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Does the use of Lasers as an Adjunct to Conventional Endodontic Treatment yield better results than Conventional Treatment alone? An Overview of Systematic Reviews

A Thesis submitted in fulfilment of the requirements for the Degree of Masters in Restorative Dentistry at the University of the Western Cape

MSc (Restorative Dentistry)

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KEYWORDS

AMSTAR

Arksey and O'Malley

Diode Laser

Disinfection

Endodontic Treatment

Er, Cr: YSGG Laser

Er: YAG Laser

Lasers

Nd: YAG Laser

Overview of Systematic Review

Photodynamic Therapy

PRISMA

Root Canal Treatment

Scoping Review

ABSTRACT

Introduction: The goal of endodontic treatment is to eliminate microbial infection and diseased dental pulp tissue residue from inside the root canals. This is routinely accomplished by mechanical preparation and chemical irrigation. However, the complex anatomy of the root canal system poses as a challenge for complete microbial debridement. Lasers were therefore introduced as an adjunct to chemo-mechanical root canal preparation to overcome the problems of disinfection inside root canals and to improve the success of root canal treatments.

Aim: To determine if the use of lasers as an adjunct to conventional root canal treatment yields better results than conventional root canal treatment alone.

Objectives: To conduct a scoping review to map the literature on the use of lasers in endodontic treatments. The next objective is to conduct an overview of systematic reviews on whether the use of lasers as an adjunct to conventional root canal treatment yields better results than conventional treatment alone.

Methodology: A scoping review of the existing literature was conducted. Arksey and O'Malley's 6-step framework for conducting scoping reviews was utilised. The overview of systematic reviews involved using the AMSTAR 2 checklist for critical appraisal of articles meeting the inclusion criteria to determine the methodological quality of the systematic review articles on the use of lasers as an adjunct to conventional root canal treatment. For both objectives, the searches extended to electronic databases including Google Scholar, PubMed, ScienceDirect, Wiley Online Library along with international conference presentations and international endodontic journals. The reference lists of included studies were searched for further studies that may not have been retrieved during the initial database searches. The searches were limited to the English language and restricted to the last 10-years.

Results: The scoping review yielded 3376 articles generated by searching the databases, of these 3101 did not agree with the objectives of this scoping review. The full texts articles assessed for eligibility were 220, from which 95 full text articles satisfied the inclusion criteria for this scoping review. These 95 articles mainly included in vitro studies conducted on the use of lasers to aid in the disinfection of the root canals utilising photodynamic therapy. Despite the results of the studies mostly supporting the additional benefits of using lasers as adjuncts to conventional endodontic treatments, there was lack of high-quality clinical studies to support these recommendations.

For the overview of systematic review, the database search yielded 159 studies of those only 9 full text studies satisfied the inclusion criteria for this study. These 9 articles mainly investigated the use of photodynamic therapy and its role as an adjunct in root canal disinfection. Most articles supported the use of lasers as adjuncts to conventional endodontic treatment. These articles were all critically appraised using the AMSTAR 2 tool, all the systematic reviews showed more than one critical flaw deeming them all to have a critically low level of confidence.

Conclusion: The use of lasers as an adjunct to conventional root canal treatment seems to be a promising modality, however not enough clinical studies or high-quality evidence is currently available to change clinical practice and start implementing using lasers to disinfect the root canals during endodontic treatment.

DECLARATION

I declare that the research entitled "Does the use of Lasers as an Adjunct to Conventional Endodontic Treatment yield better results than Conventional Treatment alone? An Overview of Systematic Reviews", is my own work. It has not been submitted previously in whole or in part for any degree or examination in any other University, and that all the sources I have used or quoted have been indicated and acknowledged by a complete list of references.

Nadine Hamadelneil

Signature Date:10.11.23

ACKNOWLEDGEMENTS

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DEDICATION

I dedicate this research to my boys Badur and Firas and my supportive family. After Allah, I could not have done it without their unconditional love and support.

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LIST OF ABBREVIATIONS

AMSTAR: A Measurement Tool to Assess Systematic Reviews

EDTA: Ethyl diamine tetra acetic acid

Er: YAG: Erbium: yttrium aluminium garnet

Er, Cr: YSGG: Erbium, chromium: yttrium scandium gallium garnet.

LASER: Light Amplification by Stimulated Emissions of Radiation

MMAT: Mixed methods appraisal tool

OSR: Overview of systematic reviews

ND: YAG: Neodymium: yttrium aluminium garnet

OSR: Overview of systematic reviews

PUI: Passive sonic and ultrasonic irrigation

PDT: Photodynamic therapy

PRISMA: Preferred reporting items for systematic reviews and meta-analysis

SCR: Scoping reviews

PRISMA-ScR: Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for Scoping Reviews

RCT: Randomised controlled trials

CHAPTER 1
INTRODUCTION

1.1 Problem Statement

Successful endodontic treatment occurs when there is neutralisation and debridement of the root canals from bacteria (Chu *et al*., 2014). Otherwise, this will result in clinical symptoms and periapical radiolucency (Tabassum and Khan, 2016). Mechanical preparation using various file systems along with chemical irrigation using the gold standard sodium hypochlorite, are commonly used to eliminate these bacteria (Marković *et al*., 2105). However, areas like lateral and accessory canals remain untouched due to inaccessibility or obscurity. In addition, intracanal instrumentation also results in the production of a smear layer that blocks the entry of chemical irrigation into the dentinal tubules. Inability to ensure adequate intracanal cleaning, subsequently acts as a favourable environment for microorganisms to regrow resulting in treatment failure (Bago and Anić, 2014; Borse *et al*., 2017; Lee *et al*., 2004; Lim *et al*., 2009). Lasers were therefore introduced as a new modality acting as an aide to chemo-mechanical root canal preparation to overcome the problems of disinfection inside root canals and to favour the success of root canal treatments (Kapasi and Kapasi, 2019).

1.2 Introduction

The global prevalence of endodontic treatment was determined to be 8.2% with 55.7% of individuals world-wide with a minimum of one root canal treated tooth (León-López, M. *et al*., 2022). Data recovered from inter-continental studies conducted on the occurrence of root canal treatments, revealed that the European population had the highest occurrence of root filled teeth at 9.3%, with 59.6% of Europeans having a minimum of one root treated tooth (León-López, M. *et al*., 2022). Contrarily, 5.5% of the African population received root canal treatment with 41.2% of them having at least one root filled tooth. The North American population showed the lowest treatment prevalence where 4.1% were found to have had root canal treatment and 48.5% required root canal treatment on at least one tooth (León-López, M. *et al*., 2022). Since over fifty percent of the world's human population have one or more root filled teeth, endodontic disease can be regarded as a frequent and important worldwide medical problem (León-López, M. *et al*., 2022).

The aetiology of endodontic disease is primarily determined by the contamination of the root canal system by microorganisms as demonstrated years ago by Kakehashi in his research on germ free rats (Kakehashi *et al*., 1965). These micro-organisms are also responsible for failure of root canal treatment if they are not adequately removed (Orstavik, 2019). Untreated endodontic disease or failed root canal treatment further leads to local inflammation of the tissues around the tooth, a condition known as apical periodontitis (Abbot, 2004). Apical periodontitis resulting from the occurrence of micro-organisms inside the root canals of teeth was found to affect about 52% of people worldwide (León-López, M. *et al*., 2022). To increase the chances of successful treatment outcomes, resulting from the adequate disinfection and debridement of the microorganisms inhabiting the root canal system, lasers have been used as an adjunctive technique aimed at assisting the conventional chemo-mechanical endodontic treatment procedures.

Chapter 2 will deal with the literature review related to conventional root canal treatment procedures, adjunctive therapeutic techniques.

Chapter 3 will look at the research question, aims and objectives of conducting a scoping review and an overview of systematic reviews on the efficiency of lasers as an adjunct to conventional endodontic therapy.

The methodology for conducting scoping and an overview of systematic reviews used to determine the aim and objectives will follow in Chapter 4.

Chapter 5 will cover the results of the scoping review and overview of systematic reviews.

Chapter 6 follows with a discussion of the results obtained for these reviews.

Chapter 7 details the conclusion reached for both these reviews.

Chapter 8 finishes with limitations of the research along with recommendations for conducting future studies.

CHAPTER 2
LITERATURE REVIEW

Endodontic treatment, also known as endodontic therapy or root canal treatment, deals with eliminating microbial infection and contaminated dental pulp tissue from inside the root canals, to allow for successful treatment. This process is achieved by mechanical instrumentation and chemical irrigation. However, the complex anatomy inside the root canals has an impact on the penetration ability of chemical irrigants inside the whole system, thereby affecting treatment success. To overcome these obstacles, additional methods have been investigated to improve the successful treatment outcomes (Anagnostaki *et al*., 2020).

2.1 Dental Anatomy

The human tooth consists of a crown and a root, where the crown is made up of enamel, dentine and pulp while the root consists of cementum, dentine and pulp (Fig 1) (Paiva *et al*., 2018) The part of the pulp that lies inside the crown of the tooth is called the pulp chamber and it consists of a single cavity with projections known as pulp horns that lie inside the cusps of the tooth. The part of the pulp that lies inside the roots is the root canal. The entry into the radicular pulp lies on the floor of the pulp chamber. The root canals follow a gradual taper from the orifice towards the apex or tip of the root, which usually follows the outer shape of the root (Fig 2) (Carrotte, 2004).

Figure 1. Anatomical parts of a molar tooth. (A) Crown; (B) cervical line; (C) root (Paiva *et al*., 2018)

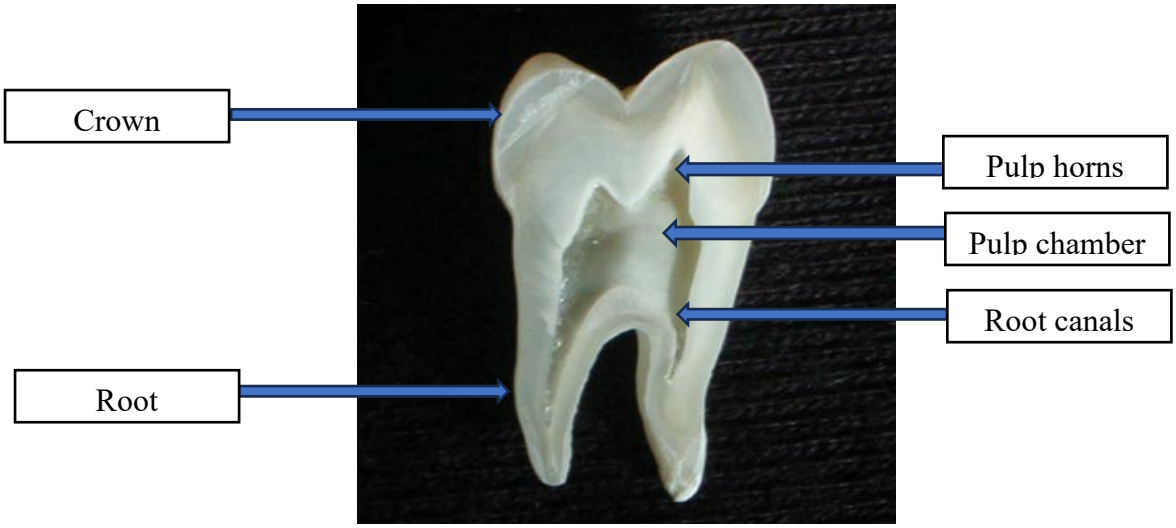


Figure 2: Cross section of a molar tooth (Carrotte, 2004).

The roots and root canals have a large number of anatomical variations affecting their numbers and shapes. In 1974 Vertucci described eight configurations, that have since been known as Vertucci classifications of the root canal system, these morphological patterns from Type I- Type VIII depend on the division that occurs in the area of the root canal from the point it leaves the pulp chamber until it reaches to the apex of the root (Fig 3) (Vertucci *et al*., 1974). The root canal system is also further complicated by the presence of lateral canals which can arise anywhere along the length of the root, at right angles to the main canal. Additionally, accessory canals can also be found, these represent the small canals found in the apical few millimetres near the root apex (Carrotte, 2004).

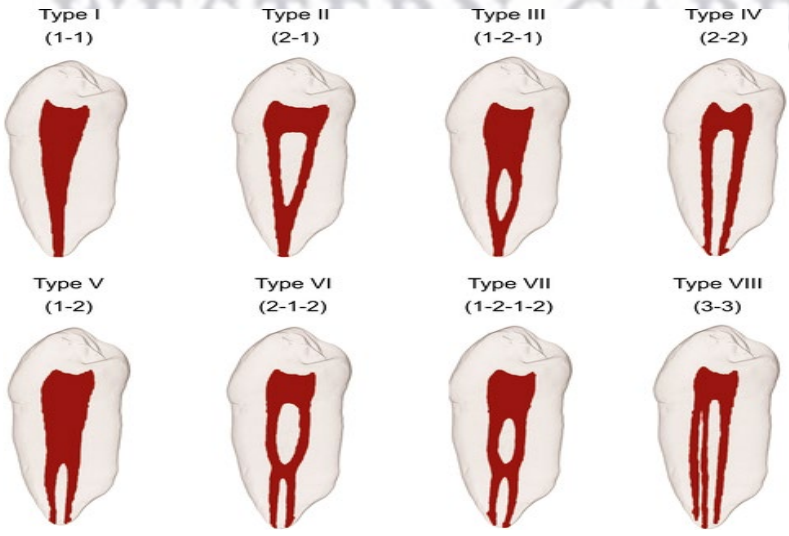


Figure 3: Vertucci classification for root canal morphology (Vertucci *et al*., 1974)

2.2 Dental Caries

The oral cavity, which houses the tooth, is the home of hundreds of different microbial species that exist in a unique ecosystem (Wong *et al*., 2021). Dental caries is a dynamic disease that is caused by many factors, it is characterized by the destruction of the tooth structure by the acidic byproducts produced by bacteria. These bacteria occur naturally in oral biofilms attached to the tooth surface. The acid produced by bacteria is a result of the fermentation of ingested sugars in the diet. (Selwitz, *et al*., 2007). Progression of untreated dental caries subsequently results in the destruction of the external tooth surface, allowing bacterial ingress into dentine, which when left untreated, allows bacteria to invade and colonize the pulp, which is otherwise a physiologically sterile tissue. Bacteria entering the pulp due to dental caries results in tissue damage that progresses to result in pulpal irritation and subsequent pulp necrosis (Abbot, 2004).

2.3 Micro-organisms occupying the root canal system

The microorganisms that occupy the root canal system are a mixture of bacteria, fungi, viruses, cocci, filaments, and spirochetes that enter the pulp from the mouth. First time infections are usually polymicrobial, dominant in Gram-negative strictly anaerobic species like Fusobacterium Prevotella and Prophyromonas*, while* secondary infections are comprised of more resistant microbial species which are mostly Gram-positive facultative anaerobes like Lactobacillus, Streptococcus, Actinomyces, Enterococcus. Other species found in both kind of infections are firmicutes, Bacteroidetes, Proteobacteria, Actinobacteria, and Fusobacteria. (Good and Hussey, 2012; Wong *et al*., 2021). When these micro-organisms increase in number, they also increase in penetration depth inside the dental tubules, lateral and accessory canals along the root canal system (Baugh and Wallace, 2005).

