GRADUATION PROJECT

Degree in Dentistry

IRRIGANTS IN ENDODONTICS

Madrid, academic year 2022/2023

Identification number: 96

ABSTRACT

Introduction: Irrigation is considered the most important step to correctly realize an endodontic procedure, since it enables antimicrobial agents and mechanical tools to remove debris, waste products and pulp remnants from the internal walls of the radicular canals of teeth. Irrigating agents, better known as irrigants, are fundamental for such purpose. **Objectives**: The primary objective of this review was to state whether or not we have available today, an irrigant capable of eradicating all debris and microbes from a root canal., secondary objectives were to explain irrigating solutions in general, specifying their features and usefulness together with a research for the best-available irrigant to be employed in an endodontic treatment. In addition, this work wanted to compare many final irrigation protocols upon results in terms of intracanal-depuration. **Materials and methods:** the information and articles supporting this review, were gathered via reliable sources such as government sites, PubMed, Journals of Dentistry and Journals of Endodontics, the online library Biblioteca CRAI and all the information that was not up to date (a decade) or unsafe was discarded.
Results: after applying the including and strict excluding criteria, 71 articles in total were found, only five articles were chosen and added to the other 23 articles included, in order to reach the objectives. **Conclusions:** after comparing the results of the articles, it was concluded that currently there is no irrigant capable of cleaning a canal by itself, destroying 100% of the bacteria and debris without a complementary chemical.
Furthermore, it is emphasized that newer irrigation protocols yield better results, however there isn't an agreed protocol superior to all the other, since experts have different modalities and it is rather the expertise of the specialist that makes a difference than the type of final irrigation procedure.

Keywords: Dentistry, Smear Layer, Sodium Hypochlorite, Endodontics, irrigation systems.

RESUMEN

Introducción: La irrigación se considera el paso más importante para realizar un procedimiento de endodoncia, ya que permite que los agentes antimicrobianos y las herramientas mecánicas eliminen los desechos y restos pulpares de los conductos radiculares de los dientes. Los agentes irrigantes son fundamentales para tal fin.

Objetivos: El objetivo principal de esta revisión fue verificar si tenemos o no disponible en la actualidad, un irrigante capaz de erradicar todos los desechos y microbios de un conducto radicular. Los objetivos secundarios fueron explicar que son los irrigantes en general, explicando sus características y utilidad en conjunto con la investigación del mejor irrigante disponible hoy en día para ser empleado en un tratamiento de endodoncia. Además, este trabajo pretende comparar diferentes protocolos de irrigación final en términos de depuración intracraneal.

Materiales y métodos: la información que sustenta esta revisión fue recopilada a través de fuentes confiables como sitos gubernamentales, PubMed, la biblioteca "Biblioteca CRAI dulce Chacón". Toda la información que no estuviese actualizada (mas de una década) o desconfiable, fue descartada.

Resultados: una vez aplicados criterios de inclusión y exclusión, se encontraron 71 artículos. Se eligieron cinco artículos y se agregaron a los otros 23 ya incluidos, para poder alcanzar los objetivos elegidos.

Conclusiones: se concluyó que actualmente no existe un irrigante capaz de limpiar un conducto por sí solo, destruyendo el 100% de las bacterias y desechos sin otro químico complementario.

Además, se destaca que los protocolos de irrigación más nuevos dan mejores resultados, pero, de momento, no existe un protocolo superior a todos los demás, ya que los expertos tienen diferentes modalidades y es más bien la pericia del especialista que el tipo de procedimiento de irrigación elegido lo que marca la diferencia.

Palabras clave: Odontología, barrillo dentinario, hipoclorito de sodio, Endodoncia, sistemas de irrigación.

INDEX

1. INTRODUCTION:

1.1 Background:

Endodontics is the branch of dentistry that studies how to resolve infections affecting irreversibly the pulp of a tooth. Irrigation is regarded among endodontists as the most important proceedings in an endodontic treatment (1). In fact, a correct irrigation is fundamental and only achievable if the right irrigants are applied. Explaining irrigation, it could be described as a complement to mechanical removal of intracanal content., however in reality, it ends up being a more important procedure than mechanical instrumentation itself since with both manual and automatic files alone, it is impossible to remove properly the biofilm adhered to the canal walls and reach the complete anatomy of the conduct system. Irrigants are able to cleanse the root-canals of a tooth further than a mechanical instrument because liquids have high capillarity, especially Sodium Hypochlorite (NaOCl), and that's how Irrigation aims to eliminate bacteria and the smear layer (2). The Smear layer is a coat of organic and inorganic material, bacteria, and their products, and when the root canal of a tooth is submitted to instrumentation with files, the smear layer forms covering all the internal walls of such canal harboring bacteria, and their toxins, complicating subsequent sealing of the canal with the gutta-percha cones or other biocompatible materials (1,2).

Moreover, another major problem that comes with this layer is that it is almost always present in the last and more challenging third of a root-canal., the smear layer prevents irrigants and medications from reaching the site of action, and again may also difficult gutta-percha adaptation and correct tooth-sealing which many times implicates the need for a re-treatment (3).

Surely, the smear layer is still a very controversial topic since there is evidence supporting its complete removal (2). But on the other hand, it is also believed that further studies and investigations are needed to state with certainty whether or not the smear layer needs to be completely removed for root-canal therapy to be effective and long lasting., some authors may even consider preserving it to avoid deeper damage to the tooth's hard structures and future retention (3).

We will be able to untangle this controversy, throughout this work.

In endodontics currently, there are many irrigating solutions (commonly called irrigants), with different properties that allow dentists to perform a root canal debridement with high efficiency rates (1). Speaking about **irrigants**, we can recognize a group called “chelants” which is of primary importance for many irrigation protocols.

Chelants, or chelating agents, were introduced in endodontics primarily to soften the root canal dentine and dissolve the non-organic smear layer thus achieving a better disinfection of the inside of different root canal systems, regardless of their anatomical complexities (4).

Ethylenediamine tetraacetic acid (**EDTA**) is the most known chelating agent., it is an irrigant usually used as a final rinse to remove the smear layer (2).

It is is a suspension having lightly-alkaline PH, that can bind to metals, and reacts to calcium ions present inside the tooth dentine, forming “calcium chelates” which are are soluble compounds (1,3).

