the effect of various final preparation sizes on the irrigant flow and apical pressure in (C. Boutsioukis et al., 2010a) and study results showed better velocity with 30 gauge open needles in 55 sized 0.06 preparations, whereas shear stress was better with 30 gauge side vented needles and 25 sized 0.06 preparation. 30 gauge side vented needles, with 55 sized 0.06 preparation showed least generated pressures.

- Root canal taper

In continuation, the same authors of (C. Boutsioukis et al., 2010a) also evaluated the effect of various preparation sizes and root canal tapers on irrigant flow and apical pressures (C. Boutsioukis et al., 2010b). The study results showed an increased irrigant flow with the least recorded apical pressures, in cases with increased root canal taper.

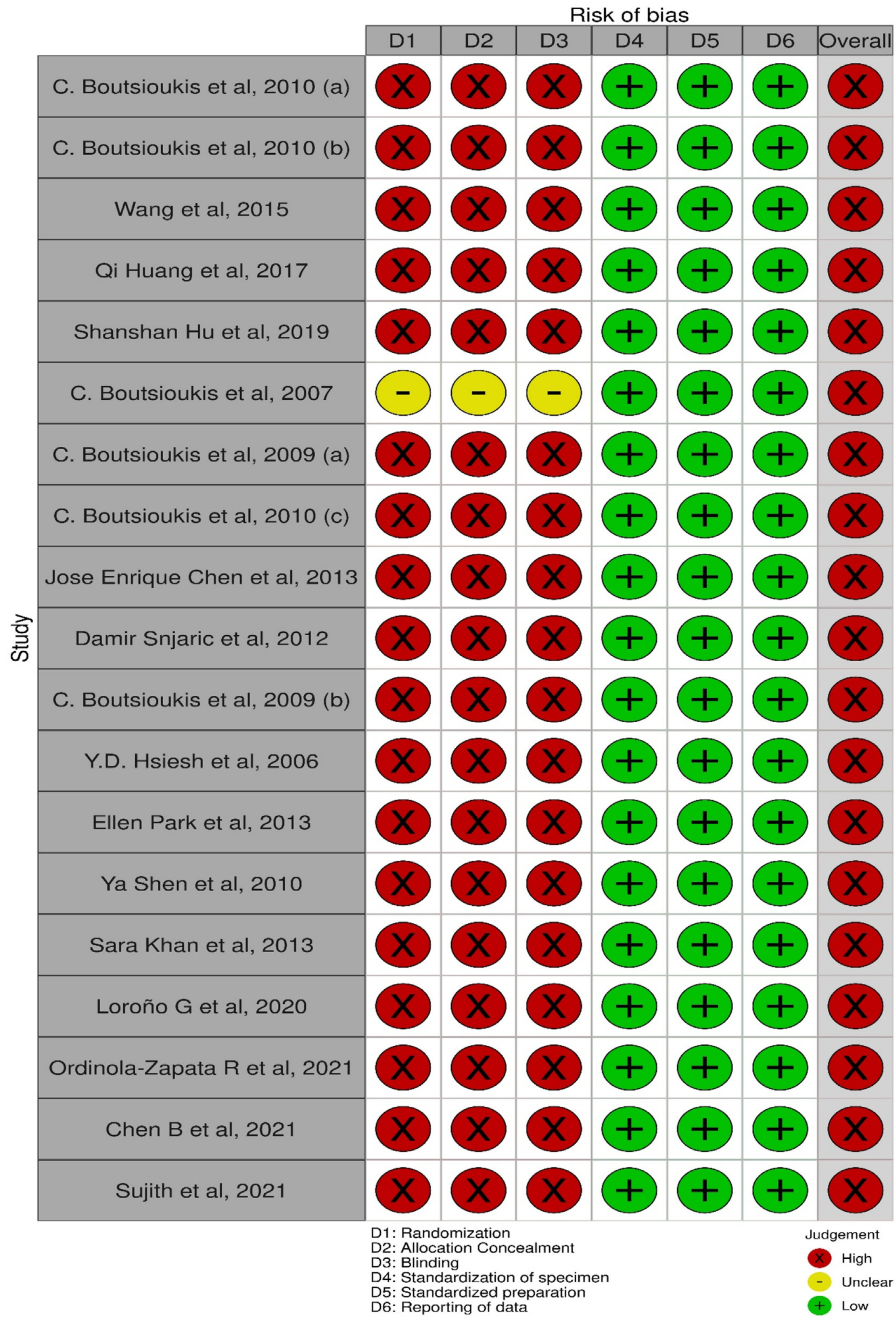

Fig. 2 Risk of bias graph.

- Needle type and needle design

The irrigant flow and apical pressure evaluation and the needle types assessed were similar to the previous study and this work revealed a better velocity with 30-gauge open-ended needle types in 60 sized 0.02 preparations (C. Boutsioukis et al., 2010b) and a better flow rate at 0.79 m/sec (Hu et al., 2019). Besides, closed vented side needles induced the least apical pressures at a 0.5 ml/min flow rate (Khan et al., 2013). These 30-gauge open-ended needles reported better shear stress (C. Boutsioukis et al., 2010b; Chen et al., 2014) and velocity magnitude at all needle depths (Christos Boutsioukis et al., 2010a).

