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REVIEW ARTICLE

Assessment of irrigation dynamics comparing syringe needle irrigation with various other methods of irrigation using computational fluid dynamics: a systematic review

ABSTRACT

The irrigation dynamics between conventional needle irrigation and other irrigation techniques were evaluated using computational fluid dynamics (CFD) in the current systematic review. Following the inclusion and exclusion criteria, three electronic databases (PubMed, Scopus and Cochrane) were searched until June 2022. Studies comparing conventional needle irrigation with various other techniques of irrigation were included. Two reviewers independently evaluated the retrieved articles. A total of 329 articles were obtained, from which 23 papers were included for full-text review. After exclusion of 18 studies, 5 articles were considered and included in the present systematic review. The risk of bias for in vitro studies was reported following modified JBI criteria and CRISS recommendations. The parameters assessed were shear stress, irrigant replenishment, velocity, turbulence, and apical pressures. It was observed that negative pressure irrigation technique was superior to positive pressure syringe needle irrigation, although the latter provided higher apical pressures.

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Introduction

The success of a root canal therapy largely depends on thorough disinfection. Syringe needles are most frequently used in daily practice for root canal irrigation (1, 2). When root canals are irrigated with traditional syringe needle irrigation, positive pressure is applied inside the canals (3). There are potential risks of irrigant extrusion beyond the periapical tissues in circumstances when an inadvertent breach of the apical foramen occurs, which could result in problems (4, 5)

Evidence from the literature stated that root canal disinfectant might not always reach the apical part of the canal when syringe needle irrigation techniques are employed (6-8). Additionally, studies revealed that the disinfectant solution has a very limited ability to penetrate canal complexities such as isthmus, lateral, and accessory canals (9, 10). Endodontic biofilm within the root canal should also be considered during the root canal treatment (11, 12). Dislodging the biofilm and improving disinfection are both crucial during root canal irrigation. Complete dislocation of the biofilm is impossible with the syringe needle irrigation solely (13). Since irrigation activation devices are negative pressure systems, they have been employed for better canal disinfection (14). Negative pressure irrigation devices improve the effectiveness of antimicrobial activity by enhancing the irrigant penetration into the apical third (15) and improving the biofilm dislodging within the root canal (16, 17). Additionally, studies have revealed that the root canal irrigant can reach the lateral, auxiliary canal, and isthmus by using the activation devices (18).

Although the aforementioned concepts are well accepted and documented in the literature, more studies are still needed to fully understand how different techniques of irrigation affect irrigation dynamics. Apical pressure, wall shear stress, turbulence, irrigant flow pattern, and exchange of irrigating solution are all components of irrigation dynamics (19). The dynamics of irrigation change depending on the type of root canal disinfection technique. Numerous techniques have been used in the literature to evaluate the dynamics of the irrigant, including apical pressure assessment devices (20, 21), dye clearance techniques (22-24), recovery trap devices (25), and computational fluid dynamics (CFD) analysis (26).

The CFD model provides thorough information on the dynamics of irrigant evaluating the various key parametrs (27). Therefore, the current systematic review aimed at assessing positive pressure syringe needle irrigation with other techniques evaluating irrigation dynamics using CFD.

Review

Data collection

The current systematic review was registered in Opensciencframework (OSF) registry (Identifier: DOI 10.17605/OSF.IO/YHF9X). Mesh terms and keywords were used during the electronic search in PubMed, SCOPUS, and Cochrane databases. The search was carried out until June 2022. To find more papers, a manual search and reference linking were conducted. Keywords used were "extracted teeth", "simulated root canal model", "computational fluid dynamics", "syringe needle irrigation", "manual root canal irrigation", "irrigation activation system", "positive pressure irrigation", "negative pressure irrigation", "fluid dynamics", and "irrigation dynamics". The review was prepared following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) standards. Basic information about study, characteristics, and assessment methods were all collected by two independent authors. In addition, data on variables such as study design, irrigant type, concentration, depth of needle placement and irrigant inlet flow rate were assessed.