EDTA is really widespread nowadays, it is used by the majority of the specialists and it is consistently preferred to other chelating agents such as Citric Acid because it has better overall performances and even lower toxicity., it is less harsh on the remaining dentin of the tooth and such property is kept in high regards since it improves the prognosis of the tooth receiving the endodontic treatment (5). Continuing, it is important to mention that EDTA is used mostly to remove the non-organic components present in the smear layer and it is preferred in the liquid form to the pasta-type, since the liquid EDTA has higher spread, yielding better results (3).

Modern literature advises to be careful with the use of EDTA since it reacts with Sodium Hypochlorite, causing NaOCl antimicrobial activity to diminish or even nullify (1).

However, many irrigation protocols still consider the use of EDTA especially in the last steps of a root canal treatment, but in order to avoid the interaction between EDTA and NaOCl, Endodontists recommend using saline water applications in-between such agents (6).

Continuing with chelating agents, we also have the already displayed **Citric Acid**. Considered one of the first irrigants ever used in endodontic treatments, it is the precursor of the modern, already stated, Ethylenediamine tetraacetic acid. Advanced endodontists today, avoid completely using citric acids since it has many limitations compared to EDTA, so we may want to consider citric acid (CA) as “in disuse”

(7). Some studies also, show that citric acid just like EDTA, may interact with **Sodium Hypochlorite (NaOCl)** causing internal erosion of the roots, especially when NaOCl was used right after Citric Acid, imposing thus, another contraindication for its use (8).

When talking about irrigating agents, it is impossible not to mention Sodium Hypochlorite (**NaOCl**), which is fundamental for the vast majority of the irrigation procedures that are carried out today. As EDTA is used for the inorganic matter, on the other hand, Sodium Hypochlorite is employed to dissolve the organic matter present along the roots' internal walls (3). Many times, during an endodontic treatment, the root canals present necrotic tissue and reservoir of bacteria that may be only removable by such irrigant., among specialized dentists, it is shared the idea that Sodium Hypochlorite is a very strong solution, perhaps the determinant agent when talking about pulp remnants and more in general, intracanal organic-matter dissolution (6).

The higher the concentration of NaOCl, the better the organic dissolution, but also the higher the weakening of the dental structure since the dentin mechanical strength is reduced. Besides, Sodium Hypochlorite not only weakens the dentin walls when improperly utilized, it can also cause accidents of serious importance (1,6). Many times, in our day to day practice, we come across a patient that experienced the infamous "hypochlorite accident" and we all agree that it is a serious hazard that has to be avoided by both, general dentists performing a simple endodontic treatment or masters of such branch. Continuing with the most commonly known irrigating solutions, we also have Chlorhexidine (**CHX**), commonly used either as an anti-microbial or as a lubricant, useful especially if applied in-between other solutions as long as we remove the traces of other substances (NaOCl, EDTA…) from the inside of the canal before applying it since unwanted interactions may occur (9). Among positive features of chlorhexidine from an endodontic point of view, we find its strong antibacterial effect that suggests its use as a complement compound for proper intracanal disinfection (1,10).

Chlorhexidine is odorless, water soluble, bio-compatible and has an alkaline ph., it may be applied after EDTA, even though evidence suggests to properly remove EDTA traces before chlorhexidine placement in order to prevent interplays between such chemicals that often leads to precipitates formation obstructing dentinal tubules (9,10).

Among disadvantages of chlorhexidine, the most eye-catching one is undoubtingly its inability to dissolve organic matter, present inside the root-canal (11).

In endodontics, thorough pulp removal is a primary-importance concern.

This latter disadvantage (incapacity to dissolve tissues), may be the reason why many specialists today prefer other irrigants to it, or decide to use it only to provide further antimicrobial action and not as the main solution (9,10). Subsequently, chlorhexidine has one more defect., it interacts not only with EDTA, but also with Sodium Hypochlorite. This interaction too, happens more commonly when no in-between solutions are applied inside the canal (such as saline solutions). The association of NaOCl and CHX results in the formation of "parachloroaniline" (PCA), a brownish-orange precipitate that impedes proper sealing of the obturation (10,11).

However, apart from the mentioned limitations, knowing it can be used as a lubricant, complement and intracanal medicament too, chlorhexidine may still be considered as a "standard compound" to be used in endodontic treatments, providing incredibly clean dentin walls (1). Endodontics is a continuing-renovating field, in fact as the years pass by, newer irrigants come up with innovative actions and capacities. Talking about new compounds used today as irrigants we find the so called **MTAD** (full name is Mixture of Tetracycline, acid and detergent).

This compound, as the name also suggests, is a mixture of the antibiotic Doxycycline, a detergent called tween 80, and the chelating agent citric acid. It is becoming more and more known for its antimicrobial activity, and the capacity to remove and dissolve completely the smear layer and the necrotic pulp remnants attached to inner linings of radicular systems (12).

Not only it dissolves remnants of undesired material, but it has also high substantivity just like chlorhexidine., Having high substantivity means that MTAD is absorbed by the tooth dentin and gradually released, having a longer action span and providing antimicrobial action constantly, while this chemical is also able to dissolve tissue, unlike chlorhexidine (10,12). After showcasing MTAD, we move forward with **Tetraclean.** It is an irrigant derived from the mixture of an antibiotic mostly bactericidal, a detergent and an acid (13). As we can observe, there are many similarities with the previously presented solution, the MTAD. Doxycycline in fact, is again present but differs in concentration (50mL this time). Regarding the available evidence, there are studies showing that tetraclean may be even more effective than sodium hypochlorite itself

when it comes to inhibiting the growth of certain bacteria, for example the Enterococcous Faecalis.,

However, we must mention that Sodium Hypochlorite is still considered more effective against bacteria that are anaerobic (13).

Continuing with newer findings, there is another, unusual for many, high-performing compound that we have to mention, and it is Ozone or better called "**Ozonated Water**"**.** This irrigant can be used for the proper disinfection of root canal systems, may even having similar to better results than more commonly known solutions such as NaOCl.

After revising reliable information, it is shareable to state that Ozonated water is a very good solution, with a similar disinfection capacity when compared to NaOCl, which has always been the role model for disinfection in endodontics. Anyway, it is not possible to claim with certainty that ozonated water is better than other irrigants and that it should be prioritized. Actually, further investigations are needed since Ozonated Water has been discovered only recently as an irrigating agent for endodontic purposes (14).