2.4 Challenges to root canal treatment

Microbial penetration plays a pivotal role in pulp disease initiation and progression (Abbot, 2004). The goal of undertaking endodontic treatment is therefore to try and remove the

diseased pulpal tissues by destroying the microbial infection and further inhibiting the microorganisms from re-entering inside the canals by creating aseptic intra-radicular conditions (Wong *et al*., 2021). The two main challenges to accomplish adequate cleaning of the root canal system are therefore anatomical and microbial. The anatomical challenges are due to the complexities within the root canals posing in the form of lateral and accessory canals, apical delta and isthmi (Wong *et al*., 2021).

On the other hand, microbial challenges are due to the micro-organisms producing biofilms and to being able to survive in nutrient depleted environments. Biofilms are made up of microbial rich communities that exist in a highly cohesive matrix that protects them against the penetration of antimicrobial agents (Wong *et al*., 2021). Mechanical disruption of the biofilm is therefore needed before chemical disinfection can act on the bacteria occupying the root canal system (Wong *et al*., 2021).

2.5 Apical Periodontitis

The presence of micro-organisms living inside the root canal system is a significant factor for the continuation of infection and endodontic disease even after treatment. Untreated and persistent endodontic infection leads to apical periodontitis, a condition characterised by inflammation and damage of the periapical tissues around the tooth (Nair, 2006). Apical periodontitis is considered the main cause of emergency dental treatments. Long standing apical periodontitis that remains untreated may exacerbate into acute infections that may spread to the facial spaces resulting in serious life threating conditions potentially requiring hospitalisation. Apical periodontitis has also been linked to chronic medical conditions like diabetes mellitus and cardiovascular disease (Wong *et al*., 2021).

2.6 Chemo-Mechanical preparation

Cleaning and shaping in endodontics refer to the chemical and mechanical actions of debriding the root canal system. This process is achieved using different kinds of manually and engine operated instrumentation in the presence of irrigating solutions. The main objectives of endodontic chemo-mechanical preparation are to remove microorganisms and their byproducts, pulp tissue and infected dentine from the root canal system. The process

also aims to keep the preparation procedure to within the confines of the tooth, ensuring that no extrusion occurs past the roots into the periapical tissues, while attempting to create sufficient space to allow the placement of the root canal filling material (Waplington and McRobert, 2014). According to Schilder (1974), root canals should have a large diameter coronally and a decreasing taper apically whilst maintaining their original shape and anatomy (Fig 4) (Shilder, 1974).

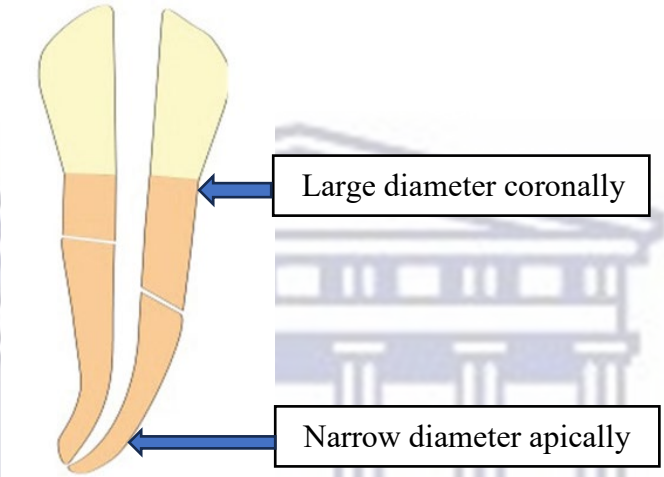


Figure 4: Endodontic Root canal shape after preparation as described by Schilder (Waplington and McRobert, 2014)

2.6.1 Root Canal Preparation Instruments

i) Design

The shaping instruments that are used in root canal preparation, known as files, are made up of different parts, these are the taper, cutting edge, flute, land, relief and tip of the instrument (Fig 5). The taper of an instrument is the amount the diameter of the file increases in mm from the tip of the file to the file handle (Fig 6). The international standard organisation's (ISO) standard hand files all have standard 2% taper along the 16mm file working length (Atmeh and Watson, 2016). Root canals can be instrumented either using files of the same taper but different tip diameter or variable tapers ranging from 4% taper to 12% taper along the working length of the instrument while maintaining the same tip size, as commonly seen with rotary instruments (Fig 6) (Young *et al*., 2007). Newer files have also been introduced

that have various tapers at different lengths from the tip of the file to the handle (Atmeh and Watson, 2016).

All files have cutting edges, these represent the sharp cutting part of the instrument and the one with the largest diameter (Fig 5). The cutting edge of the file is also the point where the flute and the land intersect. The flute part of the instrument is the groove which collects the dentine and debris that forms as a byproduct of the tooth preparation, while the land is the marginal width of the file (Fig 5). The land reduces micro cracks formation and canal transportation by reducing depth of cut and screwing of the file on the canal walls. While this helps keep the file centred in the canal it inadvertently decreases its sharpness and flexibility with use (Fig.5). Lastly, the tip of the file, which can either be cutting (active) or non-cutting (passive) tip (Mittal *et al*., 2014).

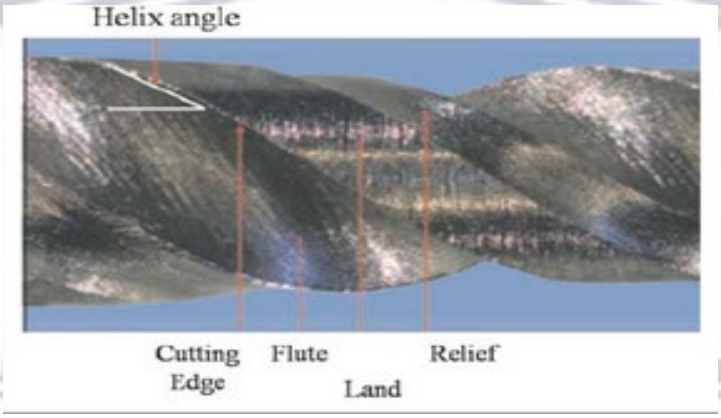


Figure 5: Parts of an Endodontic File (Mittal *et al*., 2014).

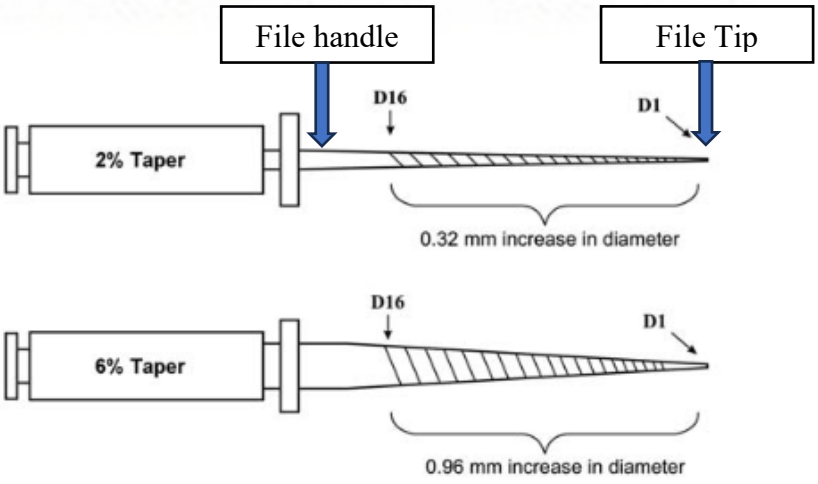


Figure 6: Endodontic File taper used manually (Young *et al*., 2007

ii) Materials

- **Stainless steel** hand files follow ISO standardisation with 2% taper from the tip off the instrument (D0) to the 16mm mark (D16) along the handle of the file. These were found to be stiff, with their rigidity increasing as the file size increases, thus resulting in unfavourable outcomes especially in curved canals (Atmeh and Watson, 2016). Stainless-steel files are used manually, by being rotated in the operator's fingers with slow controlled force (Atmeh and Watson, 2016).

- **Nickel titanium** files on the other hand can be used either by hand or as engine driven (rotary) instruments, with constant tapers of 4% and 12% or variable taper along the length of the instrument. Nickel titanium files have a lower elastic modulus, enhanced flexibility and shape memory when compared with stainless steel files. This allows them to navigate curved canals without risking instrument fracture during use (Alapati *et al*., 2004) (Waplington and McRobert, 2014). These files also allow for root canals to be shaped using fewer instruments and in a shorter period (Mittal *et al*., 2014).

2.6.2 Root Canal Preparation Techniques

In 1961, a systematic technique for root canal preparation was introduced by Ingle (Ingle, 1961). It was called the **step-back filing technique**, and it involved using stainless steel hand files from small to large incrementally. The technique consists of firstly negotiating the canal to full working length, followed by canal enlargement from the apical direction using larger files at shorter or shortened length every time (Fig 7). This was done in a push-pull method using sharp instruments (Waplington and McRobert, 2014). However, there were numerous disadvantages associated with this technique. These involved *difficulty in canal irrigation* and subsequent *blocking of the canals* with debris, as well as *ledging, transportation or perforation* (Fig 8) (Waplington and McRobert, 2014).

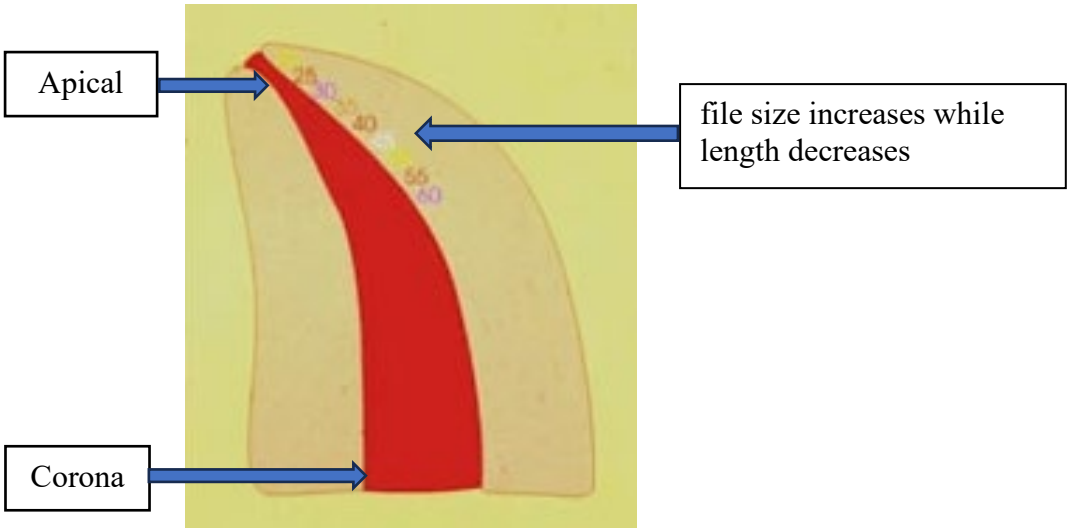


Figure 7: Step back filing technique- moves from an apical to coronal direction (Waplington and McRobert, 2014)

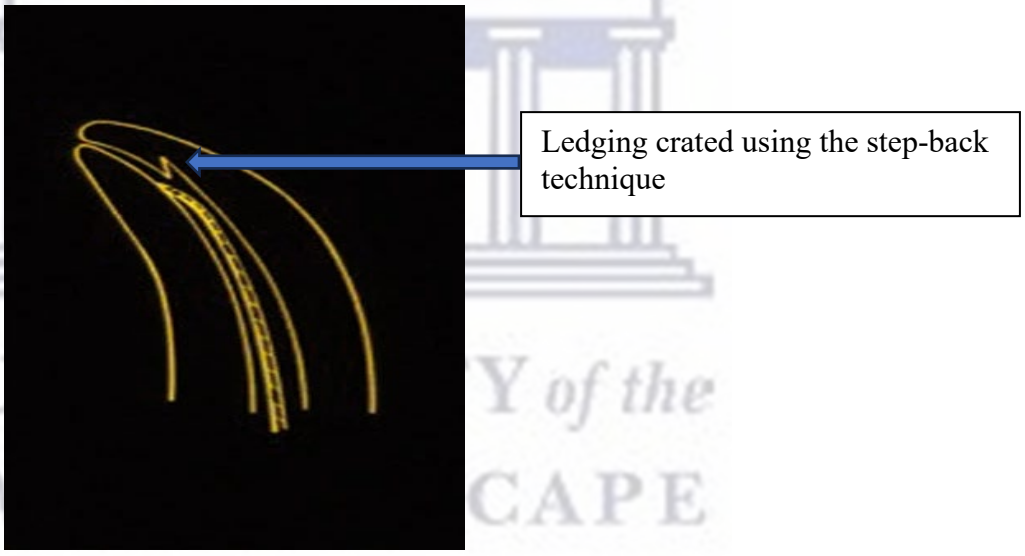


Figure 8: Apical ledge created with the step-back technique (Waplington and McRobert, 2014)

In 1980, Marshall and Papin proposed an alternative technique called **crown down technique** which aimed to overcome the shortcomings associated with the step-down root canal preparation procedure (Marshall and Papin, 1980). In this technique the root canal system is prepared from the coronal aspect, with smaller files moving down the root canal until the working length is reached (Waplington and McRobert, 2014).This technique has the advantage of allowing the irrigants to pass easily to the apical portion and reduced canal

blockage and debris extrusion, it also reduces the risks of procedural errors It is now the preferred preparation technique for shaping root canals (Waplington and McRobert, 2014).

2.6.3 Root Canal Irrigation Solutions

i) Sodium Hypochlorite

First introduced in 1843, sodium hypochlorite (NaOCl) is viewed as the golden standard irrigant, with strengths ranging between 0.5% and 6 % (Basrani *et al*., 2017). NaOCl is a caustic solution with a pH between 12-13 and having a broad antimicrobial spectrum against bacteria, yeast, and viruses (Good and Hussey, 2012) The antimicrobial properties are due to the contact of the hypoclorus acid with the organic tissue debris inside the root canal. The antimicrobial and tissue dissolution actions are concentration specific, therefore, these increase with higher concentrations (Basrani *et al*., 2017).

Despite its benefits in performing as an ideal root canal disinfectant, NaOCl as an endodontic irrigant is associated with many risks and complications (Spencer and Brennan, 2007). A minor risk is the bleaching of clothes if accidental spillage occurs. However, other more serious complications that have been reported in the literature include eye damage, skin, and oral mucosal injury when the alkaline sodium hypochlorite solution reacts with the various tissues (Spencer and Brennan, 2007). The most serious complications associated with its use arise following accidental extrusion of NaOCl beyond the tooth where it reacts with the tissues in the apical region leading to chemical burns and tissue necrosis of varying degrees (Fig 9) (Spencer and Brennan, 2007). Neurological damage may also occur if the extrusion extends into the mental, inferior alveolar or infra orbital branches of the trigeminal nerve (Spencer and Brennan, 2007). The resulting paraesthesia and anaesthesia may take months to completely resolve (Spencer and Brennan, 2007).

Hence, the higher the concentration of the sodium hypochlorite solution used in irrigating the root canals, the better the antimicrobial and tissue dissolution action, which improves treatment success(Basrani *et al*., 2017). Contrary to this, lower concentrations of the solution fail to be effective against some micro-organisms (Basrani *et al*., 2017). However, great caution needs to be exercised to try and avoid the potential risks associated with using sodium hypochlorite at higher concentrations (Spencer and Brennan, 2007).