Study questiosn

- Popultaion: studies assessing the sim-

ulated root canal models or extracted human teeth.
- Intervention: positive pressure irrigation systems.
- Comparison: other irrigation delivery methods.
- Outcome: assesment of irrigant dynamics and apical pressures.

Inclusion and exclusion criteria

This comprehensive review considered studies conducted on extracted teeth or simulated root canal models that evaluated irrigation dynamics analysed using CFD. Case reports, case series, review articles, and animal research were not included. The present systematic review was unable to pool data for a meta-analysis due to the heterogeneity of the included articles.

Risk of bias

The Joanna Briggs Institute (JBI) and Checklist for Reporting In-vitro Studies (CRISS) criteria were adapted to analyse the bias for in vitro studies. Different domains were considered to report the risk of bias such as experimental consition, blinding, incomplete data, standardization of specimen, standardization of preparation, reporting data. Based on the aforementioned standards, research was categorised across all fields as "low risk," "moderate concerns," or "high risk."

Search outcomes

Literature search resulted in 239 articles and 17 were excluded because of duplication. The rest of the 222 records were screened for applying eligibility criteria and 199 were excluded. Twenty-three articles were retrieved for full-text analysis according to inclusion and exclusion criteria. Because of no full-text access, 18 articles were not considered for review. Ultimately, five articles were considered for further analysis. The PRISMA flowchart summarizes the article selection process (Figure 3).

Study characteristics

Characteristics of included studies are presented in Table 1. Two studies were in vitro studies (28, 29) and three were ex vivo investigations (30-32). Three research articles evaluated the fluid dynamics in extracted teeth (28, 29, 31), whereas two studies assessed a model with simulated root canals (30, 32). Three studies included extracted teeth with varied morphologies (28-30). The maxillary canine was used in one study (28), mandibular premolars and oval canals of mandibular molars were considered for other studies (29, 31).

Fluid dynamic analysis comparing needle irrigation with various activation methods were assessed within included articles. Negative pressure systems were the majority of the activation devices evaluated in the included studies. Most of the articles used passive ultrasonic activation, v pro safe endo, endovac and aspiration cannula (28-32). Except for one study, which utilised pure water, the rest of papers utilised 1% to 5.25% sodium hypochlorite. The irrigation needle utilised was mostly positioned 1-3 mm from working length. One study has standardised the irrigant's inlet velocity at 6 ml/minute (29). Regarding the evaluation area, two studies (28, 29) analysed the fluid dynamics in the primary canal alone, whereas the apical ramification was assessed in one study (31). Two studies evaluated the irrigation dynamics in the primary, secondary, and isthmus regions (30, 32). Table 2 reports the outcome of the included studies.

Risk of bias

For in vitro research, the risk of bias was evaluated using modified JBI and CRISS criteria. The assessment of each domain was made as high, low, or with some concerns based on the signalling questions. In terms of reporting experimental conditions, four out five papers received a low risk of bias rating. When reporting blinding, all studies revealed a significant bias risk. Three out five studies that evaluated the uniformity of specimen and preparation reported insufficient data. As a result, all included papers had an overall high risk of bias (Figure 1 and 2).