Finishing the search for the newest and most innovative irrigants used today in high-tech clinics we have the **Herbal irrigants**. There is a recent trend that is focusing on using herbal extract as irrigants to cleanse and heal the canals of irreversibly inflamed pulps and necrotic-pulp teeth. These Herbal irrigants are still being studied and they are totally new, that's why there is not a real classification for them yet., However, some experts have already tried not only to give a classification of such rising compounds but also there is data explaining the properties and characteristics of such novel-agents. There are herbal irrigants with chelating ability, just like neem leaf extract., but also others that can even dissolve organic matter like Sapindus mukorossi extract (15). It is fundamental to say though, that these newest irrigants may be used in conjunction to NaOCl (as a supplement to it) since if used alone they may not be as efficient as common irrigants are (12). After having described the chemicals that nowadays, dentists and experts in endodontics use in the daily practice, we now have to analyze the concept of irrigant enhancement, better known as activation of the irrigating solution.

When an irrigating agent, for instance Sodium Hypochlorite, is applied into the inner lining of a radicular canal, it will provide its action regardless of additional enhancement as we have seen previously in articles (1,2,3,4…), however "activation" is almost considerable as a mandatory act as of today.

1.2 Concept of Activation of an irrigant

The term “activation” refers to all the methods by which an irrigating solution is potentiated to better perform its own actions (cleansing, lubrication, antimicrobial coverage…) and to reach further in the full anatomy and complex ramifications of the canals of a tooth. Traditionally in the past, irrigants were not activated when inserted inside the canal walls. Nowadays the majority of the specialists instead, use activation techniques since it is known that they provide better outcomes especially when having to cope with more complex cases (16).

Currently, there are many different types of activation techniques and depending on the specialist’s own opinion, one activation method may be preferred to another.

The conventional technique for root canal preparation comprehends mechanical removal and the application of some irrigating solutions that have antibacterial properties, such as chlorhexidine for example. The first activation technique we are going to see is the manual dynamic activation technique. It is a common, pretty standard technique., in which the irrigation-fluid is placed in position and then it is activated via a gutta percha cone inserted into the canal and quickly agitated. This technique enhances the irrigating solution reach and performance. Moreover, the manual activation technique increases smear layer removal when combined with solutions such as citric acid at 5% or chelating agents (17).

Continuing with activation methods, it is important to acknowledge sonic activation.

The “Endoactivator system” is an example of sonic activation that helps cleansing canals in a more thorough and precise form. Looking at all the data we have, there is also an example of comparison among different sonic activation systems and as a result we can observe that it is not fundamental the type of sonic activation or the time elapsed, as long as endoactivator system was used, results were improved in comparison to the conventional syringe irrigation systems (18).

Sonic activation is, in fact, considerable much more useful than needle irrigation alone and this is why more trained endodontists make sure to use it nowadays.

Also, it is important to precise that irrespectively of the sonic activation sequence, (activation during 30s or 60s) the smear layer removal capacity of the endoactivator-system may always be maximized (18).

Continuing with other modern activation techniques, we find the innovative and efficient laser activated irrigation (LAI).

This activation enhances root cleaning thanks to its strong thermal effect that kills the majority of the bacteria that are attached to the root canal walls (19). Increasing the temperature of the irrigating solutions inside the canal, may be considered a disadvantage by some experts (20). Continuing with activation techniques, there is also Passive Ultrasonic Irrigation (PUI). This type of irrigation technique improves the effects of the irrigants by acoustic streaming. In this way, irrigants that have been applied, reach much further even in non-instrumented parts of the canal (21).

Moreover and always in this regard, supporting our review we have reliable information not only on different activation systems such as (PUI) or Conventional needle irrigation (CNI) and laser activation (Nd:YAP), but also we have infers on their effects on bacteria inhibition, and many efficacy comparisons so that we may start figuring an opinion on such systems (20). By now we know that in the coronal third of the majority of the teeth that receive PUI, there is a more thorough and precise cleaning compared to Conventional Needle Irrigation. In the apical third instead, the antibacterial effect of the Laser activation system (Nd:YAP laser-activated irrigation), is superior to CNI, suggesting the utility and effectiveness of these newer tools. However, a continuous use of the laser activation system, is often related to a rise in temperature., to contrast this phenomenon, an irrigation that is discontinuous may be necessary (21).

Continuing with another super modern system, the self-adjusting file system (SAF), we have plenty of evidence on websites and journals, that testify the effectiveness of its use. The SAF is very flexible and can adjust to the specific anatomy of the canal that it encounters, it is made of NiTi and has shown better results than the majority of the rotatory systems used in clinics. It is important also to mention that SAF does not create micro- cracks in the remaining dentin of the tooth like other rotatory files., moreover the SAF system combined with a correct irrigation produces reliable and long- lasting results even in oval canals. Hence, we could consider its application very useful and minimally invasive, suitable even for the least-invasive approach specialists (22).

Moving forward onto the newest activation technologies, it is relevant to mention the Photon-induced photoacoustic streaming, also known as “PIPS”. It is a laser-activated irrigation system, that is spreading more and more in the field of innovative

endodontics. The articles reporting its use are very recent (2021) and show clearly that when NaOCl is activated via this method, the bactericidal effect of the irrigant (sodium hypoclorite) increases much more than when the regular Conventional Needle irrigation (CNI) is used, helping deeply in bacterial depuration (23).

"PIPS" causes significant bacterial elimination, being much more effective than CNI and also being a more-conservative irrigation method than the conventional one, because it results in less micro-damage and less sound dentin loss in total (23).

Status of the issue:

After having seen the concept and the importance of irrigants-use to perform an endodontic treatment, we may ask ourselves: "is there an irrigant capable of eliminating all bacteria from a canal?" or also:" is there an irrigation technique which is superior to the others?". Currently the issue would be the inexistence of a perfect irrigating solution that matches all the criteria that the specialists search for, such as: ability to dissolve both organic and inorganic matter, ability to erase the totality of the smear layer (100%), low toxicity, high capillarity, low cost, easy handling and abundant availability.

2. JUSTIFICATION

The reason this study was carried out was to evaluate the existence of a single irrigant capable of eliminating all types of bacteria and debris from a radicular canal., In addition to this purpose, this review aims to compare different final irrigation protocols and discuss their efficacy.

3. OBJECTIVES

The Principal objective of this study is:

- “To state whether or not there is an irrigant capable of completely clean a root canal by itself, eradicating all forms of microbes and debris”.