Figure 9: Extra Oral image indicating effect of hypochlorite extrusion into soft tissues (Spencer and Brennan, 2007)

ii) Ethylenediaminetetraacetic Acid (EDTA)

Ethylenediaminetetraacetic Acid (EDTA) used in concentrations between 15%-17% is a chelating agent with a pH of 7. EDTA is used as an irrigant alongside root canal instrumentation, as it helps open sclerosed canals and removes the smear layer (Good and Hussey, 2012). The smear layer, formed as a byproduct of tooth instrumentation, consists of a mixture of bacteria, dentine debris, pulp remnants and endotoxins (Bago and Anić, I, 2014). EDTA is commonly used alongside NaOCl, as the latter on its own is incapable of removing inorganic dentin particles or the smear layer formed during root canal instrumentation Hence, the use of EDTA and NaOCl acts concomitantly to remove both the organic and inorganic debris. Ideally, the NaOCl irrigant solution should be used as the final rinse following EDTA, to avoid the EDTA reducing the chlorine content of NaOCl and reducing its tissue dissolution and antimicrobial ability (Good and Hussey, 2012).

iii) Chlorhexidine Gluconate

Chlorhexidine Gluconate (CHX) is a bisguanide antiseptic that acts by attaching to the cell walls of microorganisms resulting in the leakage of intracellular microbial products and thereby the death of the microorganisms. CHX has a broad-spectrum antimicrobial activity, with substantivity lasting over 12 hours (Good and Hussey, 2012). CHX is bactericidal in high concentrations and bacteriostatic in low concentrations, working best at a pH of 5.5-7

(Wang *et al*., 2007). Despite the low- grade toxicity of CHX, it is not capable of dissolving organic or inorganic debris (Basrani *et al*., 20017). For this reason, it needs to be combined with NaOCl and EDTA, ensuring it does not directly mix with NaOCl to avoid the formation of parachloroaniline (PCA) which was found to be a cytotoxic agent (Naidu *et al*., 2015).

Other choices of root canal irrigants include Q Mix, which is a mixture of EDTA, chlorhexidine and a detergent (Naidu *et al*., 2015). Q Mix is used as a final rinse in root canal irrigation as it removes the smear layer and has antimicrobial properties (Naidu *et al*., 2015). Bio Pure MTAD is another irrigant that is made by combining an antibiotic, with citric acid, a chelating agent and a detergent (Naidu *et al*., 2015). MTAD is effective in removing the smear layer and can be used as a final irrigant after sodium hypochlorite. There is, however, a risk of discoloration and bacterial resistance associated with its use (Good and Hussey, 2012). Lastly, citric acid is a demineralising solution used for smear layer removal (Good and Hussey, 2012). It can either be used alone or in combination with EDTA, but it is not recommended for use with sodium hypochlorite, as it reduces the effectiveness of the later. When used in concentrations of 10%, citric acid can have anti-microbial action against the microorganisms occupying the root canal system (Good and Hussey, 2012).

Since irrigants were found to have individual limitations, and in order to overcome these problems, it was suggested to either mix different irrigating solutions together or to alternate between them. For example, it has been suggested to use sodium hypochlorite to dissolve the organic tissue components, followed by EDTA to eliminate the smear layer and a final rinse with CHX for antibacterial activity. Neutralisation using normal saline or even clean water in between the two solutions can stop any side effects of both solutions interactions (Good and Hussey, 2012). As mentioned previously, care needs to be taken to avoid mixing CHX and NaOCl as this causes tooth discoloration, affects the sealing of the root canal system, and results in the formation of a toxic substance called parachloroaniline (Naidu *et al*., 2015). Similarly, loss of free available chlorine from sodium hypochlorite occurs when it comes into contact with chelants, resulting in reduced tissue dissolution and reduced antimicrobial activities (Basrani *et al*., 20017).

2.7 Adjunctive Root canal therapeutic techniques

To increase the effects of the irrigants in disinfecting and to removing the debris from the inaccessible areas of the root canal system, various irrigation activation methods have been used in addition to conventional needle irrigation. These aim to increase the chances of treatments becoming more beneficial the success and include the use of ultrasonic irrigation and lasers (Borse *et al*., 2017).

i) Conventional needle irrigation

Syringes and needles remain the most used method for delivering chemical irrigant solutions inside the roots of teeth. Various designs of needles are available to use in root canal disinfection (Fig 10) (Boutsioukis *et al.,* 2010). The efficacy of irrigant delivery action depends on the size of needle gauge, the needle vent, in addition to the depth of needle penetration to the root apex. Needles with narrow gauges (30 gauge) are better at root canal penetration and disinfection. Close ended, single side vented needles are safe to use during irrigation (Gopikrishna *et al.,* 2016). The depth of penetration of the irrigant is usually only a few mm past the needle vent. This thus interferes with effective disinfection of difficult to reach areas like isthmi, lateral and accessory canals (Susila,2019).

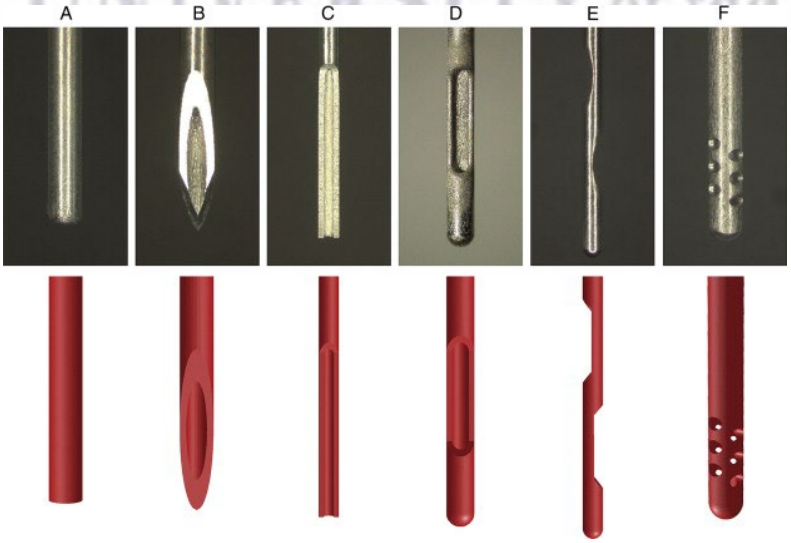


Figure 10: 30-gauge needles. A-C open ended (A-flat, B-beveled, C-notched), D-F closed ended (D-side vented, E-double side vented, F-multi vented) (Boutsioukis *et al.,* 2010).

ii) Manual Dynamic Agitation

Manual dynamic agitation is a simple and cost-effective process whereby a master gutta percha cone is used manually in up and down strokes to agitate the irrigant solution inside the root canal system (Cheung *et al.*, 2021).

iii) Passive Sonic and Ultrasonic Irrigation (PUI)

Passive ultrasonic irrigation refers to a technique by which the irrigant is activated inside the root canal system using a small file, ultrasonic tip or straight wire (Van Der Sluis *et al*., 2007). The ultrasonically oscillating file moves freely in the prepared canal activating the irrigant allowing it to reach the apical portion easily as well as lateral canals for greater efficiency of cleaning and disinfection. Passive refers to the non-cutting action of the file used in the process, to activate irrigants inside the root canals at frequencies ranging between 500-600Hz (Van Der Sluis *et al*., 2007).

iv) Photodynamic therapy (PDT)

Photodynamic therapy is also referred to as antimicrobial photodynamic therapy or photoactivated disinfection. It is a reaction that occurs between a chemical compound agitated by light at a certain wavelength, and with oxygen being present (Siddiqui *et al*., 2013). The chemical compound is a nontoxic photosensitiser that is selectively absorbed into tissues. This is usually a dye, examples of which include methylene blue (MB), toluidine blue O (TBO), and indocyanine green (ICG) (Pourhajibagher *et al*., 2019). The photosensitiser accumulates in the targeted tissues of the micro-organisms. When it is exposed to light at a certain wavelength, this results in the production of free radicals and singlet oxygen species. This action in turn damages the targeted tissues, leading to the death of the microorganisms by the destruction of the plasma membrane alone or in combination with harming the DNA (Siddiqui *et al*., 2013).

The photodynamic effect depends on several factors, the dose and type laser used, the photosensitizer incubation time, presence of oxygen, the lights wavelength (nm), the lights power density (mW/cm2), the lights energy fluency, the type of sort, dose (Chrepa *et al*., 2014). Photodynamic therapy was shown to have no adverse effects on the hard and soft

tissues with no thermal side effects in the tissues around the tooth (Marković et al., 2015). A potential side effect however is tooth discoloration following the use of dyes such as methylene blue (Chrepa et al., 2014).

2.8 Laser

LASER stands for light amplification by stimulated emission of radiation (Coluzzi and Parker, 2017). Light is a form of electromagnet energy, lasers represent a special type of light, which has specific characteristics to differentiate it from other light sources. These are monochromaticity, coherence and collimation. Monochromaticity is the ability of laser light to be emitted as a single wavelength, meaning that is it observed as a single specific colour. Coherence means that the laser light maintains the same physical properties throughout use, where the light travels in the same direction and phase, thus allowing lasers to generate a specific and defined form of energy, Lastly, collimation is the direction of laser emission which occurs in parallel waves (Bhatia and Kohli, 2013; Coluzzi and Parker, 2017).

In 1913, a Danish scientist Bohr, theorised the concept that atoms that can become stimulated leading to the release of photons. He termed this phenomenon spontaneous emission. This can easily be observed when a light bulb is switched on and a white light is seen. The white light is made up of different wavelengths and travels in different directions and phases (Coluzzi and Parker, 2017). In 1916, Einstein proposed the theory of stimulated emission, which carries on from the state of spontaneous emission coined by Bohr and can be observed by laser light. It is characterised by monochromaticity and coherence (Coluzzi and Parker, 2017). Laser light amplification occurs following the stimulated emission phase of photon release, in the presence of a constant source of energy, which is supplied by a laser machine (Carroll and Humphreys, 2006).

2.8.1 Laser Tissue Interactions

Laser transmission to the target tissue is either by direct contact using optical (Nd: YAG, Diode) (Fig 11) or by indirect contact delivery using hollow waveguides or articulated arms

that remain at the canal orifice only (Er: YAG, Er, Cr:YSGG) (Figs 12-13) (Coluzzi and Parker, 2017). Laser energy is transmitted in either a continuous wave or in a pulsed mode (Coluzzi and Parker, 2017). Transmission of the laser energy in a continuous wave means that while the laser is activated, there will be a continuous and constant laser tissue interaction (Diode). On the other hand, laser transmission in a pulsed mode occurs in short interrupted bursts (Nd:YAG, Er:YAG, Er,Cr:YSGG)(Coluzzi and Parker, 2017).The effect that the laser interaction has on the target tissues can be controlled by choosing the mode of laser energy transmission, the size and length of the laser beam in direct contact with the tissues and the amount of laser energy conducted (Bago and Anić, I., 2014) (Saydjari *et al*., 2016). In addition, the amount of laser energy being absorbed inside the tissues depends on the water content of the tissue, the wavelength of the laser and the degree of pigmentation or chromophores within the target tissue (Carroll and Humphreys, 2006).

Figure 11: Optical fibre used for direct contact laser transmission (Coluzzi and Parker, 2017).

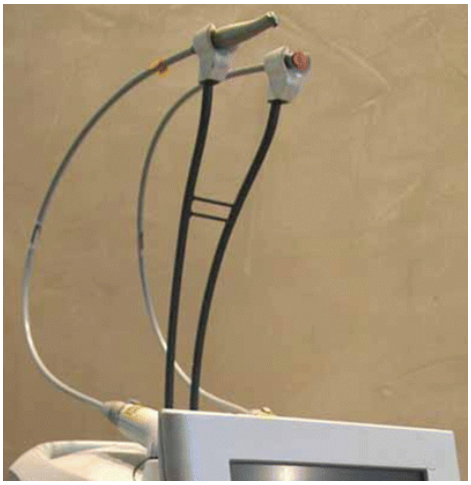


Figure 12: Hollow wave guide used for indirect contact laser transmission (Coluzzi and Parker, 2017).

Figure 13: Articulated arm used for indirect contact laser transmission (Coluzzi and Parker, 2017).

When the laser comes into contact with the target tissue, depending on the tissue characteristics, the laser can be reflected on the surface without entering inside the tissue, transmitted through the tissue without having any effect on that tissue, scattered within the tissue or absorbed inside the tissue (Figure 14) (Parker, 2007).In the first interaction, the laser is reflected from the surface of the tissue and as a result causes no change in the tissue. For the second effect, the laser light is transmitted directly through the tissues, again resulting in no change to the target tissues. In the third effect, scattering of the laser light results in a reduction of its energy and usually results in no beneficial effects from using the laser. Lastly, absorption, which is the desired effect from laser tissue interaction (Coluzzi and Parker, 2017).

Once absorbed inside the target tissue, the resulting effect of the laser energy can be described using 3 terms: *photo-bio-modulative* when using a low-level laser, *photothermal*, that is when using a high-power laser or, *photoacoustic* when high energy laser at short repetitive pulses is delivered (Bago and Anić, I, 2014). Lasers used in endodontics are either photothermal, by direct contact delivery when the laser is absorbed into the tissues (diode, Nd: YAG), or photoacoustic, by indirect contact delivery, through PIPS (Er:YAG, Er,Cr:YSGG)

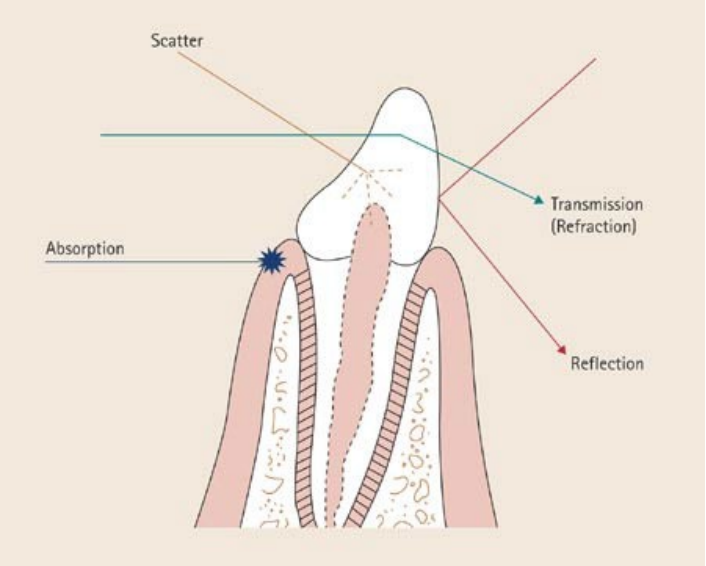


Figure 14: Laser tissue interaction-reflection, transmission, scatter, absorption (Parker, 2007)

2.8.2. Types of lasers

Lasers were first developed by Maiman in 1960 and were called ruby Laser. Their use in endodontics first came about by Weichman and Johnson in 1971 (Kimura *et al*., 2000). However, it was not until 1990's that lasers began to be used clinically in endodontics. Nowadays, various lasers are used in endodontics for the purposes of disinfection. These lasers' function using different wavelengths along the electromagnetic spectrum (Fig 15) (Coluzzi and Parker, 2017).