The disinfection of the apical part of

Table 1
Study characteristics

Author and year	Parameters evaluated	Study design	Simulation using CFD (Teeth selection)	Study groups	Needle insertion	An inlet flow rate of needle	Region of assessment	The concentration of the irrigant
Chen et al 2014 (30)	Irrigant velocity, turbulence, Shear wall stress, intensity, overall flow patterns	Ex vivo	Root canal simulation	Group 1: syringe irrigation openended needle, Group 2: syringe irrigation with a side-vented needle, Group 3: Apical negative pressure. EndoVac using the micro-cannula. Group 4: Passive ultrasonic-assisted irrigation.	Group 1 and 2: 3 mm short of apex Group 3: point before binding Group 4: 1 mm from the apical terminus	Groups 1 and 2: 0.15 mL/s-inlet flow rate	Simulation of the primary and secondary canal, isthmus	Distilled water with a density r=998.2 kg m-3 and a constant viscosity m=1.0×10^{-3} kg/m-s.
Dhingra et al 2014 (28)	Turbulence of irrigants. Comparing passive ultrasonic and syringe. Irrigation. Assessment of continuous and intermittent. irrigating methods Removal of dentin debris.	Invitro	75 extracted single-rooted maxillary canines	Group 1: ultrasonic irrigation (3 min continuous flow) Group 2: ultrasonic irrigation (1.5 min continuous flow) Group 3: ultrasonic irrigation (3min intermittent flow) Group 4: 1.5 min intermittent flow ultrasonic irrigation Group 5: needle irrigation for 1 min.	3 mm short of working length	Flow-inlet at 0.1 g/s, and the turbulent intensity was set at 0%	Simulation of primary root canal	2% Sodium hypochlorite with a density equal to 1.04 g/cm^3 and viscosity 0.986×10^{-3}.
Widjiastuti et al 2018 (29)	Fluid dynamics simulation	Invitro	27 extracted-single-root mandibular premolars	Controlgroup: positive pressure irrigation system with side vented (closed-ended) needle. Group 1: positive-pressure irrigation (open-ended needle). Group 2: Negative pressure irrigation system [V pro Endo Save].	Not mentioned	Not mentioned	Simulation of primary root canal	2.5% Sodium hypochlorite
Lorono et al 2020° (32)	Irrigant pressure, Velocity Shear stress	Ex vivo	Root canal simulation	Groups 1: Positive pressure needle. Group 2: negative pressure (aspiration cannula).	Group 1 and 2: 3 mm short of apex	Inlet flow rate 0.18 mL/s	Simulation of primary, secondary canal and isthmus	1% sodium hypochlorite with 1.04 g/cm^3 and 0.9998 Pa-S viscosity
Lorono et al 2020b (31)	Irrigant flow, irrigant velocity, shear wall stress, apical pressure	Ex vivo	Mandibular molar with oval root canal	Group 1: Positive pressure needle Group 2: Negative pressure	Positive pressure: 1 mm from working length Negative pressure: 3 mm from working length	Inlet flow rate 0.1 g/s (6 ml/min)	Apical ramification	5.25% sodium hypochlorite

the root canal system is crucial for the treatment's success (33). It's not optimal to only rely on the conventional needle for root canal irrigation, as the irrigant cannot reach the canal complexities (34). This systematic review compared syringe needle irrigation to other techniques of irrigant activation to evaluate the differences in irrigation dynamics. Different fluid dynamics are elicited by various activation systems, eventually altering the debridement outcome. It's widely known that the use of syringe needle irrigation causes a vapour lock effect, which prevents irrigant penetration (35, 36). On the contrary, reports showed