The two secondary objectives of this study are:

- “To inform about irrigants’ activation techniques and to compare the cleansing capacity of different final irrigation protocols”.
- “To know with certain grade of assurance, the best type of irrigant to perform an endodontic treatment with”.

4. MATERIALS AND METHODS

In order to fulfill the objectives of this project such as comparing different irrigation protocols and investigating the most effective irrigant to be utilized in a root canal therapy, recent evidence-based information was used. All the present information was gathered from reliable sources which can be traced back at any time and analyzed by a third part. Articles written by known and confirmed authors were included in this work while any information that was not up to date or coming from un-reliable websites or books was discarded.

Being precise, the databases used in order to obtain the pertaining information to create this review were PubMed, Google scholar, Medline, and also the online library of the European University of Madrid called “Biblioteca CRAI”.

This possibility was given to students of the Universidad Europea de Madrid (UEM) to properly reunite evidence-based information avoiding biased scripts.

Among the including criteria that were used to filter the research for information to support this work, we observe recent information from journals such as the International endodontic Journal, Journal of Applied Oral Science, Journal of Dentistry, Journal of Lasers in Medical Sciences and so on.

Articles were written in English or Spanish. In fact, among the excluding criteria we see scripts and thesis in languages other than English or Spanish, but also outdated articles and low-value studies such as randomized trials with small samples were rejected. Articles written in Portuguese or Italian, even being written by certified Authors, and although having clear relevance were not included due to the exclusion criteria.

Furthermore, clinical cases and works that didn’t match the objectives of this review were discarded, only relevant and certified reports were taken into consideration.

All the articles employed to write this project are cited inside the text and referenced in Vancouver style at the end of the paper in the section “Bibliography”.

In addition, many of the articles used, were written in 2021 and 2022 in order for this study to be up to date and interesting, especially when explaining novels irrigation protocols and techniques, together with the latest irrigating agents available today on the market.

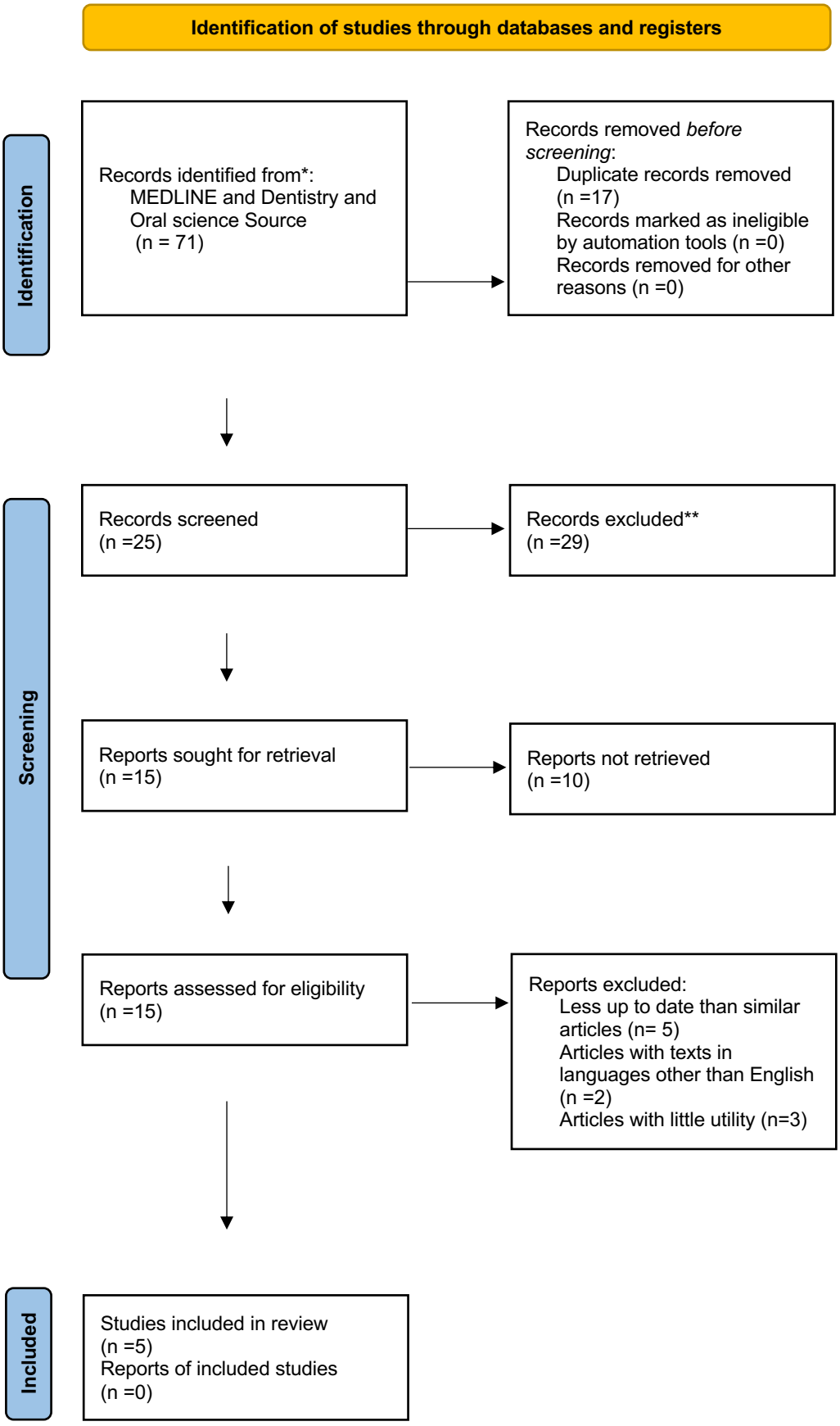
However, it is also important to mention that few, slightly older articles were included in this review because of their unmatched clinical relevance and value.

Inclusion was also due to the fact that key information regarding the most common irrigating solutions used in endodontics today, was present in such works and not in other newer articles, since irrigants such as NaOCl have been discovered and investigated long time ago. The methodology used in this study is not only reproducible, but it is also verifiable.

Key Words: Dentistry, Smear Layer, Sodium Hypochlorite, Endodontics, irrigation systems, EDTA.