Lasers that fall in the visible and near infra-red end of the spectrum (Nd: YAG, diode) have good bactericidal effects in dentine, being able to reach deep depths and hard to reach areas of the root canal system (Fig 15). However, these are poorly absorbed in water and hydroxyapatite. On the other hand, those lasers with wavelengths falling in the mid infra-red range of the spectrum (Er: YAG, Er, Cr:YSGG) have high absorption rates in water and hydroxyapatite but poor effects in dentine (Fig 15). These are thus mainly used to remove the biofilm and smear layer (George and Walsh, 2017).

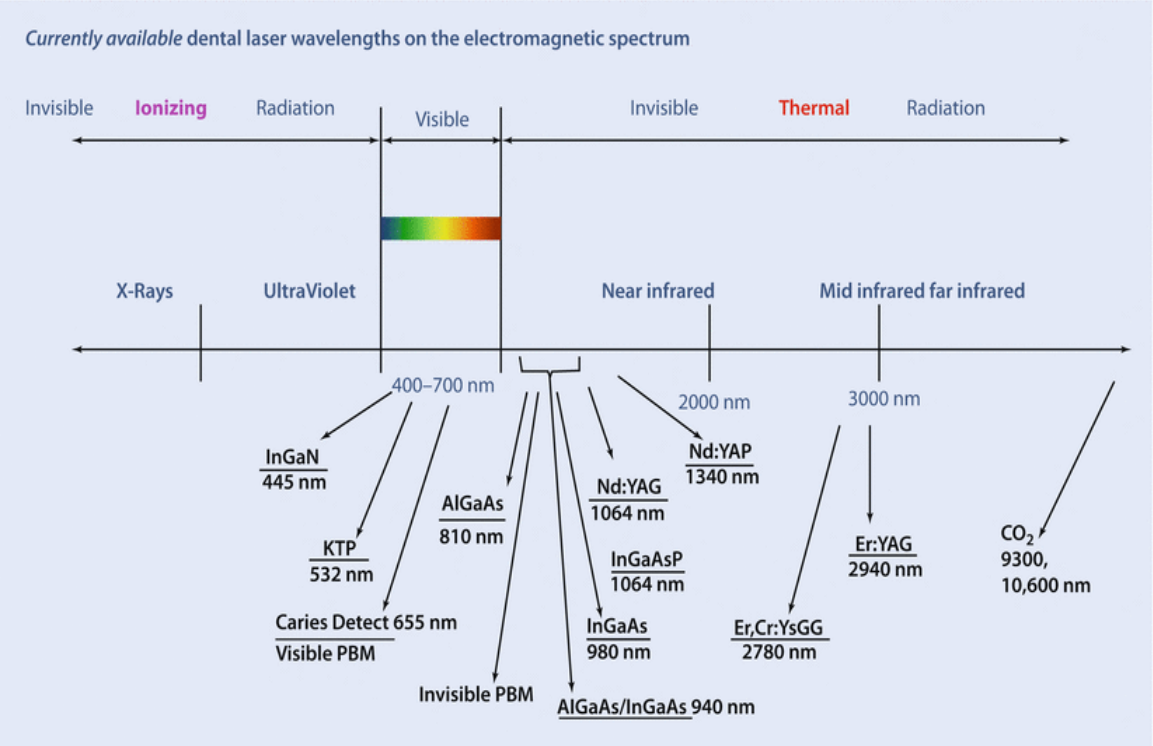


Figure 15: Different types of lasers on the electromagnetic spectrum (Coluzzi and Parker, 2017)

i) Neodimium: Yttrium Aluminium Garnet laser (Nd: YAG)

Nd: YAG lasers have a wavelength of 1064nm, placing them in the near infra-red part of the electromagnetic spectrum (Fig 15) (Coluzzi and Parker, 2017). Nd: YAG lasers have a fibre-optic delivery system for getting inside tight canals. These lasers are poorly absorbed in water while they are well absorbed in chromophobes like melanin and dark pigmented bacteria. Their action is by heating chromophobes inside bacteria, resulting in bactericidal effect of bacteria which can reach up to 1mm inside the radical dentine surface (George and Walsh, 2017). Nd: YAG lasers are however not as effective against E. faecalis (nonpigmented bacteria) or other bacterial biofilms. For the bacteria to be killed, higher energy is required. To avoid damage to the peri-radicular tissue by heat, the recommended protocol is for the laser tip to be moved apically to coronally in a circular motion. (Bago and Anić, I, 2014).

ii) Diode lasers

Diode lasers have wavelength of 980nm and are referred to as low level lasers or therapeutic lasers (Pawar *et al*., 2014). Diode lasers fall near the infra-red zone of the electromagnetic spectrum but before the Nd: YAG laser and are mainly uptaken by melanin and haemoglobin with high water penetrability. Their bactericidal action against endodontic pathogens is due to their ability to penetrate deep into dentine and dentinal tubules and interact with melanin pigments in bacterial cell membranes, effectively disinfecting the root canal system (Martins *et al*., 2018). Similar to Nd:YAG laser, Diode lasers are also capable of removing the smear layer. They also have the added advantage of not causing unwanted temperature rise compared to Nd: YAG laser. However, this also means that these are less efficient in cases of very deep infections (Bhatia and Kohli, 2013). The recommended protocol for diode laser use is in circular movements apically to coronally (Martins *et al*., 2018).

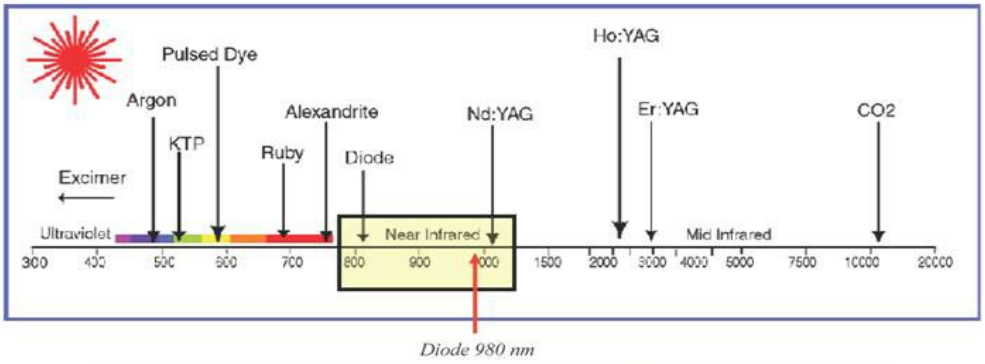


Figure 16: Diode 980 nm laser falling in the near infra-red zone of the electromagnetic spectrum (Desiate *et al*., 2009).

iii) Erbium: Yttrium Aluminium Garnet (Er: YAG) laser and

Erbium, Chromium: Yyttrium Scandium Galium Garnet (Er, Cr: YSGG) laser

Both Er: YAG laser and Er,Cr:YSGG laser have wavelengths of 2940 nm and 2780 nm respectively (Fig 15) (Coluzzi and Parker, 2017). These fall in the mid-far infra-red spectrum of the electromagnetic spectrum (Fig 15). These are absorbed well in both hydroxyapatite and water and can thus be used for removing the smear layer, biofilms and for deep root canal dentin disinfection (Bago and Anić, I, 2014). Erbium lasers are used for photon induced photoacoustic streaming (PIPS) in low settings with ultra-short pulses. PIPS is a process where involves both expansion and implosion of vapour bubbles formed by laser heating of

irrigant solutions inside the root canals, followed by secondary cavitation effect inside the dentinal tubules. Hence, PIPS has the advantage of facilitating irrigant passage inside canal irregularities such as lateral and accessory canals that are otherwise difficult to reach and to allow their disinfection (Jaramillo et al., 2016). In photon induced photoacoustic streaming, the tip is placed near the canal orifice (with continuous irrigation) (Bago and Anić, I, 2014). Due to their non-thermal nature, these lasers produce clinically safe temperatures along the root canal wall (Martins *et al*., 2018).

2.9 Scoping review

Scoping reviews (ScR) are like systematic reviews, where they follow a structured process, however they are performed for different reasons, and have key methodological differences' (Munn *et al*., 2018). ScR determine what volume and coverage of literature are available related to a specific topic by mapping the available evidence (Munn *et al*., 2018). Scoping reviews cover a wide range and an have broad scope for inclusion of studies (Munn *et al*., 2018). These include different kinds of design studies and methodology; however, their focus as a rule does not include the critical appraisal of single studies or generation of evidential information from studies (Pham *et al.,* 2014). ScRs can also be conducted prior to undertaking a systemic review. They are helpful when new evidence is unclear or if more specific questions need to be addressed regarding conciseness of a particular topic (Peters *et al*., 2015). Several guidelines or frameworks have been developed by researchers to assist in conducting these ScR and some of these will be discussed in greater detail below.

A scoping review was conducted in this study to ensure that the relevant primary research, to recommend the role of using lasers in endodontic treatment, was completed. Even though several SR were already completed, it was still not clear what is being recommended as Laser use as adjuncts to conventional root canal treatment is a relatively new modality that is still under research.. Thus, the decision to firstly see what primary and then secondary research were completed to better inform researchers and clinicians. Thus, the decision to focus on the synthesis of evidence for better understanding of the best laser aided endodontic disinfection protocol to use during root canal treatments. Then the decision to conduct an overview of systematic reviews to gauge the quality of research in order to recommend implementation of the laser use in endodontics.

2.9.1. Arksey and O'Malley framework

Scoping studies or reviews 'aim to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available' and can be undertaken as a stand-alone project, especially where a research topic is complex or has not previously been reviewed comprehensively (Arksey and O'Malley, 2005).

Arksey and O'Malley (2005) described four reasons for conducting such a review which are:

1. To examine the extent, range and nature of research activity related to a particular topic.

2. To determine the value of undertaking a full systematic review related to a specific research question.

3. To summarize and disseminate research findings.

4. To identify research gaps in the existing literature regarding a particular topic.

Arksey and O'Malley (2005) also outlined the first framework for a ScR which consists of 6 steps and include the following:

1. Identifying the research question

2. Identifying relevant studies

3. Study selection

4. Charting the data

5. Collating, summarizing, reporting the results

6. Consultation exercise (which is optional).

Table 1 below outlines these 6 steps in greater detail and explains each step thoroughly.

Table 1: Stages for the Arksey and O'Malley Scoping Review framework (Arksey and O'Malley, 2005)

Arksey and O'Malley framework stage	Description of the framework stage
1. Identifying the research question	A clearly defined research question is important as it forms the basis for all the subsequent stages of the scoping review, including the search strategy. The research question needs to be broad to allow for breadth examination and summarisation.
2. Identifying relevant studies	A plan needs to be made at this stage to determine what words to use, what sources to search: that is, electronic databases, reference lists, hand searching of journals & conference proceedings. Comprehensiveness, breadth, time budget, personal resources are all important factors. Feasibility issues should also be considered and limitations of the review (eg, language, dates)
3. Study selection	This includes using the predetermined inclusion, exclusion criteria and study outcomes which are based on the research question. These are included in the search strategy
4. Charting the data	This step involves creating a custom-made form for extracting the data as set out by the predetermined criteria including outcomes from each included study.
5. Collating, summarizing, reporting the results	An overview of the breadth of the extracted evidence is provided in an analytical framework or thematic construction. Tables and charts are used to express the nature and extent of the evidence from the included studies. A thematic analysis of the data may then be presented. It is important to have both clarity and consistency in presenting the results.
6. Consultation exercise	This is an optional stage, where stakeholders or consumers can suggest additional references and provide further insight, clarity and missing data to that from the evidence obtained by searching.

Arksey and O'Malley encouraged other researchers to build on their framework to improve and expand on the methodology. One such example are the recommendations made by Levac et al (2010). They made recommendations to every step in Arksey and O'Malley's framework which include:

1. Linking the research question and the purpose or aim of the study (stage 1)

2. Balancing comprehensiveness with the feasibility of conducting ScR (stage 2)

3. Systematic multidisciplinary team approach to selecting studies (stage 3)

4. Means to aid data extraction (stage 4)

5. Using number summaries and qualitative theme analysis, reporting of the results and considering the results of the findings in a wider context in relation to policy, practice and research (stage 5)

6. Determining clearly why consultation is required (Levac *et al.,* 2010)

Table 2: Levac et al enhancements of the Arksey and O'Malley framework stages for the conduction of scoping reviews (Colquhoun *et al*., 2014)

Stages of the Arksey and O'Malley Framework	Enhancements by Le Vac et al
1.Identification of research question	1. Adequate clarity is needed despite the broad nature of the research question, to include a format: population, intervention, comparator, outcome, (PICO). 2. The rationale for conducting the scoping review should be used to determine the research question. 3. What outputs will be the result of conducting the review-list of recommendations and frameworks.
2.Identification of relevant studies	1. Using the research question and the purpose in order to guide decision making around the scope of the review. 2. Justifying decisions made for limiting the scope of the review as well as acknowledging the potential limitations that come as a result of these limitations. 3. Ensuring reviewers have the necessary content and methodological expertise to conduct the review.

3.Study selection	1. This involves literature search, along with refining the search strategy according to the different databases requirements and reviewing studies to be included independently by the researchers. 2. Better decision making by having discussions regarding inclusion and exclusion criteria, independence of abstract and full text articles review by two reviewers, if in doubt the use of a third reviewer for final inclusion decision, regular meetings at different stages of the ScRs to discuss challenges, uncertainties, refinement of search strategy.
4.Data charting	1. Determining variables to extract as set on custom made data extraction form to answer research question. 2. Continuous data extraction and updating of data charting form. 3. Piloting of the charting form to ensure for consistency with the research question and purpose of the study. 4. Contextual/ process-oriented data might require qualitative content data approach-useful for analysing large amounts of verbal data collected through communication.
5.Collation, summarisation, result reporting	1. Descriptive numerical and qualitative thematic analysis or summarisation of data. 2. Results reporting including outcomes. 3. Discussion of findings relating to study purpose and future research, practice, and policy implications.
6.Consultation	Should be considered for every review. 1. Have a clear purpose. 2. Findings to inform the consultation. 3. Clarity and details of stakeholder consultation and how this data will be collected, analysed, reported. 4. 4. Opportunities for knowledge exchange and transfer with others in the field.

2.9.2. Enhancements to the Arksey and O'Malley framework

The (2005) was modified by enhancements from Levac and colleagues (2010). Levac and colleagues' work provided more information for the steps of the process of the review to make it more transparent. All this helped improve the work of the Joanna Briggs Institute (JBI), a recognized global leader in evidence-based healthcare, for conducting ScR (Peters *et al*., 2015).

The enhancements by Peters et al following the work of the JBI led to these steps:

1. Aligning and defining the questions and objectives (stage 1)

2. Aligning and developing the inclusion criteria with the questions and objectives (stage 2)

3. Explaining a planned approach to searching and selecting the evidence (stage 3)

4. Evidence of the searching process and strategies (stage 4)

5. Evidence of the study selection process (stage 5)

6. Extracting the evidence (stage 6)

7. Analysis of the evidence charting (stage 7)

8. Presentation of the results (stage 8)

9. Summarizing the evidence in relation to the purpose of the review, making conclusions and noting any implications of the findings (Aromataris and Munn, 2020)

Table 3: Peter et al enhancements to the Arksey and O'Malley framework (Peters *et al*., 2015).