Table 2
Outcome evaluation

Author and year	Shear wall stress	Irrigant flow	Velocity	Turbulence	Irrigant exchange	Apical pressure	Outcome
Chen et al 2014 (30)	Group 1: 185 Pa Group 2: 425 Pa Group 3: 45 Pa Group 4: 875 Pa	Group 1: 1.5 mm apical to needle tip Group 2: 0.5 mm apical to needle tip Group 3: not mentioned Group 4:reported negligible	Group 1: 7.0 m s-1 at the exit of the needle Group 2: 1.0 m s-1 Group 3: Not mentioned Group 4: Not mentioned	Group 1: 70% Group 2: <10% Group 3: not measurable Group 4: >96%	Parameter not addressed	Parameter not addressed	The needle with an open end had a higher wall shear stress than the needle with a side vent. Passive-ultrasonic irrigation had the highest velocity magnitude and the least amount of wall shear stress compared to the apical negative pressure method of irrigation.
Dhingra et al 2014 (28)	Not addressed	Not addressed	Not addressed	Group 5- Highest turbulence at the apical one-third of the root canal	Parameter not addressed	Parameter not addressed	The needle should be kept loose in the canal and kept short of the working length, as evidenced by the fact that the exit had the highest turbulence.
Widjiastuti et al 2018 (29)	Not addressed	Not addressed	Not addressed	Parameter not addressed	Mean (SD) of the distance between the apical end and the peak of the irrigation solution Control: 2.209 (0.001) Group 1: 0.441 (0.005) Group 2: 0.068 (0.015)	Parameter not addressed	The negative pressure irrigation system can reach the apical end more effectively than positive pressure irrigation
Lorono et al 2020° (32)	FE-1628.44 Pa FEC-1256.87 Pa FEM-1185.69 Pa LE-1298.24 Pa LEC-1355.24 Pa LEM-1261.36 Pa	Parameter not addressed	FE-8.44 FEC-8.59 FEM-8.63 LE-8.48 LEC-8.61 LEM-8.61	Parameter not addressed	Parameter not addressed	FE-131100 Pa FEC-168328 Pa FEM-171748 Pa LE-130893 Pa LEC-144932 Pa LEM-149647 Pa	FE and FEM, showed irrigation flow through the isthmus in the most apical section
Lorono et al 2020b (31)	SV1-4.5 mmHg SV3-0.9 mmHg FV1- 3.8 mmHg FV3-1.1 mmHg N1-0.9 mmHg N3-0.4 mmHg MiC-0.6 mmHg	SV3-flow lower in the most apical area & apical ramification. SV1-generalized fluid flow in the main canal but not near apical ramification. FV3-reduced flow in the apical 2 mm. V1-flow in apical few millimeters of the main root canal and the apical ramification. N3-reduced flow with no evidence in apical area. N1-irrigant reached the main canal but no flow in apical ramification. MiC-irrigant flows the entire canal.	SV1 & 3-the flow velocity is low in an apical ramification FV 3-low velocity in an apical direction FV 1-medium- High velocity last few apical millimeters N3-low velocity in the two most apical millimeters. N1-medium velocity in the main canal. MiC-velocity was low	Parameter not addressed	Parameter not addressed	SV1-12 mmHg SV3-1.5 mmHg FV1-52.5 mmHg FV3-14.3 mmHg N1-19.5 mmHg N3-8.3 mmHg MiC-3.4 mmHg	SV needle- reduced positive pressure and increased shear wall stress. FV1 needle-increased apical pressure. The notched needle showed least irrigant flow at the apical ramification and the reduced shear wall stress was reported with positive pressure needles Microcannula generated better irrigant flow in the ramification with negative apical pressure values but, had reduced shear wall stress and irrigant velocity.

LE-Lateral Exit Needle, FE-frontal exit needle, LEC-Lateral Exit and cannula in the crown, FEC-frontal exit and cannula in the crown, LEM-LE and cannula in middle third, FEM-Frontal exit and cannula in the middle third.
SV1-side vented 1mm from working length, SV3- side vented 3mm from working length, FV1- front vented 1mm from working length, FV3- front vented 1mm from working length, N1- notched needle 1mm from working length, N3- notched needle 3mm from working length, MiC- Microcannula.

Figure 1

Study	Risk of bias D1	D2	D3	D4	D5	D6	OVERALL
Chen et al 2014	✚	✖	✖	✚	✚	✚	✖
Dhingra et al 2014	✚	✖	✖	✚	✚	✚	✖
Widjiastuti et al 2018	✖	✖	✚	✚	✚	✖	✖
Lorono et al 2020 (31)	✚	✖	✚	✚	✚	✚	✖
Lorono et al 2020 (32)	✚	✖	✖	✚	✚	✖	✖

D1: Experimental condition
D2: Blinding
D3: Incomplete data
D4: Standardization of specimen
D5: Standardization of preparation
D6: Reporting data