Better velocity magnitude was observed with bevelled open-ended 30-gauge needle types, but wall shear stress was better and mean apical pressures less with multi-vented closed-ended needle types (Christos Boutsioukis et al., 2010b). The effect of needle gauge and design on the irrigant flow and apical pressures at different flow rates were studied by (Park et al., 2013). The authors highlighted the better irrigant flow rates with 30-gauge open-ended needles.

The effect of needle type, gauge and design on the irrigant flow, intra barrel pressure, duration and volume of irrigation with the extracted human permanent maxillary central incisors were assessed in one study (Boutsioukis et al., 2009). The side vented and monojet needles with gauges 25, 27 and 30 were assessed. Results found that 30-gauge side vented needles recorded a longer duration for irrigation with high intra barrel pressures. The volume of irrigant delivery and the average flow was better with 27-gauge and 25-gauge side vented needles respectively.

- Needle placement

Dye clearance was better at 4 ml/min flow rate in all the groups assessed and low apical pressures were noted when needles were placed 1 and 3 mm from the apex. But the effect of needle tip design on irrigant flow and apical pressures at different needle placements were observed with 27-gauge side vented closed-ended needles when placed 3 mm and 5 mm from the apex. The least apical pressures were elicited when the needles were placed 5 mm from the apex (Shen et al., 2010).

Similarly, another study assessed on 27-gauge closed and notched open-ended, and bevelled open-ended needles with different percentages of the needle placements from the working length reported flow pattern and velocity were better with a 27-gauge notched open-ended needle with the placement of 95% from the working length (Šnjarić et al., 2012).

The efficient irrigant flow was reported with 27-gauge needles when placed 3 mm from the root apex (Hsieh et al., 2007). However, it is also noted that 30-gauge side vented needles showed lower positive pressures with higher shear stress at the apical position. Front vented needles noted high apical pressures when placed at 1 mm short of the working length (Loroño et al., 2020). Besides, closed-ended needles generated lesser apical pressures than open-ended needle types (Ordinola-Zapata et al., 2021) and decreased apical pressures were noted on increasing the apical sizes on using syringe needle irrigation (Chen et al., 2021). A better irrigant flow with the least apical pressures in 30-gauge needles was reported in prepared single-rooted premolars when placed 3 mm from the apex (Sujith et al., 2021).

- Needle orientation

Wang et al., 2015 has evaluated the effect of the orientation of 30-gauge side vented needle on the irrigant flow and apical pressure and reported heterogeneous outcomes, but it revealed that needle orientation has been shown to influence the flow and apical pressures (Wang et al., 2015).

- Canal type and frequency of needle movement

Another similar experimental setup in (Boutsioukis et al., 2007) showed less pressure build-up in anastomosed canals, as the connecting channels allowed the irrigant distribution than single canal models. Frequent needle movement also improved the irrigant flow by keeping needles in motion with the amplitude of 3 mm at a frequency of 1HZ generated the slightest pressures and induced efficient flow (Huang et al., 2017). The seven included studies used different extracted specimens, study designs, needles and models for assessment of irrigant flow and apical pressures. Therefore, the extrapolation of study results was a little cumbersome.

4. Discussion

The present systematic review mainly aimed to evaluate the various parameters affecting the irrigant flow rate and apical pressure on using manual syringe needle alone for root canal irrigation based on in-vitro and ex-vivo reports. The main reason for performing a systematic review of the current topic was because the most challenging thing to standardize in endodontic therapy, especially in a clinical scenario, is manual syringe needle irrigation (Boutsioukis et al., 2007). The literature on the specific aspect is still confusing and comprehensive. Various studies were conducted at in-vitro and ex-vivo levels, and the data obtained from these studies are extensive. One cannot conclude a single parameter in the enhanced irrigation dynamics, especially in the crocked space of the root canal.

When the clinical translation of the present review is considered, there are various parameters, especially during manual syringe needle irrigation. Most of them are under the operator's control, such as taper, choice of syringe needle type and design, choice of the different volume barrels for irrigation, placement of needle from the estimated working length. By evaluating all these parameters, one can clinically translate these variables for enhanced irrigation in root canal space.

4.1. Compilation of study results and critical appraisal

The systematic review was comprehensive, and the data obtained from the different included studies was cumbersome, as multiple data was obtained and it was difficult to correlate the efficiency of irrigation to a single factor. So, we decided to compile all the study results according to the parameters and factors assessed and critically appraise its clinical application.

As mentioned previously, multiple factors and parameters were assessed to evaluate the efficacy of root canal irrigation using manual syringe needle irrigation. Firstly when each parameter was critically evaluated, the irrigant flow and irrigant flow pattern varied widely, and there is no single clear-cut parameter for its enhanced flow.