5. RESULTS

flow chart



6. TABLE OF THE RESULTS

Reference	Group	Control	Mehtods	Outcome
Comparative Evaluation of Smear Layer Removal in Apical Third Using Four Different Irrigants With Ultrasonic Agitation: An In Vitro Scanning Electron Microscopy (SEM) Analysis	Sodium Hypochlorite Oxum Ozonated Water EDTA	Saline solution	50 extracted mandibular premolars taken. Every tooth was instrumented with protaper file the irrigants were randomly divided into 5 subgroups. Samples were subjected to SEM analysis and scored on a scale 1 to 4.	EDTA is the most effective irrigant for smear layer removal. Oxum may be used as an alternative to EDTA. Ozonated Water is especially useful when combined with other irrigating solution to create a synergism capable of eradicarting more bacterias providing further antimicrobial action.
Influence of size and taper of basic root canal preparation on root canal cleanliness: a scanning electron microscopy study	Group1: preparation up to size 20,04 taper Group2: up to size 20,06 taper Group3: up to size 25,04 taper	None	40 mandibular molars were submitted to root canal treatment with the same irrigants but different canal preparation techniques.	in all of the groups more residual debris was appreciated in the last third of the canal. There was no difference between middle and coronal thirds. An apical size of 25 also, was associated

	Group4: up to size 25,06 taper			with cleaner overall canals.
Root canal debridement efficacy of different final irrigation protocols: Efficacy of final irrigation protocols	group1 manual agitation Group2 canal brush agitation with Naocl and edta Group 3 h2o2 with 1% Naocl Group 4 passive ultrasonic agitation of Naocl and edta	None	107 molars instrumented with Rotatory Niti instruments then randomly divided into 4 groups for final rinsing.	Passive ultrasonic irrigation and canalbrush were both more effective in removing debris compared to manual agitation. Evidence showed: h2o2 alternated with NaOCl was more efficient in removing pulp remnants than manual agitation and passive ultrasonic irrigation
Activation of Alkaline Irrigation Fluids in Endodontics	Naocl , EDTA , Ultrasonic agitation	Laser Agitation	Various methods have been used to clean properly the canals of a tooth in need of endodontic treatment. The study compares the performances of NaOCl and EDTA	Both NaOCl and EDTA performances in cleaning root canals are enhanced when agitation is carried. Both agitation via ultrasonic energy or pulsed lasers are effective in activating

			when agitated by different activation protocols.	these chemical compounds. Nevertheless, these activation protocols increase the fluids temperature and thus related safety concerns arise. EDTA has low toxicity but NaOCl causes severe irritation when extruded into periapical soft tissues, hence this danger must be controlled.
Current Trends in Irrigation Solution and Adjunct Use During Endodontic Therapy Among Dental Professionals in Jeddah, Saudi Arabia: A Cross-Sectional Study	General practicioners	Endodontics specialists	Self-administered survey sent to general dental practitioners and Specialists in endodontics. From 2019 until may 2020, survey randomly distributed.	Most practitioners used NaOCl at full concentration as the main irrigation solution. Only the 47% of the contestants used irrigation adjuncts.

7. DISCUSSION

Endodontics is a field that is always upgrading.

However, as we have seen, it has cardinal points difficult to forget.

Looking at our objectives we may now want to discuss all the information reunited to create this review. Starting from early on, in the article by Zahed Mohammadi et Al (2), many irrigating solutions were compared to see their effectiveness in removing the smear layer. Comparing this article to the information present in the report of Alamoudi et Al (3), we see the defects of chlorhexidine, such as the incapacity to dissolve organic content and tissues., together with the defects of chelating agents such as EDTA, that even being very effective in smear layer removal, still lack chelating action in the final third of the canal and may not prevent extrusion of other substances to the periapical tissues (3). Nevertheless, in both articles EDTA appeared to be the most common chemical for smear layer removal, yet it may be surpassed by compounds such as Maleic Acid in the future (2). As of now, anyway, we may consider fundamental the use of more than one irrigating agent to properly cleanse the canal and remove the smear layer, as strongly suggested in both reports (2,3). At this point, EDTA seems to be arguably one of the most useful irrigants currently. Moving forward, in the articles by Xu et al (6) and Arslan et al (7), we have seen how different concentrations of a cleansing solution can influence their effects and related consequences on dentinal structures.

We can say in this regard, that Sodium Hypochlorite when mishandled and used in high concentrations, ends up reducing the fracture resistance of the tooth, while there is not enough data to say the same for citric acid. However, the current trend still sees NaOCl to be used much more than citric acid, which is often replaced by EDTA even though there is positive evidence that the combination EDTA-NaOCl may be vicious on the remaining tooth structure (6,7). These results may appear controversial, since we have seen the disadvantages of combining Sodium Hypochlorite and EDTA as final irrigation protocol, yet they are still often used by many experts worldwide, probably due to personal preference and familiarity, apart from the ability of the very expert to avoid unwanted interactions between the two (8).

Regarding chlorhexidine's (CHX) use, articles by the journal of dentistry and quintessence publishing Deutschland (10), reiterate the properties and availability of

such compound., nowadays its complementary role is in no doubt, but apart from having low toxicity and great antimicrobial activity, it still needs further evaluation, so that we can thoroughly know in the future its utility in the endodontic field. Regarding other characteristics of CHX, there is also evidence showing how it may cause darkening pigmentation of teeth carrying a canal obturation, since sodium hypochlorite usage is expected in almost 100% of endo-treated teeth and chlorhexidine and NaOCl interaction causes the formation of brown precipitates (9,10). Chlorhexidine degradation has also been associated with the creation of free radicals, which may in turn harm biological vital tissues., another aspect that imposes the need for further research on given chemical (11).

Previously in this text, we have seen the rise of newer irrigating solutions.

Innovative compounds with an enormous potential and many beneficial properties, among which we recognize: Ozonated water, tetraclean, MTAD and irrigants derived from herbal extracts, commonly called Herbal Irrigants (12). Evaluating all the information gathered, we may believe at this point that these compounds rarely used until now in endodontics, will likely be the initiators of a “shift of route” for future proceedings. Even though there is little evidence as of today, herbal extracts and innovative chemicals mixtures (such as Tetraclean), have already shown their capacities as irriganting agents. Nevertheless, we cannot prepend herbal irrigants or Ozone or any of the previously cited irrigants, to Sodium Hypochlorite since these new discoveries need deeper exploration and evaluation, while NaOCl has been trustworthy for decades already (13). The potential of herbal irrigants, MTAD and Tetraclean is significant, even Ozone has shown interesting properties, so even if they are not as indicated as NaOCl right now, we can certainly think ahead and see these compounds being employed more and more in the future (14,15).