Judgement
✖ High
✚ Low

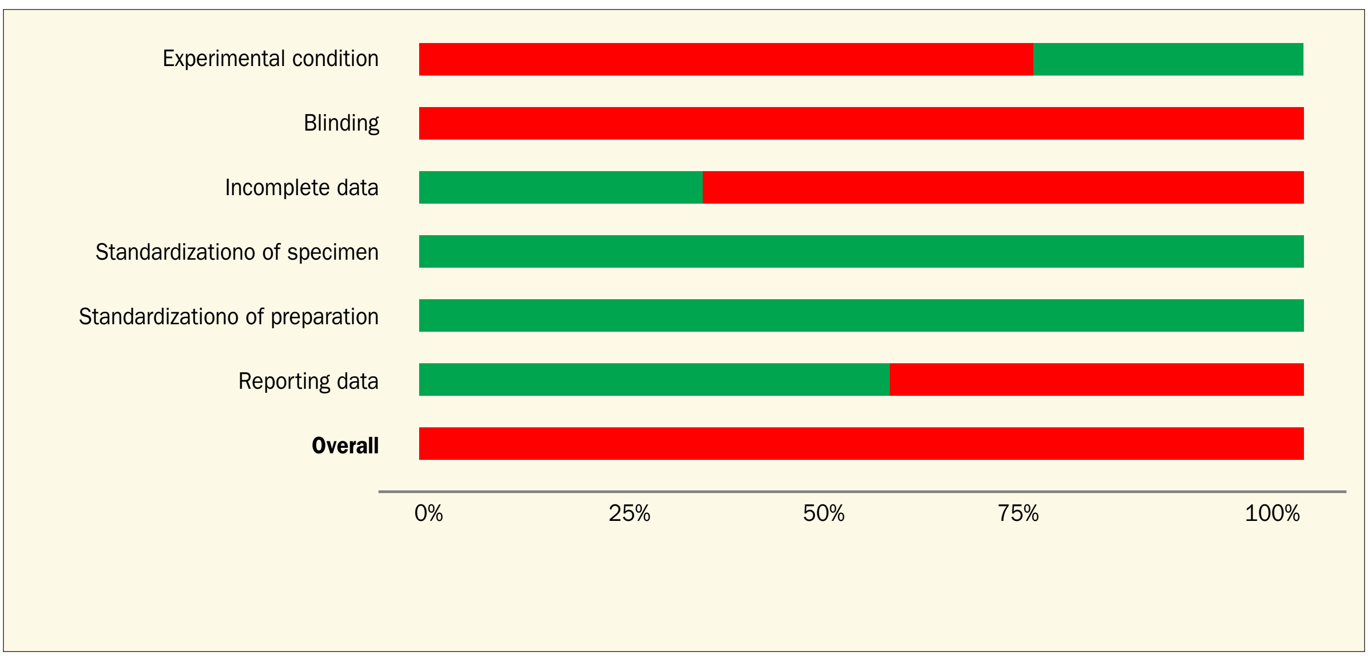

Figure 2

that the use of activation devices eliminates vapour locks (36). Study results showed that dislodging a vapour lock that had formed may be accomplished by irrigating at 0.260 mL/s (35).
Previous researches discussed the significance of wall shear stress (26, 37). The effectiveness of irrigant agitation is inversely proportional to the extent of an irrigant's wall contact (38). Although the pressure created in the canal varies, previous study reported an increased wall shear stress at pressures of -35 mmHg and flow rates of 0.5 to 8 mL/min. According to Lorono et al. (31), passive ultrasonic activation demonstrated a higher apical pressure compared to needle irrigation, whereas micro-cannula showed a reduced value.
The shear wall stress is significantly influenced by the root canal's taper. Studies demonstrated that even a small amount of taper preparation can increase wall shear stress (26, 37). Preavius reports