When velocity magnitude, turbulence, and streaming velocity is compared, both open-ended and bevelled or notched needles proved similar results. As the vent was large and facing towards the open space of the root canal either apically or lateral walls, the recorded velocity magnitude, turbulence and streaming velocity were higher. When the closed-ended side vented needles were compared, the facing was opening 2–3 mm short and the recoded values would be much lower than the other type of needles. The needle gauge selection was dependent on the taper and preparation sizes. In the narrow canals, with lesser preparation sizes, thinner gauge needles are preferred as they reach till apical one third. So, the irrigant delivery volume and irrigant exchange volume depended on needle type, design, and gauge.

The movement of the needle and depth of the needle placement was also a factor of interest, which plays a significant role in enhanced irrigant delivery. Stationary needles bound to canal walls will cause irrigant extrusion and increased apical pressures. Hence, it's always preferable to oscillate the needle in the canal placing 1–3 mm short of the working length.

When wall shear stress was evaluated, the side vented needle proved beneficial compared to any other type of needle. Irrigant wall contact is higher with the side vented needle, as the needle port directly faces the root canal wall. So, the induced shear wall stress is higher with a side vented needle. Whereas, with the open-ended and bevelled needle types, the opening port always faces the root apex. So, the irrigant flow is in an apical direction rather than in a lateral. Hence, the velocity and turbulence are higher in such needle types. The effect of needle gauge on wall shear stress is again dependent on the taper and preparation sizes. Included studies in the present systematic review revealed that decreased apical preparation sizes and tapers have shown higher shear wall stress as compared to the other sizes. But, the apical pressures recoded in optimally shaped canals are also higher in due course of irrigation. Hence, it is preferable to use a 30 or 31 gauge side vented needle in such cases.

When apical pressures were evaluated among the different flow rates assessed, 0.5–1 ml/min flow rates induced the slightest pressures with optimal 4 ml/min (Park et al., 2013). The reason is the increased apical pressure, with uncontrolled irrigant flow. So, the irrigant flow should be optimal to prevent the increased apical pressures and chances of irrigant extrusion.

When different needle types and designs are compared, side vented needles generated the most negligible apical pressures than other needle types. As for other needle types, the port will directly face the root apex. But for the side vented needle, the port faces laterally, causing more irrigant wall contact and less generated apical pressures. As usual, the choice of needle gauge depends on the taper and preparation sizes of the root canal. When the depth of needle placement is considered, needles placed 3 mm short of working length induced the least apical pressures. As the needle tip is nearer to the apex, the generated forces were also much higher. Hence, the generated apical pressures decrease, when the needle is placed short of the working lengths.

When the results on the effect of taper and apical sizes on the flow were assessed, the increased taper and apical preparation sizes improved the irrigant flow with the slightest apical pressures. Increased taper would allow the adequate placement of the needle to the working length, allowing the oscillation of the needle at preferred frequencies, leading to less binding of irrigation needle and thereby decreasing apical pressures.

As the systematic review is based on the in-vitro or ex-vivo based studies, results should be extrapolated for their clinical translation (Spagnuolo et al., 2013). Considering the limitations of the current systematic review, compiling all the study results for enhanced irrigation efficiency during syringe irrigation, it's preferable to use non-binding sided vented needles for irrigation with dynamic needle movement throughout the entire course of irrigation. The choice of needle gauge is preferable to be decided based on the canal taper and preparation sizes. When the needle placement is considered, it's preferable to be placed 1–3 mm short of working length during irrigation.

4.2. Future research

Although with the advancement of dynamic agitation devices, syringe needle irrigation should not be considered a neglected factor. The initial step in root canal irrigation is primarily syringe needle-based, which involves various dynamic mechanisms. Although the present review evaluated various in-vitro and ex-vivo level studies, none of them concentrated on the efficacy of irrigation in narrow and curved canals. So better future studies focus on this factor. The other crucial neglected factor to be studied is the intrabarrel pressure involved in root canal irrigation. Better, future studies formulate more on this aspect. Although studies proved increased taper and preparation showed enhanced irrigant flow with the least apical pressures, the concept of optimal shape is preferable in a clinical scenario (Teja and Ramesh, 2019) by employing passive root canal irrigating strategies (Teja and Ramesh, 2020). So better, future studies have to evaluate different shapes in different teeth with different curvatures to come to a conclusive remark on optimal flow and apical pressures. Again, we want to re-emphasize the importance of syringe needle irrigation, especially during the preparatory phases of the root canal treatment. Hence, the future scope is more in this aspect.

5. Conclusions

From this present systematic review, it is difficult to compile a single factor or a single parameter contributing to the enhanced irrigant flow and slightest apical pressures. The most studied and reliable parameters addressed were:

The choice of needle: 30 gauge closed-ended side vented needles induce the least apical pressures with improved wall shear stress. Larger diameter needles with open-ended and bevelled types showed increased irrigant flow with increased apical pressures.

Needle placement: Thinner gauge needles placed 3 mm away from the working length, oscillated continuously showed better irrigant flow and least apical pressures.

Taper and apical preparation sizes: Increased taper and apical preparation sizes would increase the irrigant flow with the least recorded apical pressures.

6. Ethical issues

No ethical issues were during the study presentation

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Declaration of Competing Interest

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