Framework stages	
1.Identifying the research question	Aligning and defining the questions and objectives
2.Identifying the relevant studies	Aligning and developing the inclusion criteria with the questions and objectives
3.Study selection	Explaining a planned approach to searching and selecting the evidence
4.Charting the data	Evidence of the searching process and strategies
5.Collating, summarising, reporting results	Evidence of the study selection process
6.consultation	Extracting the evidence
7.	Presentation of the results
8.	Summarizing the evidence in relation to the purpose of the review, making conclusions and noting any implications of the findings
9.	Consultation of the information to experts

2.9.3 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement was published in 2009. It consists of a flow diagram (Fig 17) and a 27-item checklist (Fig 18) (Moher *et al*., 2009).

Prisma 2009 was meant to aid in the transparent preparation of review accounts. It was the minimum required information to be used in a systematic review report. It provided information for why a review needed to be undertaken, the databases used to identify the

relevant studies, the results of the analysis conducted, and the implications of the findings. The checklists were followed with explanations, elaborations, rationales, and guidance for each item on the checklist for complete reporting (Matthew J. Page *et al*., 2021).

The PRISMA 2009 statement consists of a 27-question checklist along with a four-phase flow diagram. The four phases are: Identification, screening, eligibility and included studies. The Prisma flow diagram is a visual summary of the screening process (Moher *et al*., 2009).

2.9.3.1 Prisma 2009 Flow Diagram

i) Identification

Involves recording the number of articles found through searching the databases, along other sources like trial registries, reference lists and conferences for the use of lasers in root canal disinfection. The articles were limited to those in the English language over the last 10-year period. Once the search has been completed a reference manager system 'Mendeley' was used to export the results. Any duplicate records were then removed.

ii) Screening

The titles and abstracts of relevant studies were selected based on the inclusion and exclusion criteria by the two reviewers NH and SK. This is done to minimise selection bias, and to ensure that relevant studies are not excluded (Page *et al*., 2021).

iii) Eligibility

The relevant full text articles are then identified, similarly screened for eligibility based on the inclusion criteria. Any excluded articles are identified and the reason for their exclusion noted.

iv) Included

All included studies eligible full text articles are now identified.

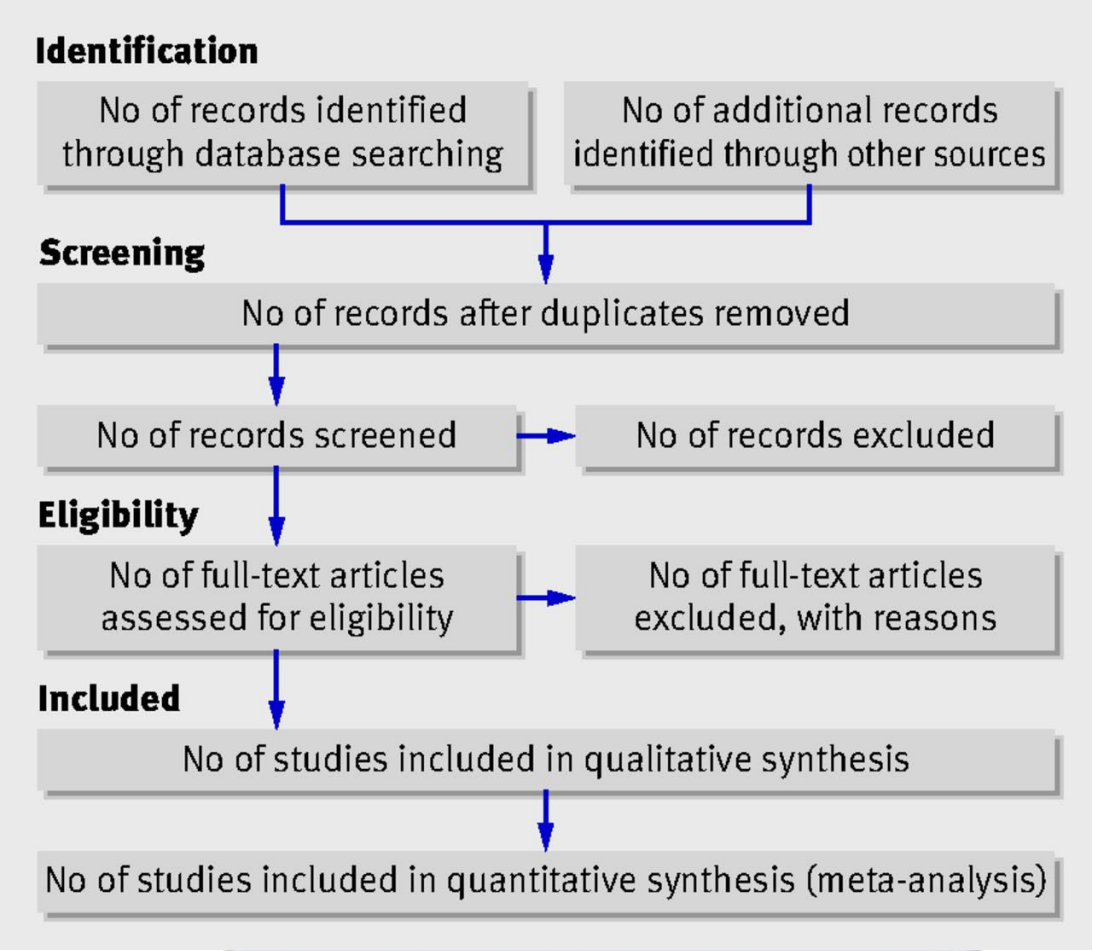


Figure 17: Original PRISMA Flow diagram (Moher *et al*., 2009).

2.9.3.2 Prisma 2009 Checklist

The 2009 Prisma checklist consists of 27 questions (Appendix 1). These are explained in more detail below:

i) Title

It is advisable to identify the report as a systematic review or a meta-analysis. Using PICOS components-population, intervention, comparator, outcome, study design-in the title is advisable to make the title informative (Liberati *et al*.,2009).

ii) Structured summary

The abstract provides information about the whole research and allows the reader to decide if the whole research should be read. A structured abstract gives complete information and allows for information to be found easily (Liberati *et al*.,2009).

iii) Rationale

To say why the study is being undertaken and what extra additions can be made. It should say if its a new review or an update. Any update should why it needed to be updated and what extra information was shared since the last review (Liberati *et al*.,2009).

iv) Objectives

These should be stated precisely. They should include PICOS components (Liberati *et al*., 2009).

v) Protocol and registration

Having a protocol is important because it has pre-determined objectives and methods of the review. Registration of the review reduces chances of the same question being reviewed multiple times and provides transparency when updating reviews (Liberati *et al*., 2009).

vi) Eligibility criteria

This is important in appraising the comprehensibility, validity and applicability of the review. It's also needed in the review methodology and search strategy.

Both the study and report characteristics need to be reported. For the study eligibility criteria, the PICOS components should be included as well as exclusion criteria. The report eligibility criteria should include language and time of publication as well as publication status (Liberati *et al*., 2009).

vii) Information sources

More than one database must be searched to ensure detailed reporting. For the databases searched authors need to report the database or platform searched along with start and end search dates and who conducted the search. If supplementary approaches-like hand searching journals or checking reference lists or searching trial registries- were used these need to be reported (Liberati *et al*., 2009).

viii) Search

This is an important part of any review. It is recommended that a full electronic search strategy for at least one major database is recorded. Any limitations should be included (Liberati *et al*.,2009).

ix) Study selection

It is advisable to state how the records were screened and excluded based on the eligibility criteria and to use the Prisma flow diagram for summarizing the study selection process. It is important to state if each stage of the process was conducted by one or more people, who the people were and if disagreements arose, how they were resolved (Liberati *et al*.,2009).

x) Data Collection Process

Reviewers extract information to critique and summarise evidence in a review. The steps taken to reduce bias and mistakes during data collection and extraction should be described. A data extraction form can be sued -these should show what information was sought and how it was extracted. Authors may inform if the form was piloted. Investigators may need to be contacted for further information if needed. Any steps taken to avoid duplicate records are also mentioned (Liberati *et al*.,2009).

xi) Data items

It is important that any information sought is reported, regardless of whether this information can actually be found to reduce bias. If variables were added following the start of the review, then theses need to be noted as well (Liberati *et al*.,2009).

xii) Risk of Bias in individual studies

Reviewers should describe methods that they used to determine the risk of bias in the included studies and how that information was used. If blinding was done and who completed the assessments. If no assessment of risk of bias was done, a reason should be provided. This helps determine the quality of the review (Liberati *et al*.,2009).

xiii) Summary Measures

Pre-specifying the outcomes of primary interest and the intended summary effect measure for each outcome is desirable. Examples include risk ratio, odds ratio, difference in means (Liberati *et al*.,2009).

xiv) Planned method of analysis

Extracted data from review studies may need processing before they can be analysed or presented in an evidence table. The report should include how to evaluate inter-study variability-heterogeneity or inconsistency (Liberati *et al*.,2009).

xv) Risk of Bias across studies

Exploration of the possibility of bias in the studies. This can be missing studies /publication bias or missing data from the included studies/selective reporting bias (Liberati *et al*.,2009).

xvi) Additional analysis

Extra analyses should be conducted to help understand if the results of the review are robust. Type of analysis conducted include subgroup analysis, sensitivity analysis and meta-regression.

Subgroup analyses determines if the summary effects change in relation to certain characteristics of the included studies or their participants.

The Sensitivity analyses explores the degree that the main findings of a review are affected by changes in the methods or data used from individual studies-like the inclusion criteria/ results of risk of bias assessment.

Meta-regression allows reviewers to examine the effect of different variables to the heterogeneity in study findings (Liberati *et al*., 2009).

xvii) Study selection

A flow diagram should be used to determine total number of records identified and their sources-electronic databases/hand searching/reference list. The flow diagram should also describe the process of report selection and exclusion through the review, with reasons for exclusion provided. Duplicates should also be noted (Liberati *et al*., 2009).

xviii) Study characteristics

To be able to determine validity and applicability of a review, information about each included study must be provided like PICOS. Authors should also provide a source of the citation for all included studies. The information is provided in a table along with a narrative summary of the studies (Liberati *et al*., 2009).

xix) Risk of bias within studies

Reporting the methodological features evaluated for each study and presenting these in a tabular form or narrative summary (Liberati *et al*., 2009).

xx) Results of individual studies

All information should be provided for every outcome considered in the review, including benefits and harms (Liberati *et al*., 2009).

xxi) Synthesis of results

Results of reviews should be presented in an orderly manner. If a meta-analysis was conducted, the results should be presented as an estimated effect across studies with a confidence interval. A forest plot can be used to show results of included studies (Liberati *et al*., 2009).

xxii) Risk of Bias across studies

The results of any assessments of risk of bias across studies should be presented. Any statistical significance of asymmetry test as well as selective reporting of outcomes should be noted (Liberati *et al*., 2009).

xxiii) Additional Analysis

Any conducted additional analyses should be reported, not only that with statistically significant results. This will help prevent selective outcome reporting bias (Liberati *et al*., 2009).

xxiv) Summary of evidence

A brief and balanced summary of the nature and findings of the review needs to be provided. Applicability of the findings also needs to be mentioned (Liberati *et al*., 2009).

xxv) Limitations

These include the validity/ risk of bias, the reporting of the included studies, the limitations of the review process, the generalizability of the review. Other limitations include limitations of

the search restricting it to a certain language, difficulties in the study selection, appraisal, and meta-analysis processes (Liberati *et al*., 2009).

xxvi) Conclusions

Aims to relate the results of the review to other evidence and to make explicit recommendations for future research (Liberati *et al*., 2009).

xxvii) Funding

It is important to disclose if the review received funding or not and if funders played any role in the review. Any conflict of interest should be reported (Liberati *et al*., 2009).

2.9.3.3 Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for Scoping Reviews -PRISMA-ScR Checklist 2020

The PRISMA 2009 statement' extensions were created to guide the reporting of network and individual participant data meta-analyses, systematic reviews of harms, diagnostic test, accuracy studies, and scoping reviews. In 2020, the PRISMA-ScR checklist (Appendix 2) superseded the PRISMA 2009 statement' extensions (Matthew J. Page *et al*., 2021). PRISMA-ScR checklist is used to improve the methodological and reporting quality of ScR, to make reporting more transparent. The checklist was made by The Joanna Briggs Institute (JBI) based on the work by Arksey and O'Malley and Levac and colleagues. It is a modification to the original PRISMA statement, where 5 items were discarded as they didn't relate to ScR, 2 items were optional, and the overall wording was modified to fit a scoping review. The final PRISMA-ScR checklist thus consists of 20 questions that are mandatory and 2 that are optional as seen in Table. This development followed guidance by Enhancing the Quality and Transparency Of health Research (EQUATOR) Network for the development of reporting guidelines (Tricco *et al*, 2018).

2.9.4. Mixed Methods Appraisal Tool (MMAT)

The Mixed Methods Appraisal Tool is a tool that is used for the critical appraisal of reviews that include mixed studies, like qualitative, quantitative, and mixed methods studies. It is intended to be a checklist for appraising methodological quality of studies included in systematic mixed studies reviews. The studies included are randomised control trials, non - randomised controlled trials, quantitative descriptive studies, qualitative research, and mixed methods studies (Hong *et al.,* 2018).

The MMAT tool cannot be used to appraise the non-empirical studies like review or theoretical papers. It can be used for the appraisal of empirical studies like observational, primary research based on experiments and simulation papers. The tool was created based on the feedback obtained from several workshops to overcome the absence of a consensus on the criteria for appraising the methodological quality of mixed methods studies. It does not however appraise the quality of reporting or writing involved.

At least 2 independent reviewers need to be involved in the critical appraisal process. The MMAT tool involves a checklist (Appendix 3) and an explanation of the criteria. Any response of 'No' or 'Can't tell' to the screening questions indicates that the study is non empirical and therefore the MMAT tool can be used (Hong *et al.,* 2018).

2.9.4.1. MMAT checklist

1. A 'no' or 'can't tell' response to one or both of the two screening questions mean that the study is not an empirical study- theoretical and review paper-and the MMAT checklist cannot be used here.

2. For each study involved, use the correct category of studies to appraise

3. Rate the criteria for that chosen category-can't tell response means insufficient information to choose a yes or no answer (Hong *et al.,* 2018).

Calculation of an overall score from each criteria's rating is not encouraged, a more detailed presentation of these ratings, gives better information on the quality of the studies and may

lead to conducting a sensitivity analysis. It is also not advised for studies with low methodological qualities to be removed.

The latest version of the MMAT tool was developed in 2018 (Hong *et al.,* 2018).

2.9.4.2. Explanation of the criteria

A) Qualitative research

Qualitative research is an approach for the exploration/understanding of meanings individuals place for a human/social problem. Types include narrative research, case study, qualitative description (Hong *et al.,* 2018).

i) Understanding Qualitative research checklist questions

Is the qualitative approach appropriate for the research question and problem. Are the data collection methods-interviews and observations-and the data forms adequate to address the research question, if they are modified then a justification is required. Is a data analysis used to ensure that adequate data are derived from the studies. Are there clear links and coherence existing between sources of data, data collection, data analysis and interpretation (Hong *et al.,* 2018).

B) Quantitative randomised control trials (RCT)

A study type where individual participants are randomly allocated into an intervention or control group (Hong *et al.,* 2018).

i) Understanding Quantitative research checklist questions

Is generation of a randomisation schedule until the point of allocation mentioned by researchers to determine if randomisation was done correctly. Are the groups comparable at baseline to ensure that there are no problems with randomisation. Is a complete outcome data agreed upon initially. Is there blinding of the outcome assessors to the intervention provided.