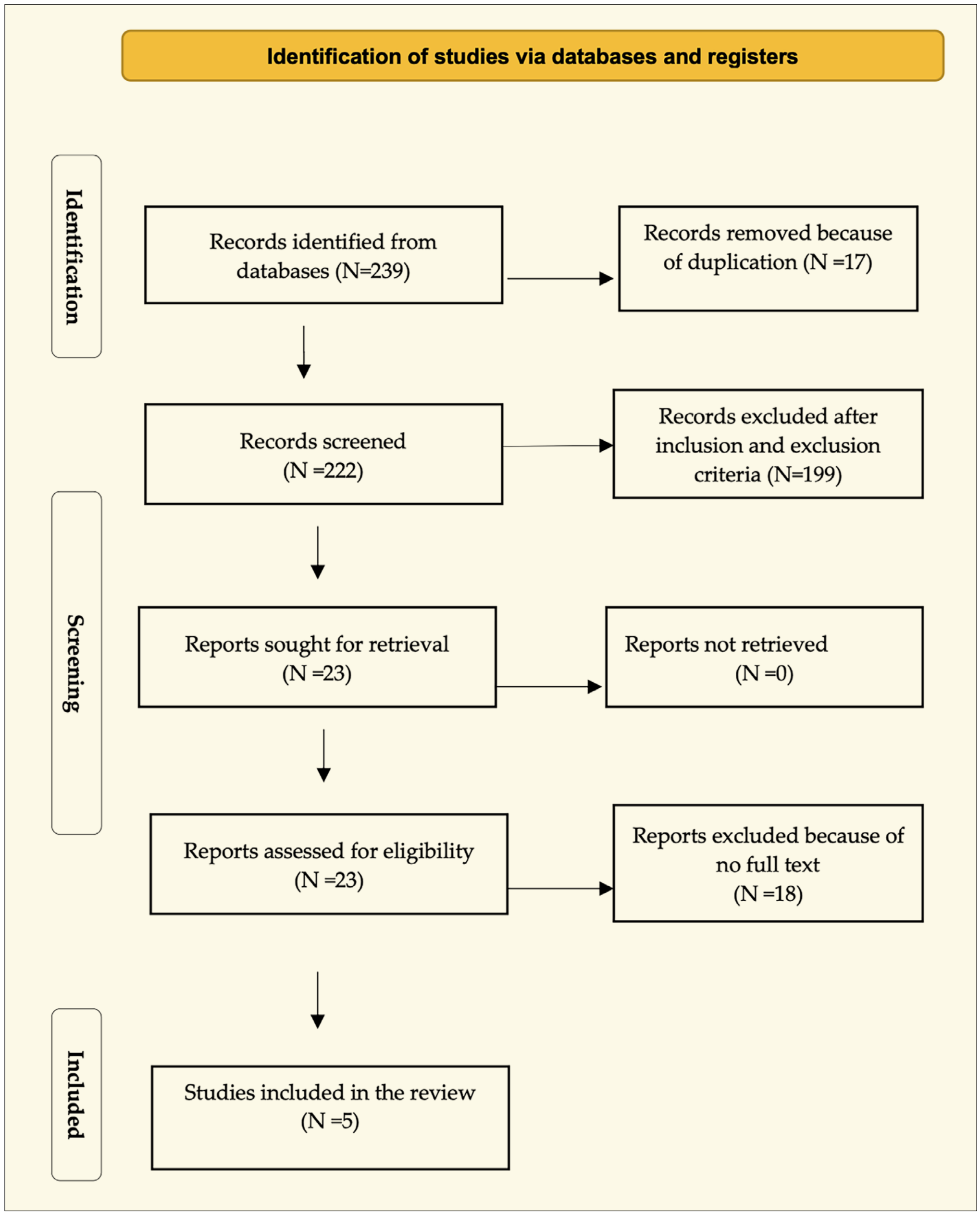

Figure 3
PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only.

indicated that shear wall stress may be generated with a preparation size of 25/04 (26, 37). Three included studies reported canal taper and sizes between 35/06 and 40/06 (28, 29, 31). However, it became clear that larger preparation sizes allowed better irrigant replenishment as compared to 25/06 when evaluating the replacement or exchange of irrigant in the apical third (39-41). Wall shear stress helps in the biofilm detachment from the root canal walls. Whereas in cases of larger canal preparation, the effect is negligible as a result of decreased wall shear stress (42).