On another note, I believe it is important, to observe how in all the previously mentioned articles, in no case authors, specialists or general dentists, relied on a single irrigant to perform any endodontic treatment.

Thus, we could start believing in the current inexistence of a perfect compound able to do intra-canal irrigation by itself.

Subsequently, comparing different articles such as those of Niu et Al, Race et al and Chiniforush et al (18,19,20), we have plenty of information regarding activation

protocols. Concerning the well-known EndoActivator (EA), it is safe to say that it offers better outcomes compared to needle irrigation only. It seems clear to me that modern methods outweigh older traditions in terms of intra-canal results, and they have far more upsides than downsides. But apart from sonic activation (EA), in those same articles, we have seen the performances of ultrasonic (PUI) and Laser activation systems. Evidence shows that especially the Laser activation was very efficient in the last third of the canal, even more than the others that, anyway, were sufficient overall systems (19). We may consider Ultrasonic (PUI) and laser (Nd:YAP laser) activation systems as the two best choices, upon results, but also Sonic activation (endoactivator) showed very good cleansing results so whether to use one or the other, it mostly depends on the specialist and the case itself. Also, some specialists may choose one method over the other based on safety and manageability reasons, rather than merely intracanal-cleanliness (18,20,21).

Continuing with the comparative evaluation of smear layer removal, article by Murugesan K et al (24), we observe that removing the smear layer is necessary and not questionable. Such procedure is important especially in teeth with history of infection in order to disinfect properly the canals that will subsequently receive a final obturation, and we may find aid by implementing newer technologies such as the previously exhibited PIPS to do so (23). At this point I want to make sure that, upon the multitude of articles that state such concept: Mohammadi et al (2), Alamoudi et al (3), Murugesan (24), Haapasalo ecc, I believe in the importance of the smear layer removal, and I discard its preservation.

Continuing, always referring to the comparison made by Murugesan in his article (24), looking at one of our objectives, we may interpret EDTA as one of the best irrigants available on the market., evidence of this idea is given also in the article by Haapasalo et al (1). Despite this information, we may want to remember here what we already have outlined in the introduction: “EDTA dissolves inorganic matter, not organic matter”., meaning we are far from considering it the “perfect” irrigating solution for an endodontic treatment. Surely yet, thanks to the breadth of articles we gathered and mentioned in this work, we might consider EDTA as an essential irrigant, to carry out an endodontic procedure. For smear layer demolition, also Oxum is a viable option., it can be considered as an alternative to EDTA and other chelating agents. However, EDTA has

to be viewed as the main choice and best irrigant for smear layer removal, even if Oxum is both biocompatible and easily combined with other solutions for synergistic effect (24). Now, analysing the article by Gianluca Plotino (25) on the influence of size and taper in root canal preparations, we can corroborate that the most challenging third to cleanse is the apical third, commonly packed with debris, pulp remnants and a viscous smear layer. This is no news for us, we have acquired this concept not only thanks to this Italian Author, but also from a variety of other already mentioned articles., also it is common knowledge for dentists, that the last third of the canal is the most problematic one. Here's why we have activation systems today and many irrigants available. What is even more interesting in this article though, is seeing that no matter what kind of preparation was chosen (no matter the size or taper with which the instrumentation was performed), in all the coronal and middle thirds of the teeth instrumented, there was a successful debris removal. Regarding the last third of the root, the apical third, it appears that the size 25 had higher cleanliness and smoother canals in the study, when compared to a size 20 (25). I do not believe that this finding can be determinant, but some authors could suggest that having a bigger apical size may enhances debris removal. Looking at our objectives and reviewing this report, we are not able to state with certainty if there is a preparation technique or irrigation protocol that ensures the best results, it rather depends on the specialists' own preferences and choices., furthermore, the first two thirds of any root canal, in general, are successfully cleaned with almost every instrumentation technique around (25). It may be the apical size that makes a difference as we have seen., however, I believe that further investigations are needed to have an evidence-based positive association between apical enlargement and canal depuration.

Continuing with the article written by Al-Ali et al (26), concerning the debridement efficacy of different final irrigation protocols, we can finally have significative data to evaluate which is, among all, the best step by step procedure to prepare a root canal for obturations with biocompatible materials (gutta percha).

Looking at the results over 107 extracted human maxillary and mandibular molars, we can see that passive ultrasonic irrigation (PUI), is superior to manual agitation and h2O2 alternated with NaOCl, when it comes to removing the infamous, smear layer. However, h2O2-NaOCl alternated protocol, was even more effective than PUI in removing the

organic pulp remnants, very challenging in the last third (26).

This last data may reinforce what we have already seen in the introduction., that is to say that, NaOCl is the most effective and widespread irrigant in terms of dissolving the organic matter entrapped in any radicular canal (1,2,5,8).

In any case in my opinion, about this article by Al-Ai et al (26), it is safe to say that Passive Ultrasonic irrigation is a very good choice as final rinse protocol, clearly better than manual ones. The sample of this study, I believe, is surely significant, but may still needs further backup from other sources. About other irrigating agents present in endodontics today, we find interesting information in the article by Laurence j Walsh t al (27).

It is said in fact, that nowadays practices almost always include alkaline irrigation fluids, not only Sodium Hypochlorite. This is a good sign of attitude towards progress, since every general practitioner and Endodontic specialist should employ at least more than one irrigant during an endodontic proceeding, and should always activate such compounds. Here again we observe that NaOCl is quite often used in combination with EDTA, even though their interaction may be dangerous. However, what's even more meaningful, is seeing that it has now become fundamental to activate irrigants, otherwise their effectiveness is decreased to unacceptable standards (26,27).

It is by now a fact, that activation of the irrigating fluids via ultrasounds or laser energies, ensures better results compared to older outdated methods, such as manual agitation.

We can corroborate then, that the endodontic evolution sees newer activation techniques to outweigh the standard previous ones, making us wonder if conventional mechanical activation should be considered "in disuse" at this point.

Both activation techniques, by ultrasonic moving tips and stationary tip (laser activation), improve significantly cleanliness of the root canals because they make it possible for the irrigating solutions to reach areas that are normally not attained by rotatory instruments. Nevertheless, it is important to remember that activations, (especially the laser ones), cause fluids to have higher temperatures and higher risk of extrusion into the periapical tissues., this is dangerous especially when using solutions containing Sodium Hypochlorite (27).