Was the assigned intervention being adhered to by the participants in the study (Hong *et al.,* 2018).

C) Quantitative non-randomised studies-cohort, cross sectional analytic, non RCT, case control studies

Any quantitative study where intervention effectiveness are not randomly allocated to groups (Hong *et al.,* 2018).

i) Understanding non-Quantitative research checklist questions

Do the participants represent the target population in terms of inclusion and exclusion criteria. Are appropriate measurements used for intervention and outcome. Is a complete outcome data agreed upon initially. Are baseline confounders-that predict outcome of interest and the intervention received- accounted for in the design and analysis. Is the intervention administered appropriately (Hong *et al.,* 2018).

D) Quantitative descriptive studies

Studies used to describe existing distributions of variables without causation or hypothesis-incidence/prevalence, case report/study, survey.

i) Understanding Quantitative descriptive research checklist questions

Is the sampling-probability or random selection/non-probability-relevant to address research question. Is the sample representative of the population. Are the variables clearly defined and accurately manged. Is non response bias-no observation due to no success in attaining desired information- risk low. Is statistical analysis appropriate for answering research question (Hong *et al.,*2018).

E) Mixed Methods studies-research combining qualitative and quantitative studies

i) Understanding mixed methods research checklist questions

Justification for using this design to answer research question. Is there integration between different components in the study-quantitative and quantitative -to answer the research question. Are the outputs of the integration between qualitative and quantitative studies-meta interference-addressed. Are divergences and inconsistencies addressed and explained upon integration of the findings. Do different study components have separate quality criteria involved (Hong *et al.,* 2018).

Once all stages are completed of conducting and appraising a ScR statements are connected to every part of the ScR literature, methodology, results, appraisal, and reporting. Different checklists have been developed for different types of research and research designs for example: CONSORT; PRISMA; STROBE.

2.10 Overview of Systematic Reviews (OSR)

Evidence based on high quality research is needed by health care providers to make clinical decisions. Systematic reviews generate clinical information from numerous primary research. They present a reliable way for clinicians to make healthcare decisions due to the rigor of its required methodology. However, due to the presence of numerous systematic reviews on a topic, methodologists developed an approach to synthesize research and called it an overview of systematic reviews. By definition, "an overview of systematic reviews is a study designed to integrate and produce a synthesis of information from existing systematic reviews on a particular clinical condition, considering all the available interventions for treating or preventing this condition" (Silva *et al*., 2012).

Overview of systematic reviews thus play an important role when evidence pertaining to a certain topic is available but the results from different systematic reviews are conflicting. The process of collecting, critically appraising and analysing evidence enables informed decisions to be made on the topic (Hunt *et al.,* 2018). Hence, the best and most reliable evidence on a

particular search topic is integrated with patients values to allow for better clinical practise and healthcare delivery (Ganeshkumar and Gopalakrishnan, 2013).

Cochrane standards and PRISMA reporting guidance, aim to guide researchers to produce systematic reviews with high standards of reporting. Despite this, poor quality of systematic reviews still exists. To overcome this, researchers developed special tools such as the AMSTAR, AMSTAR 2 and Risk of Bias in Systematic Reviews (ROBIS) to critically appraise these SRs and comment on the quality thereof. The quality of SRs will indicate its value and reliability and ultimate use to change clinical (Gates *et al.,* 2018).

2.10.1 A Measurement Tool to Assess Systematic Reviews (AMSTAR)

Primary research publications have reached extremely large numbers making it practically impossible for healthcare providers to read through all the articles and find the most appropriate and highest quality evidence necessary to make healthcare decisions needed by patients. Systematic reviews have thus become the gold standard of presenting the relevant evidence which can then be critiqued and used for evidence-based health care in forming guidelines and clinical decisions appropriate for patients (Munn *et al.*, 2018).

On the scale of quality research, one SR is better than primary research due to the quality appraisals it undergoes. But accepting the results of one SR blindly still comes with risks as these are still open to bias due to the rate at which these are churned out by researchers.

Results of several SRs related to one concept or topic may be synthesized and it will again be exposed to a critical appraisal of the methodology, eliminating any further bias. High level methodological quality is therefore a very important factor to interpret and apply review findings to clinical practise. If reported poorly, the value of SRs is diminished, thus the importance of always using the PRISMA checklists. To overcome this a tool was developed to allow researchers to critically appraise and assess the quality and conduct of SRs. Quality in research and more specifically related to SRs and as defined by Shea et al, is *"the likelihood that the design of a systematic review will generate unbiased results"* (Shea *et al*, 2009) (Shea *et al.*, 2017).

The instrument to appraise a SR was developed in 2007 and is called AMSTAR tool. It came about by reviewing and updating the existing instruments (Shea *et al.*, 2009; Shea *et al.*,

2017). The best available instruments at the time were the Overview Quality Assessment Questionnaire (OQAQ) developed by Oxman and Guyatt (Year) and the rating scale of Sacks or Sacks' instrument (Shea *et al.*, 2009; Shea *et al.*, 2017). AMSTAR tool is a reliable, easy to use and valid instrument used for the evaluation of SRs of RCTs consisting of 11 domains as seen in (Appendix 4) below. The AMSTAR tool, however, did not provide risk assessment of bias for non-randomised controlled clinical trials included in a review. This led to the development of AMSTAR 2 tool (Shea *et al*, 2009; Shea *et al*, 2017). AMSTAR 2 tool is an updated version of AMSTAR and is the one used in study.

2.10.2 AMSTAR 2 TOOL

The AMSTAR 2 tool consists of 16 domains as seen in Figure 8 below, that provides a risk assessment for both randomised and non-randomised clinical trials (Shea *et al*., 2017). It is thus a broad tool for critically appraising SRs of different designs. The AMSTAR 2 differs from the AMSTAR tool in several ways. It retained 10 of the original domains of the AMSTAR tool but included changes in the wording of these domains. Two other domains from AMSTAR tool were given more emphasis, instead of being under the same domain as is in AMSTAR, that are now two separate entities in AMSTAR 2. These domains are for duplicate study selection and data extraction. Another change was the separation of the influence of funding of the individual studies or of the review itself. Other changes included the emphasis on risk of bias for randomised and non-randomised clinical trials (Shea *et al.*,2017).

While four domains were added to the AMSTAR 2 tool, one domain was removed. The grey literature is no longer a separate entity but falls under the broad category of literature search. The added items include Population, Intervention, Comparator, Outcome (PICO) framework components, how is risk of bias handled in the included studies for the synthesis of evidence, justification of the selection of the study designs and the causes and significance of heterogeneity (Shea *et al.*,2017).

Changes to AMSTAR tool also included the way the response was recorded, where the 'not applicable' and 'cannot answer responses' in AMSTAR 1 (Fig 20) were removed in AMSTR 2 and replaced by 'yes' and 'no' answers (Fig 21). It is also highly recommended that an

overall score is not generated from individual item ratings. This might disguise any critical weakness and reduce confidence in the results of the review (Shea *et al.*, 2017). Instead, the overall quality of the review is determined by a weighted system ranging from critically low to high (Fig 20) depending on the responses to the 16 questions of the AMTAR 2 tool (Fig 18) which are categorised into 7 critical and 9 non-critical domains (Fig 19) (Table 4) (*Shea, B.J. et al. 2017)*.

AMSTAR 2

1. Did the research questions and inclusion criteria for the review include the components of PICO?

For Yes:
- ☐ Population
- ☐ Intervention
- ☐ Comparator group
- ☐ Outcome

Optional (recommended)
- ☐ Timeframe for follow-up

- ☐ Yes
- ☐ No

2. Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?

For Partial Yes:
The authors state that they had a written protocol or guide that included ALL the following:
- ☐ review question(s)
- ☐ a search strategy
- ☐ inclusion/exclusion criteria
- ☐ a risk of bias assessment

For Yes:
As for partial yes, plus the protocol should be registered and should also have specified:
- ☐ a meta-analysis/synthesis plan, if appropriate, *and*
- ☐ a plan for investigating causes of heterogeneity
- ☐ justification for any deviations from the protocol

- ☐ Yes
- ☐ Partial Yes
- ☐ No

3. Did the review authors explain their selection of the study designs for inclusion in the review?

For Yes, the review should satisfy ONE of the following:
- ☐ *Explanation for* including only RCTs
- ☐ OR *Explanation for* including only NRSI
- ☐ OR *Explanation for* including both RCTs and NRSI

- ☐ Yes
- ☐ No

4. Did the review authors use a comprehensive literature search strategy?

For Partial Yes (all the following):
- ☐ searched at least 2 databases (relevant to research question)
- ☐ provided key word and/or search strategy
- ☐ justified publication restrictions (eg, language)

For Yes, should also have (all the following):
- ☐ searched the reference lists/bibliographies of included studies
- ☐ searched trial/study registries
- ☐ included/consulted content experts in the field
- ☐ where relevant, searched for grey literature
- ☐ conducted search within 24 months of completion of the review

- ☐ Yes
- ☐ Partial Yes
- ☐ No

5. Did the review authors perform study selection in duplicate?

For Yes, either ONE of the following:

- ☐ at least two reviewers independently agreed on selection of eligible studies and achieved consensus on which studies to include
- ☐ OR two reviewers selected a sample of eligible studies and achieved good agreement (at least 80 per cent), with the remainder selected by one reviewer

☐ Yes
☐ No

6. Did the review authors perform data extraction in duplicate?

For Yes, either ONE of the following:

- ☐ at least two reviewers achieved consensus on which data to extract from included studies
- ☐ OR two reviewers extracted data from a sample of eligible studies and achieved good agreement (at least 80 per cent), with the remainder extracted by one reviewer

☐ Yes
☐ No

7. Did the review authors provide a list of excluded studies and justify the exclusions?

For Partial Yes:

- ☐ provided a list of all potentially relevant studies that were read in full text form but excluded from the review

For Yes, must also have:

- ☐ Justified the exclusion from the review of each potentially relevant study

☐ Yes
☐ Partial Yes
☐ No

8. Did the review authors describe the included studies in adequate detail?

For Partial Yes (ALL the following):

- ☐ described populations
- ☐ described interventions
- ☐ described comparators
- ☐ described outcomes
- ☐ described research designs

For Yes, should also have ALL the following:

- ☐ described population in detail
- ☐ described intervention and comparator in detail (including doses where relevant)
- ☐ described study's setting
- ☐ timeframe for follow-up

☐ Yes
☐ Partial Yes
☐ No

9. Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?

RCTs

For Partial Yes, must have assessed RoB from

- ☐ unconcealed allocation, *and*
- ☐ lack of blinding of patients and assessors when assessing outcomes (unnecessary for objective outcomes such as all cause mortality)

For Yes, must also have assessed RoB from:

- ☐ allocation sequence that was not truly random, *and*
- ☐ selection of the reported result from among multiple measurements or analyses of a specified outcome

☐ Yes
☐ Partial Yes
☐ No
☐ Includes only NRSI

NRSI

For Partial Yes, must have assessed RoB:

- ☐ from confounding, *and*
- ☐ from selection bias

For Yes, must also have assessed RoB:

- ☐ methods used to ascertain exposures and outcomes, *and*
- ☐ selection of the reported result from among multiple measurements or analyses of a specified outcome

☐ Yes
☐ Partial Yes
☐ No
☐ Includes only RCTs

10. Did the review authors report on the sources of funding for the studies included in the review?

For Yes

- ☐ Must have reported on the sources of funding for individual studies included in the review. Note: Reporting that the reviewers looked for this information but it was not reported by study authors also qualifies

☐ Yes
☐ No

11. If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?

RCTs

For Yes:

- ☐ The authors justified combining the data in a meta-analysis
  - ☐ AND they used an appropriate weighted technique to combine study results and adjusted for heterogeneity if present

☐ Yes
☐ No
☐ No meta-analysis conducted

☐ **AND investigated the causes of any heterogeneity**

For NRSI

For Yes:

☐ **The authors justified combining the data in a meta-analysis**
☐ **AND they used an appropriate weighted technique to combine study results, adjusting for heterogeneity if present**
☐ **AND they statistically combined effect estimates from NRSI that were adjusted for confounding, rather than combining raw data, or justified combining raw data when adjusted effect estimates were not available**
☐ **AND they reported separate summary estimates for RCTs and NRSI separately when both were included in the review**

☐ Yes
☐ No
☐ No meta-analysis conducted

12. If meta-analysis was performed, did the review authors assess the potential impact of RoB in individual studies on the results of the meta-analysis or other evidence synthesis?

For Yes:

- ☐ included only low risk of bias RCTs
- ☐ OR, if the pooled estimate was based on RCTs and/or NRSI at variable RoB, the authors performed analyses to investigate possible impact of RoB on summary estimates of effect

☐ Yes
☐ No
☐ No meta-analysis conducted

13. Did the review authors account for RoB in individual studies when interpreting/discussing the results of the review?

For Yes:

- ☐ included only low risk of bias RCTs
- ☐ OR, if RCTs with moderate or high RoB, or NRSI were included the review provided a discussion of the likely impact of RoB on the results

☐ Yes
☐ No

14. Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?

For Yes:

- ☐ There was no significant heterogeneity in the results
- ☐ OR if heterogeneity was present the authors performed an investigation of sources of any heterogeneity in the results and discussed the impact of this on the results of the review

☐ Yes
☐ No

15. If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?

For Yes: ☐ performed graphical or statistical tests for publication bias and discussed the likelihood and magnitude of impact of publication bias	☐ Yes ☐ No ☐ No meta-analysis conducted
16. Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?	
For Yes: ☐ The authors reported no competing interests OR ☐ The authors described their funding sources and how they managed potential conflicts of interest	☐ Yes ☐ No

Figure 18: AMSTAR 2: a critical appraisal tool for systematic reviews (*Shea, B.J. et al., 2017)* https://doi.org/10.1136%2Fbmj.j4008

AMSTAR 2 critical domains

- Protocol registered before commencement of the review (item 2)
- Adequacy of the literature search (item 4)
- Justification for excluding individual studies (item 7)
- Risk of bias from individual studies being included in the review (item 9)
- Appropriateness of meta-analytical methods (item 11)
- Consideration of risk of bias when interpreting the results of the review (item 13)
- Assessment of presence and likely impact of publication bias (item 15)

Figure 19: AMSTAR 2 Critical domains (*Shea, B.J. et al. 2017)*

Table 4: AMSTAR 2 with critical and non-critical domains (*Shea, B.J. et al. 2017)*

Domain number	Critical or non-critical	Content of the domain	Yes or partial yes	No
1	Non-critical domain	Did the research questions and inclusion criteria for the review include the components of PICO		
2	Critical domain	Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?		
3	Non-critical domain	Did the review authors explain their selection of the study designs for inclusion in the review?		
4	Critical domain	Did the review authors use a comprehensive literature search strategy?		
5	Non-critical domain	Did the review authors perform study selection in duplicate?		
6	Non-critical domain	Did the review authors perform data extraction in duplicate?		