It's questionable to maintain the balance with the flowing liquid and created apical pressures during root canal irrigation. Increasing taper to more than 35/06, reduces the apical pressure and wall shear stress. One of the included study showed a reduced shear stress when comparing a negative pressure micro-cannula to a positive pressure syringe needle (31).

In addition, when a negative pressure method was used as opposed to syringe needle irrigation, there was a noticeable increase in shear stress in the isthmus area (32). Endovac showed lesser shear stress compared to passive ultrasonic irrigation while contrasting two negative pressure systems (30). Shear wall stress is elicited better with the side-vented needle types as compared to the open-ended ones (30).

Teeth with increased diameters and tapers reduce irrigation extrusions (43, 44). The apical pressures and irrigant flow are also influenced by the canal's curvature (45) and the root canal's morphology (46). The vent of the needle being utilised typically affects the pressures that are created (21, 47). Compared to a side-vented needle, an open-ended needle generates more apical pressure. It was clear that an open-ended needle could irrigate the apical end more effectively than a closed-ended needle. It's been reported that front-vented needles increased apical pressure as compared to micro-cannula irrigant disinfection (31). In addition, needle with a side vent reported lower apical pressure than one with a front vent (31).

Apical pressure is reported to be directly proportional to the irrigation flow rate. Indeed, a flow rate of 4 ml/min can effectively reach the apex and generate enough apical pressure (23, 26, 48); moreover, the flow rate varies depending on the needle type (49). Only five articles have compared syringe needles to other methods of irrigant activation within the scientific literature.

Another important parameter of irrigation dynamics is the turbulence of the flowing fluid. Clinically various irrigating solutions help in adequate debris removal and canal contents (50, 51). However, the turbulence of flowing liquid helps in enhancing the ability of the disinfectant solution. The inlet velocity has a significant impact on the irrigant's turbulence. The irrigant inlet velocity in three of the included articles was kept at 6 ml/min. Only two articles have compared the turbulence on using syringe needle irrigation with irrigant activation systems (28, 30). Comparing the various syringe designs, open-ended syringes were found to produce more turbulence than side-vented needles. Additionally, it was noted that the irrigant velocity was high with an open-ended needle (7 m/s) and low with a side-vented needle (1 m/s). Endovac had the least turbulence as compared to passive ultrasonic activation (30). It was stated that, to accomplish maximal disinfection, it is imperative to sustain maximum turbulence at the outflow where the needle does not bind the canal. Syringe needle irrigation had the least turbulence, according to Dhingra et al. (28) that assessed the turbulence of fluid in ultrasonic irrigation and syringe irrigation.

Overall the results of the present systematic review showed favourable results in terms of fluid flow with least recorded pressures in negative pressure irrigation systems. The negative pressure irrigation system outperformed the syringe needle irrigation in terms of irrigant replenishment because it allowed adequate irrigant penetration to the apical third.

The main limitation of the current systematic review was represented by the inclusion of in vitro studies that reported a high risk of bias and might have questionable translation on clinical settings. In addition, since multiple factors and parameters were evaluated, a meta-analysis was not possible. Future high quality laboratory researches are more warranted on this topic to get a conclusive evidence.

Conclusions

Negative pressure irrigation technique was superior to positive pressure syringe needle irrigation, mainly in terms of irrigant replacement and enhanced flow, that may reduce the irrigant extrusions. However, higher apical pressures were demonstrated by the positive pressure irrigation systems.

Clinical Relevance

Current systematic review assessed the irrigation dynamics on using various irrigation systems. Negative pressure irrigation system showed better irrigant replacement and enhanced flow. So considering the clinical scenario, negative pressure irrigation systems shown to reduce the irrigant extrusions with enhanced flow.

Conflict of Interest

None.

Acnowledgements

None.

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