A Hypochlorite accident may not be prevented when misusing such activation techniques., while with manual activations, accidents may be always avoided by a trained specialist (17). Subsequently, we need to take into consideration the size of the

apical opening. The bigger the higher the risk of extrusion and it is far more dangerous if there is extrusion of NaOCl rather than EDTA due to their intrinsic difference in cytotoxicity. Considering this concern, I think it's important to remember that the Endoactivator (EA) sonic system prevents extrusion of materials (21).

Sonic systems provide significantly good results, complementing such knowledge with the fact that EA is extremely safe, we may now understand why certain dentists prefer it to ultrasonic or laser activation (18). Hence, we have to consider not only intracanal purity when trying to deduce the best available protocol, but also other important features such as safety, that we just mentioned, and ease of use.

Ultimately, very important information is provided by the last article present in the table of the results., which explains the current trends in endodontics procedures in Saudi Arabia. We can consider Saudi Arabia a big sample and a significant evidence applicable worldwide. The article in question, (28), is based on the answers given by respondents in Saudi Arabia, including both General dentists and Endodontics experts.

The questions were presented to them in a questionnaire through which the trends of the current moment emerged in a marked way.

Thanks to this cross-sectional survey in fact, we can say that mixing NaOCl and Chlorhexidine is not a safe option even if they have a strong antimicrobial action when combined., a concept also seen in other previously mentioned articles (10,28).

Always in this same report from Saudi Arabia, it is said that there is no "ideal" irrigant available today, and that two or more irrigating solution have to be applied for irrigation to be acceptable. Actually, this article from Alzamzami et al (28) was published in December of 2022, it is incredibly up to date, complete, interesting, and provides highly reliable information about the majority of the irrigants used nowadays, with their defects and qualities, reiterating how none of them possesses all and each of the ideal properties' endodontists look for.

Subsequently, regarding percentages and real data, we have information about trends and can observe how almost 80% of the practitioners decided to remove the smear layer rather than preserving it. This data again, supports the idea that I previously exposed, meaning it is better to eradicate the smear layer, rather than keeping it. The optimal time regarding canal irrigation is not clear, but we can claim that the longer the irrigant contacts the root canal lining, the more probable it will be that microbes are culled.

When using NaOCl anyway, we should interchange it with other irrigating solutions, leaving it acting a maximum time of 2 minutes and not for longer intervals. Eventually, the most important piece of information emerging from this study comes out being that the General dentists mainly use sodium hypochlorite (NaOCl), and do not use other adjuncts to perform the irrigation such as ultrasonic activation. Specialists in Endodontics instead, used commonly adjuncts to perform the treatment., also 70% of respondents said that the choice of the irrigating solution, was given by the apex, depending if it was open or closed (28).

The most important features that an irrigant had to have for dentists in saudi Arabia, were the ability to dissolve remnants and organic matter, together with a strong antimicrobial capacity (28)., which, if we focus, are exactly the main properties of NaOCl itself (1,2,6). Therefore, here's why I consider Sodium Hypochlorite to be the gold standard for endodontic procedures, as of today.

Lastly, after having highlighted multiple times the importance of activation methods throughout this review, I would say that even in the case of the discovery of a totally flawless irrigant in the future, it would still need a modern activation system (results are acceptable with sonic, ultrasonic, laser systems ecc…) to perform intra-canal irrigation correctly and thoroughly.

8. CONCLUSIONS

Reuniting all the information about irrigating solutions present in this work, we can conclude that it doesn't exist an irrigant capable of completely cleaning a root canal by itself. In the introduction we explained and mentioned all the irrigants available nowadays on the market, but no one, not even Sodium Hypochlorite is capable of eradicating all microbes and debris present in a radicular canal, alone. A combination of chemicals is still needed, since each one has a different complementary property.

Furthermore, we reached our objective of informing about activation techniques and we also compared the efficacy of different final irrigation protocols discovering that newer methods such as Passive Ultrasonic Irrigation and Laser agitation are far more effective than conventional manual activation when it comes to canal depuration.

Afterwards we may recall the last objective of this review., We can assure that the best overall irrigation solution available, remains Sodium Hypochlorite. It is the most used worldwide, dissolves organic matter like no other and provides a strong antimicrobial action. However, NaOCl still lacks a preferable low toxicity (has high toxicity and causes accidents when extruded) and still does not dissolve inorganic matter, and that is why to correctly perform an endodontic procedure today, we need to use more than one irrigating agent. The inexistence of an irrigant capable of performing the irrigation of a root-canal by itself, is therefore ascertained.

Upon results we can also state that Sodium Hypochlorite followed by EDTA, activated via either sonic or ultrasonic energy, is the best irrigation protocol to be employed, but it may be discarded by experts that have other tendencies.

The information provided in this work validates the idea that it is the specialist's own competency with the chosen activation method, what affects the outcome the most and that intracanal final cleanliness is not the only criteria to be considered., safety and manageability are crucial too.

9. BIBLIOGRAPHY

1. Haapasalo M, Shen Y, Wang Z, Gao Y. Irrigation in endodontics. Br Dent J. 2014 Mar;216(6):299–303.

2. Mohammadi Z, Shalavi S, Yaripour S, Kinoshita JI, Manabe A, Kobayashi M, et al. Smear Layer Removing Ability of Root Canal Irrigation Solutions: A Review. J Contemp Dent Pract. 2019 Mar 1;20(3):395–402.

3. Alamoudi RA. The smear layer in endodontic: To keep or remove – an updated overview. Saudi Endod J. 2019;9(2).

4. Ferrer-Luque CM, Conde-Ortiz A, Arias-Moliz MT, Valderrama MJ, Baca P. Residual Activity of Chelating Agents and their Combinations with Cetrimide on Root Canals Infected with Enterococcus faecalis. J Endod. 2012 Jun;38(6):826–8.

5. Mohammadi Z, Shalavi S, Jafarzadeh H. Ethylenediaminetetraacetic acid in endodontics. Eur J Dent. 2013 Sep;07(S 01):S135–42.

6. Xu H, Ye Z, Zhang A, Lin F, Fu J, Fok ASL. Effects of concentration of sodium hypochlorite as an endodontic irrigant on the mechanical and structural properties of root dentine: A laboratory study. Int Endod J. 2022 Oct;55(10):1091–102.