7	Critical domain	Did the review authors provide a list of excluded studies and justify the exclusions?		
8	Non-critical domain	Did the review authors describe the included studies in adequate detail?		
9	Critical domain	Did the review authors use a satisfactory technique for assessing the risk of bias in individual studies that were included in the review?		
10	Non-critical domain	Did the review authors report on the sources of funding for the studies included in the review?		
11	Critical domain	If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?		
12	Non-critical domain	If meta-analysis was performed, did the review authors assess the potential impact of risk of bias in individual studies on the results of the meta-analysis or other evidence synthesis?		
13	Critical domain	Did the review authors account for risk of bias in individual studies when interpreting/ discussing the results of the review?		

14	Non-critical domain	Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?		
15	Critical domain	If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?		
16	Non-critical domain	Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?		

Rating overall confidence in the results of the review

• **High**

• N o or one non-critical weakness: the systematic review provides an accurate and comprehensive summary of the results of the available studies that address the question of interest

• **Moderate**

• More than one non-critical weakness*: the systematic review has more than one weakness but no critical flaws. It may provide an accurate summary of the results of the available studies that were included in the review

• **Low**

• One critical flaw with or without non-critical weaknesses: the review has a critical flaw and may not provide an accurate and comprehensive summary of the available studies that address the question of interest

• **Critically low**

• More than one critical flaw with or without non-critical weaknesses: the review has more than one critical flaw and should not be relied on to provide an accurate and comprehensive summary of the available studies

*Multiple non-critical weaknesses may diminish confidence in the review and it may be appropriate to move the overall appraisal down from moderate to low confidence.

Figure 20: Rating overall confidence in the results of the review (*Shea, B.J. et al. 2017)*

CHAPTER 3
RESEARCH QUESTION, AIMS AND OBJECTIVES

3.1. Thesis Framework

3.1.1. Rationale for conducting this research

The most important factor in the success of endodontic treatments is disinfection of the root canals. The use of lasers in canal debridement is a new modality of treatment in the armamentarium for endodontic procedures. And it is still unclear from some of the literature used in this research protocol what the efficacy of its use is, or what treatment protocol, of which several were proposed by the researchers, should mostly be used.

3.1.2 Aim

To determine if the use of lasers as an adjunct to conventional root canal treatment yields better results than conventional root canal treatment alone.

3.1.3 Objectives

1. To conduct a scoping review to determine the efficacy of laser use on success of endodontic treatment

2. To conduct an overview of systematic reviews to critically appraise the evidence on the use of lasers to aid the success of endodontic treatment.

3.1.4 Research question for this research

What is the efficacy of using lasers as an adjunct to conventional root canal treatment.

3.2. Scoping Review Framework

A scoping review (ScR) was conducted in order to systematically map the research done to determine the efficacy of laser use on success of endodontic treatment as well as to identify any existing gaps in knowledge related to laser disinfection.

3.2.1. Aim for conducting ScR

To determine the efficacy of laser use on success of endodontic treatment.

3.2.2. Objectives of ScR

1. To determine what kind of studies have been conducted on the use of lasers in root canal disinfection in adults.
2. To determine what types of lasers are available to use for root canal disinfection in adults.
3. To determine what laser parameters are used in root canal disinfection in adults.
4. To determine any gaps in the existing literature on using lasers as an adjunct to conventional endodontic treatment.

3.2.3 Research question for ScR

The following research question was thus formulated:

Will the use of lasers enhance disinfection of the root canals for adult endodontic patients?

Using the framework of PICO for the research question

- Population

Male and Female adult patients with permanent teeth requiring endodontic treatment.
Extracted permanent teeth

- Intervention

Lasers used in endodontic treatment.

- Context

Global dental clinics or laboratories involved with conducting endodontic treatments or experiments.

- Outcome

Reduction in the amount of intracanal microorganisms depicted by the absence of clinical symptoms showing as flareups or associated nerve damage that indicate the endodontic treatment has been a success.

3.3. Overview of Systematic Reviews

After conducting the ScR, numerous systematic reviews were found on the use of lasers as an adjunct to root canal disinfection. However, the results of systematic reviews cannot be accepted without critical appraisal, as these may be conflicted, methodologically flawed, and open to bias, thus diminishing their value. An overview of systematic reviews (OSR) was thus conducted utilising the AMSTAR 2 tool to critically appraise each included systematic review.

3.3.1. Aim for conducting OSR

To evaluate the quality of the outcomes of systematic reviews conducted on the use of lasers as adjuncts to enhancing root canal disinfection.

3.3.2 Objectives of OSR

1. To determine the best type of laser to be used for root canal disinfection in adults.

2. To determine the beneficial wavelength for laser use.

3. To determine the protocol of laser use for endodontic disinfection in adults.

4. To determine success with laser use

3.3.3 Research question for the OSR

The research question ‘What laser protocols successfully achieve disinfection of root canals amongst adult endodontic patients’ was constructed using the following PICO format.

- Population

All studies of adult human subjects with permanent dentition who underwent conventional, and laser aided root canal treatment.

- Intervention

Lasers used to aid with conventional root canal disinfection.

- Context

Conventional root canal treatment

- Outcome

Determined by the success of laser aided endodontic treatment signified by the absence of any post-operative or clinical symptoms including pain and infection.

CHAPTER 4
METHODOLOGY

4.1 Methodology for Scoping Review

A scoping review of the existing literature was conducted using Arksey and O'Malley (2005) framework stages for the conduct of scoping reviews combined with Levac et al enhancements (2010) (Fig 21) (Colquhoun *et al*., 2014). The stages are explained in further detail below:

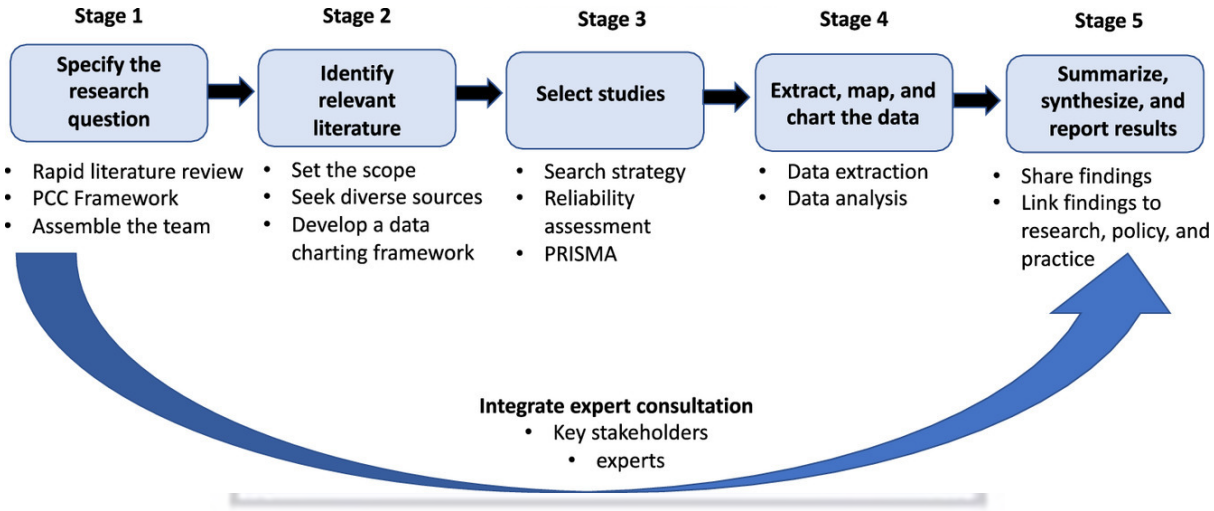


Figure 21: Levac's recommendations to the Arksey and O'Malley framework (Westphaln et al, 2021)

i) Identifying the research question

This scoping review was conducted to answer the research question 'Will the use of lasers enhance disinfection of the root canals for adult endodontic patients?'

ii) Identifying relevant literature

A comprehensive literature search of the following electronic databases was conducted: Google Scholar, PubMed, Wiley Online Library, ScienceDirect to identify the articles

relevant to the use of lasers in root canal disinfection in adult patients. In addition, searches were conducted in grey unpublished literature (books, clinical trials, conference presentations) and endodontic journals for relevant studies. Keywords created, along with Boolean operators helped to identify articles relevant to the research question. The same search strategy was utilised in the process of identification of the relevant studies, this search strategy was:

(Laser* OR laser treatment OR "photodynamic therapy") AND (root canal treatment OR endodontic treatment) AND (disinfection).

The search was limited to the English language and restricted to the last 10-years. Further to the electronic database search, the reference lists of related studies was checked for those articles that may have not been picked up in the initial search.

iii) Study selection

The researchers (NH and SK) determined the inclusion and exclusion criteria that was applied to the studies generated by the searching the literature. Using the framework of population, intervention, comparator, outcome (PICO) for the research question, the inclusion criteria thus generated was:

The concept of laser intervention in the context of laboratories experiments, or global dental clinics involved with conducting root canal treatments, in the population of male and female patients with permanent teeth or extracted teeth requiring root canal treatment. On the other hand, all studies conducted on either animal teeth or children's deciduous teeth were excluded. The reduction of intracanal microbial load in addition to the absence of symptoms like pain, swelling, neurological damage are the outcomes from this review.

All the studies meeting the inclusion criteria were then searched for the presence of any duplications, which were then removed. The remaining articles underwent further screening and exclusions, this was conducted in a systematic matter. First, only the titles of all selected articles were investigated for eligibility, resulting in further exclusions to the total number of articles included in the scoping review. The abstract screening followed, and finally full text articles were viewed and only those articles where lasers were used for root canal disinfection

using adult human teeth were included. During study selection and the screening process, any disagreement arising between (NH and SK) on articles selection was rectified by discussion between the reviewers and resolved by consensus. Mendeley reference manager system, Desktop version 1.19.8. was used to aid in the study selection process.

iv) Charting the data

Forms were developed by the reviewers to determine which variables to extract from eligible articles (Appendix 5). The extracted data was charted to allow for logical and descriptive summary of the results that aligns with the objective of the scoping review. A charting table was drafted with the following headings- author, year, journal, study design, study setting, study population, intervention used and conclusion (Appendix 6).

v) Collating, Summarizing and reporting the results

No weight was placed on the quality of evidence generated. The results were collected in the form of visual representations for ease of their reporting. Similar findings were tabulated together-type of study, the study setting (in vitro, in vivo, review) the type of laser was used, the laser parameters tested. A PRISMA flow diagram was used for the reporting of the various stages involved in this scoping review to aid in the data analysis (Fig 22) (Moher *et al.*, 2009). This serves as a guide to determine what existing literature is available on the use of lasers in root canal disinfection.

vi) Consultation exercise (optional)

This is an additional step in the Arksey and O'Malley (2005) framework. However, it is one of the steps in both the Levac et al enhancements (2010) and JBI frameworks (2015). It is considered a useful step that helps inform findings related to the scoping review. In this scoping review, multiple systematic reviews were generated from the literature search, hence

instead of conducting another systematic review on the topic, it was decided to conduct an overview of systematic reviews instead.

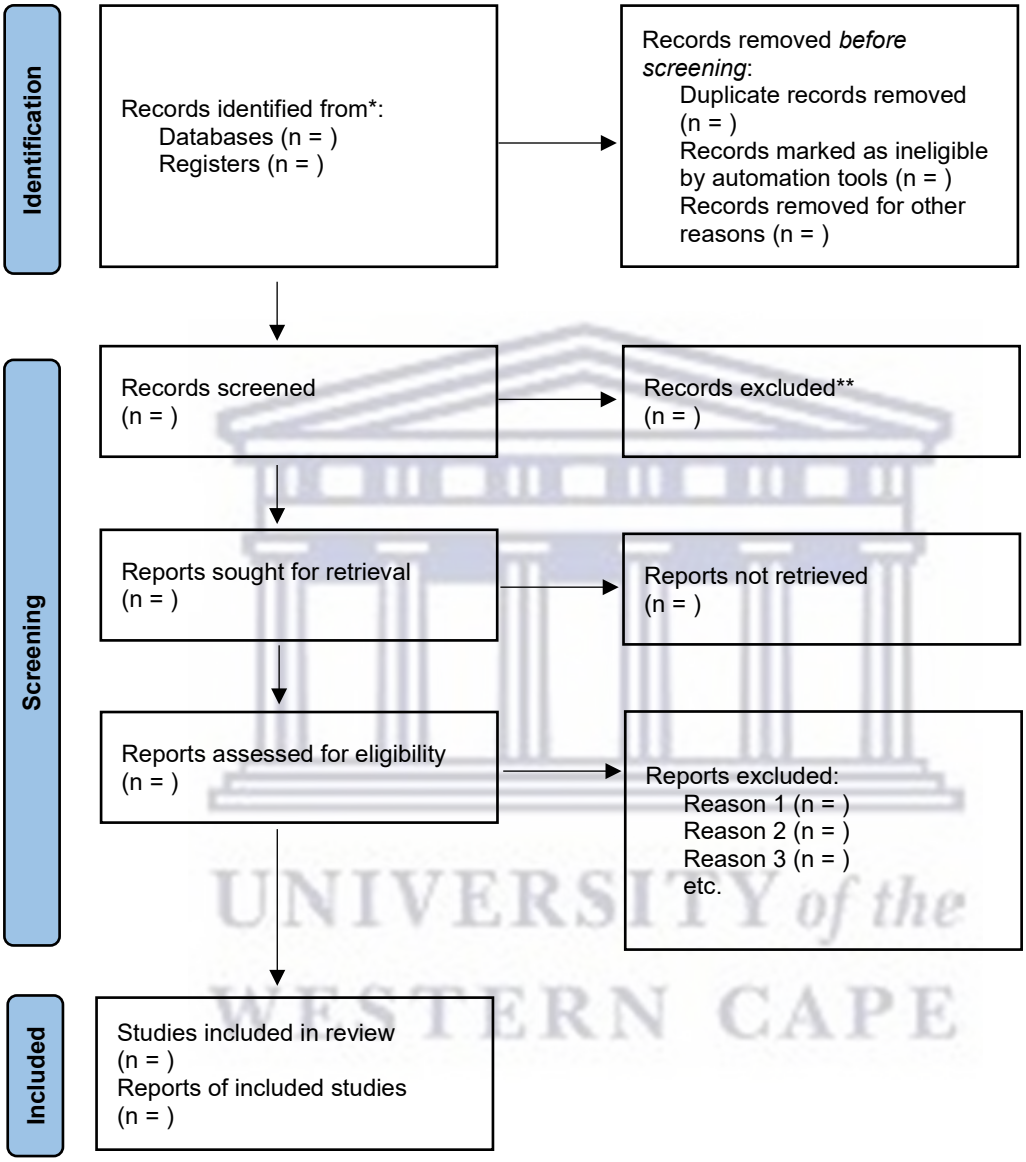


Figure 22: PRISMA flow diagram for scoping review (Page *et al.*, 2021)

4.2 Methodology for Overview of Systematic Review

Scoping of the existing literature was conducted in a similar way to the scoping review previously conducted, utilising the Arksey and O'Malley (2005) framework stages combined with Levac et al enhancements (2010) (Colquhoun et al., 2014). However, specific emphasis was placed on only systematic reviews conducted on the use of lasers as adjuncts to

conventional root canal treatment. This overview of systematic reviews was conducted to determine 'What laser protocols successfully achieve disinfection of root canals amongst adult endodontic patients?'. Following identification of the research question, the relevant articles were identified by searching the electronic databases- Google Scholar, PubMed, ScienceDirect, Wiley Online Library -in addition to international conference presentations and international endodontic journals. The search strategy formulated using Keywords and Boolean operators used was:

(Laser* OR laser treatment OR "photodynamic therapy") AND (root canal treatment OR endodontic treatment) AND (disinfection) AND (systematic review OR meta-analysis).