7. Arslan H, Barutcigil C, Karatas E, Topcuoglu HS, Yeter KY, Ersoy I, et al. Effect of citric acid irrigation on the fracture resistance of endodontically treated roots. Eur J Dent. 2014 Jan;8(1):74–8.

8. Qian W, Shen Y, Haapasalo M. Quantitative Analysis of the Effect of Irrigant Solution Sequences on Dentin Erosion. J Endod. 2011 Oct;37(10):1437–41.

9. Brookes ZLS, Bescos R, Belfield LA, Ali K, Roberts A. Current uses of chlorhexidine for management of oral disease: a narrative review. J Dent. 2020 Dec;103:103497.

10. Gomes BPFA, Vianna ME, Zaia AA, Almeida JFA, Souza-Filho FJ, Ferraz CCR. Chlorhexidine in endodontics. Braz Dent J. 2013;24(2):89–102.

11. Bernardi A, Teixeira CS. The properties of chlorhexidine and undesired effects of its use in endodontics. Quintessence Int Berl Ger 1985. 2015;46(7):575–82.

12. Jaju S, Jaju PP. Newer Root Canal Irrigants in Horizon: A Review. Int J Dent. 2011;2011:1–9.

13. Giardino L, Savoldi E, Ambu E, Rimondini R, Palezona A, Debbia E. Antimicrobial effect of MTAD, Tetraclean, Cloreximid, and sodium hypochlorite on three common endodontic pathogens. Indian J Dent Res. 2009;20(3):391.

14. Shetty N, Mathew T, Shetty A, Hegde MN, Attavar S. Ozonated water as an irrigant in disinfecting root canal systems - a systematic review. Evid Based Dent [Internet]. 2022 Sep 8 [cited 2022 Dec 11]; Available from: https://www.nature.com/articles/s41432-022-0800-7

15. Kale PP, Raut AW. A proposed classification system for herbal endodontic irrigants. J Conserv Dent JCD. 2021;24(3):293–5.

16. Susila A, Minu J. Activated Irrigation vs. Conventional non-activated Irrigation in Endodontics - A Systematic Review. Eur Endod J. 2019;4(3):96– 110.

17. Olivieri JG, García Font M, Stöber E, de Ribot J, Mercadé M, Duran- Sindreu F. Effect of manual dynamic activation with citric acid solutions in smear layer removal: A scanning electron microscopic evaluation. J Dent Sci. 2016 Dec;11(4):360–4.

18. Niu L na, Luo X juan, Li G hua, Bortoluzzi EA, Mao J, Chen J hua, et al. Effects of different sonic activation protocols on debridement efficacy in teeth with single-rooted canals. J Dent. 2014 Aug;42(8):1001–9.

19. Race J, Zilm P, Ratnayake J, Fitzsimmons T, Marchant C, Cathro P. Efficacy of laser and ultrasonic-activated irrigation on eradicating a mixed-species biofilm in human mesial roots. Aust Endod J. 2019 Dec;45(3):317–24.

20. Chiniforush N, Pourhajibagher M, Shahabi S, Bahador A. Clinical Approach of High Technology Techniques for Control and Elimination of Endodontic Microbiota. J Lasers Med Sci. 2015;6(4):139–50.

21. Liu C, Li Q, Yue L, Zou X. Evaluation of sonic, ultrasonic, and laser irrigation activation systems to eliminate bacteria from the dentinal tubules of the root canal system. J Appl Oral Sci Rev FOB. 2022;30:e20220199.

22. Metzger Z. The self-adjusting file (SAF) system: An evidence-based update. J Conserv Dent JCD. 2014 Sep;17(5):401–19.

23. Wen C, Yan L, Kong Y, Zhao J, Li Y, Jiang Q. The antibacterial efficacy of photon-initiated photoacoustic streaming in root canals with different diameters or tapers. BMC Oral Health. 2021 Oct 21;21(1):542

24. Murugesan K, Vishwanath S, Kadandale S, Thanikachalam Y, Parthasarathy R, Ilango S. Comparative Evaluation of Smear Layer Removal in Apical Third Using Four Different Irrigants With Ultrasonic Agitation: An In Vitro Scanning Electron Microscopy (SEM) Analysis. Cureus [Internet]. 2022 Mar 14 [cited 2023 Feb 28]; Available from: https://www.cureus.com/articles/88961-comparative-evaluation-of-smear-layer-removal-in-apical-third-using-four-different-irrigants-with-ultrasonic-agitation-an-in-vitro-scanning-electron-microscopy-sem-analysis

25. Plotino G, Özyürek T, Grande NM, Gündoğar M. Influence of size and taper of basic root canal preparation on root canal cleanliness: a scanning electron microscopy study. Int Endod J. 2019 Mar;52(3):343–51.

26. Al-Ali M, Sathorn C, Parashos P. Root canal debridement efficacy of different final irrigation protocols: Efficacy of final irrigation protocols. Int Endod J. 2012 Oct;45(10):898–906.

27. Walsh L, George R. Activation of Alkaline Irrigation Fluids in Endodontics. Materials. 2017 Oct 23;10(10):1214.

28. Alzamzami ZT, Alqurashi AA, Almansour LA, Ashi HM, Abulhamael AM, Alghamdi FT, et al. Current Trends in Irrigation Solution and Adjunct Use During Endodontic Therapy Among Dental Professionals in Jeddah, Saudi Arabia: A Cross-Sectional Study. Cureus [Internet]. 2022 Dec 3 [cited 2023 Feb 28]; Available from :https://www.cureus.com/articles/126513-current-trends-in-irrigation-solution-and-adjunct-use-during-endodontic-therapy-among-dental-professionals-in-jeddah-saudi-arabia-a-cross-sectional-study

ANNEXES

Abbreviations:

° EDTA= Ethylenediaminetetraaceticacid

° CA= Citric Acid

° NaOCl= Sodium Hypochlorite

° CHX= Chlorhexidine

° MTAD= mixture of tetracycline, acid and detergent

° 5. Flow chart of the results

° 6. Table of the results

° Ozone= Ozonated Water

° Herbal irrigants= irrigants derived from herbal extracts

° PIPS= photon-induced photoacoustic streaming

° EndoActivator= EA

° PUI= Passive Ultrasonic Irrigation

° CNI= conventional needle irrigation

° LAI= Laser activated irrigation

° Nd:YAP laser= neodymium-doped yttrium aluminum perovskite laser

° h2O2= hydrogen peroxide