The search was limited to the English language and restricted to the last 10-years. Hand searching of the reference lists of included studies was performed to ensure comprehensiveness of the search conducted. The studies identified by the search strategy were screened by (NH AND SK) for eligible studies based on the inclusion and exclusion criteria generated by PICO framework. The inclusion criteria applied is lasers used to aid conventional root canal treatments in enhancing root canal disinfection in permanent dentition. The exclusion criteria are any animal studies or animal teeth, deciduous teeth, systematic reviews in disciplines other than endodontics and study designs other than systematic reviews and meta-analysis. The outcome for this review is the success of treatment determined by the absence of symptoms like postoperative pain, infection, discomfort, abscess and neurological damage.

Following selection of included articles, the duplicates were removed, then the titles were screened for eligibility, followed by the abstracts and finally full texts were screened. Full text articles of systematic reviews following the inclusion criteria were selected, while all others were excluded. At any point, where there was disagreement on study selection, discussion between reviewers was conducted and resolved by consensus. This is done to minimise selection bias, and to ensure that relevant studies are not excluded as recommended by Page et al in his recent study (Page et al.,2021).

The necessary data was extracted with the aid of a charting form (Appendix 5). The collected data was then charted using subheadings (author, year, title, journal, study design, aim, conclusion) to allow for summarising the results of the overview of systematic review in

accordance with the study objectives. Disagreement on included articles was resolved by discussion between the review authors (NH and SK) until a consensus was reached.

The collected results were then tabled under specific headings to allow for ease of interpretation. A PRISMA flow diagram (Fig 22) was used to summarize the scoping process. All included systematic review articles were then critically appraised using the AMSTAR-2 tool. This involved answering 16 questions with either 'yes', 'partial yes' or 'no' answers for all the included systematic reviews. Depending on the answers generated to these questions, which are classified into 7 critical and 9 non-critical domains, a weight is given to the review ranging from critically low (more than one critical flaw with or without non-critical weaknesses) to high (no or one non-critical weakness). These generate an overall confidence in the results of the review.

4.3 Ethical Consideration

Ethical approval was obtained from The University of Western Cape's Ethical committee for undertaking this study (Appendix 7). No patient related information has been collected during the scoping review or the overview of systematic reviews. Ethical approval for conducting review studies is therefore not necessarily required. However, registration of any undertaken research should be recorded, as this ensures transparency in the conduction of the research.

CHAPTER 5
RESULTS

The first section of this chapter on results will cover the outcomes regarding the scoping review conducted to 'determine the efficacy of laser use on success of endodontic treatment'. The second section of the chapter will report the results of the overview of systematic reviews where the focus was to critically appraise the evidence on the use of lasers to aid the success of endodontic treatment. Both reviews represent secondary, low risk research, nevertheless, ethical approval for conducting these reviews was obtained from the University's ethical committee prior to engaging in the study (Appendix 7).

5.1 Results for the scoping review

The Arksey and O'Malley framework combined with Levac et al enhancements was adapted for this scoping review. A search strategy using PICO framework or design was used (Grant and Booth,2009). The databases searched were Google Scholar, PubMed, Wiley Online Library, ScienceDirect, in addition to other sources (grey literature) such as conference presentations and endodontic journals. The search results in the identification of 3376 articles. The results will be demonstrated guided by the PRISMA flow diagram (Fig 23).

The PRISMA flow diagram represent a four -phase flow diagram which is a visual summary of the search process. It aided mapping the literature for the studies in this scoping review. These phases are described below in more details specific to this study:

i) Identification

This process involved identifying the number of articles generated from searching the databases like Google Scholar, PubMed, Wiley Online Library, ScienceDirect, conference presentations, endodontic journals, for the use of lasers in root canal disinfection. Keywords used for the searching process were laser, laser treatment, photodynamic therapy, root canal treatment, endodontic treatment, disinfection. Boolean operators along with the keywords created helped to identify articles relevant to the research question.

The search strategy utilised in the process of identification of the relevant studies was: (Laser* OR laser treatment OR "photodynamic therapy") AND (root canal treatment OR endodontic treatment) AND (disinfection). The search was limited to the English language,

which may have an impact on other articles in other languages being identified and included, thereby affecting the thoroughness of the search; and it was restricted to the time period from 2010-2020. A total of 3376 articles were included, these were exported to the Mendeley reference manager system, Desktop version 1.19.8. and any duplicates were removed thereafter, resulting in 3321 included studies.

ii) Screening

The articles, totalling 3321, were then screened based on the inclusion and exclusion criteria set by the two reviewers NH and SK, this was done to minimise selection bias. The titles and abstracts of relevant studies conducted on laser use in endodontic disinfection on adult human teeth were selected, while all others were excluded, leaving a total of 220 articles.

iii) Eligibility

The relevant full text articles identified were 220, these were similarly screened for eligibility based on the inclusion and exclusion criteria set by NH and SK.

iv) Included

A total of 95 eligible full text articles were finally identified. The included studies investigated the use of lasers in disinfection of the root canals in adult teeth using in vivo, in vitro and review studies.

v) Excluded

The number of excluded articles was 125, they were excluded because they were conducted on deciduous teeth, or animal teeth, or used lasers for management of endodontic pain rather than for endodontic disinfection and did not meet the aims or objectives of the study.

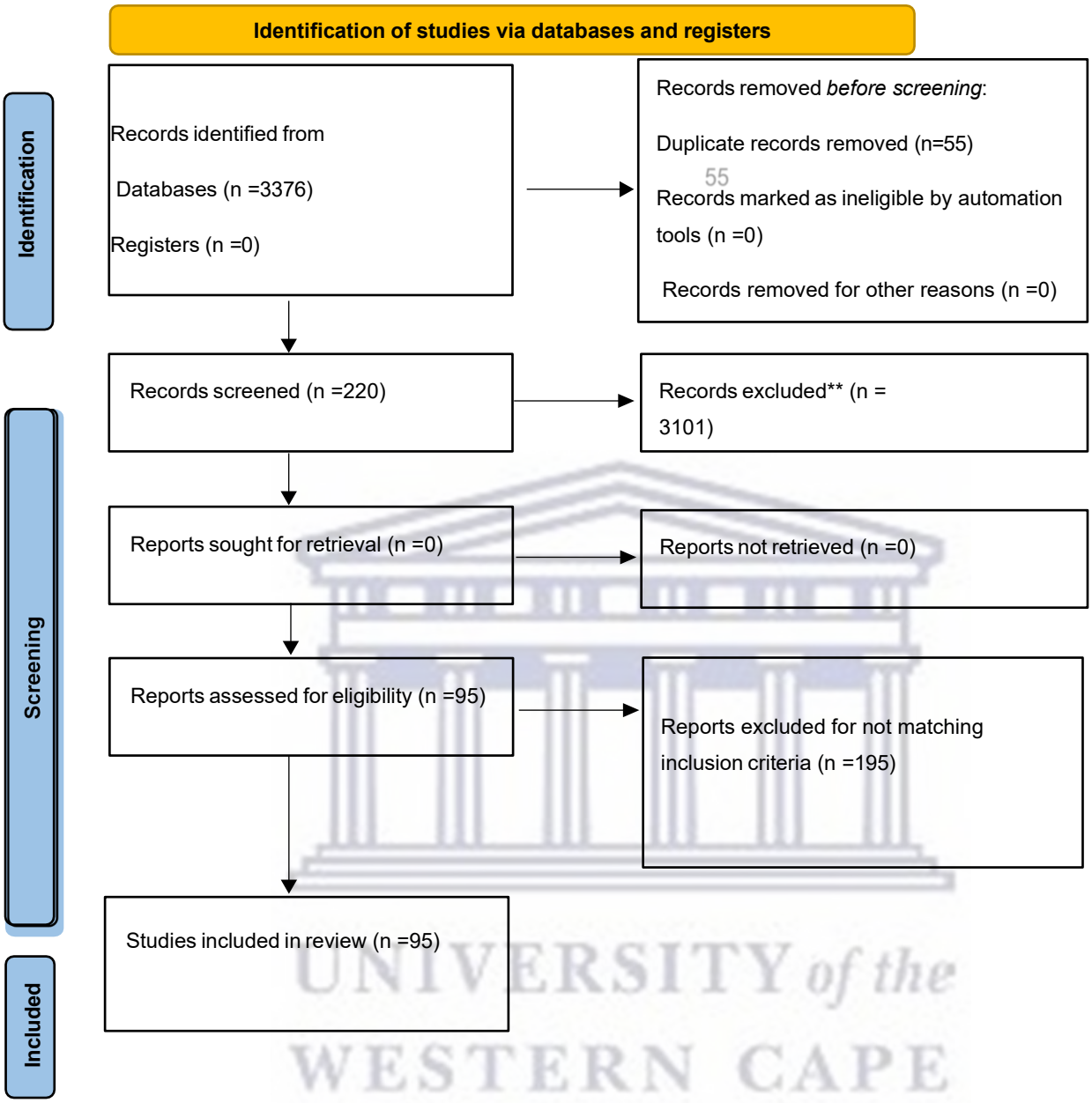


Figure 23: PRISMA 2020 flow diagram showing results of Scoping Review

5.1.1 Demographics of the included studies

The results of the scoping review will be presented in themes, where common factors were decided to be grouped together, these included the *study designs* of the 95 included studies, the *type of lasers* investigated in these studies and their *effect on reducing bacterial loads* and acting as adjuncts to conventional root canal treatment, the laser parameters tested.

i) Study designs

The study designs included in the scoping review were mainly in vitro studies conducted on extracted human teeth. These in vitro studies contributed to 47 studies of the 95 studies included in this scoping review, followed secondly by review articles which totalled to 17 out of the remaining articles. The reason maybe be due to laser use in endodontic treatment being a new modality that is not routinely conducted; hence the majority of studies are still experimental. From the remaining articles, 14 were in vivo studies conducted on patients at dental clinics while 17 remaining articles did not clearly specify the study design conducted.

ii) Type of laser investigated

The majority of studies found that lasers are adjuncts to conventional root canal treatment, where they aid in reduction of the bacterial load when used with conventional root canal treatment irrigants. Various study characteristics and designs were researched, and most studies investigated the in vitro effect of PDT on root canal disinfection (Table 5). The other

lasers being investigated and shown to have an adjunctive effect in root canal disinfection are diode lasers, ER: YAG lasers, Er, Cr: YSGG lasers and, Nd: YAG lasers (Table 5).

The use of lasers in endodontic treatment wasn't always found to have a beneficial or additive effect. This was the conclusion resulting from various studies on lasers utilising various types of study designs included in this review. Those studies involving in vitro designs tested diode lasers, PDT and Er, Cr: YSGG lasers against NaOCl and EDTA. Studies included those by Azaripour *et al*., 2010 who found that using 3% NaOCl was better than using laser; Cretella et al., 2017 and Batinić *et al*., 2018 who determined that PDT used with NaOCl and EDTA is similar to just using NaOCl on its own. Other studies on Er,Cr:YSGG lasers were found to have questionable antimicrobial effects according to Bolhari *et al*., 2014 and Christo *et al*., 2016; other in vitro studies that reached similar conclusions were those by Dewsnup *et al*., 2010; Dumani *et al*., 2019; Er Karaoğlu *et al*., 2020; Ghorbanzadeh *et a*l., 2018; Ozkan *et al*., 2014; Samiei *et al*., 2016; Sohrabi *et al*., 2016; Souza *et al*., 2010; Thammasitboon *et al*., 2010; Yildirim *et al*., 2013.In terms of in vivo studies, Granevik *et al*., 2017 determined that Nd:YAG laser was not effective with conventional 1% NaOCl solution. Mashalkar *et al*., 2014 concluded that lasers and conventional RCT yield the same results and Kalyoncuoğlu *et al*., 2013 determined that EDTA and NaOCl remains an effective technique. Lastly, the systematic reviews by Trindade *et al*., 2015; Siddiqui *et al*., 2013; Fransson *et al*., 2013 using PDT was ineffective, questionable or lacked sufficient evidence to support the use of lasers being an adjunctive treatment modality to enhance the success of conventional root canal treatments (Appendix 7).

Table 5: Showing the types of lasers used in root canal treatments and the study characteristics and designs investigated

Laser type used to aid conventional RCT	Conventional RCT irrigant used	Name of Author, year	Study characteristics and designs
PDT/PAD	NaOCl EDTA	Afkhami *et al*., 2020; Bumb *et al*., 2014; Cheng *et al*., 2012; de Oliveira *et al*., 2015; da Silva *et al*., 2018; Ghorbanzadeh *et al*., 2020; Poggio *et al*., 2011; Prażmo *et al*., 2017; Rios *et al*., 2011; Rödig *et al*., 2017; Sabino *et al*., 2015; Sard *et al*., 2019; Schiffner *et al*., 2014; Soares *et*	In vitro laboratory studies

		al., 2016; Susila *et al*., 2016; Tokuc *et al*., 2019 Wang *et al*., 2017	
		Asnaashari *et al*., 2016; Jurič *et al*., 2014; Lane *et al*., 2019; Pourhajibagher *et al*., 2017; Rabello *et al*., 2017; Sonarkar *et al*., 2018; Tennert *et al*., 2014	in vivo clinical trial;clinical study,RCT
		Ali *et al*., 2018; Arneiro *et al*., 2014; Bordea *et al*., 2020; Chiniforush *et al*., 2016; ; Chrepa *et al*., 2014; Lane *et al*., 2019; Pourhajibagher *et al*., 2019; Sin *et al*., 2020	Reviews
Diode laser	NaOCl EDTA	Arslan *et al*., 2013; Braun *et al*., 2016; Garcia Basualdo *et al*., 2018; Pérez *et al*., 2018; Sun *et al*., 2017;	In vitro laboratory studies
		Romeo *et al*., 2015; Zhou *et al*., 2016	In vivo clinical trial, RCT
			Review
Er: YAG laser	NaOCl EDTA	Akyuz *et al*., 2015; Cheng *et al*., 2012; Cheng *et al*., 2016; Cheng *et al*., 2017; Guidotti *et al*., 2014; Henninger *et al*., 2019; Zhou *et al*., 2016	In vitro laboratory studies
			In vivo
			review
Nd: YAG laser	NaOCl EDTA	Akyuz *et al*., 2015; Cheng *et al*., 2012; Rahimi *et al*., 2012;	In vitro laboratory studies
			In vivo
			review
Er, Cr: YSGG Laser	NaOCl EDTA	Cheng *et al*., 2012; Samaksamarn and Thalerngsaks, 2013; Suer *et al*., 2020; Licata *et al*.,2015	In vitro laboratory studies
			In vivo
			reviews
Laser	Er, Cr: YSGG Laser	NaOCl EDTA	In vitro laboratory studies
		Lagemann, *et al*., 2014	RCT
		Asnaashari *et al*., 2013; Jurič *et al*., 2014; Plotino *et al*., 2019;	review

iii) Laser Parameters used

The laser parameters used by the studies that included these details are heterogenous and difficult to group together to determine the best laser protocol to be used for aiding root canal disinfection in conventional root canal treatment. Different types of lasers were used for different time durations and with different power output settings (Table 6). This makes it difficult to determine the best type of laser to use and to standardise the method of using that particular laser during treatment.

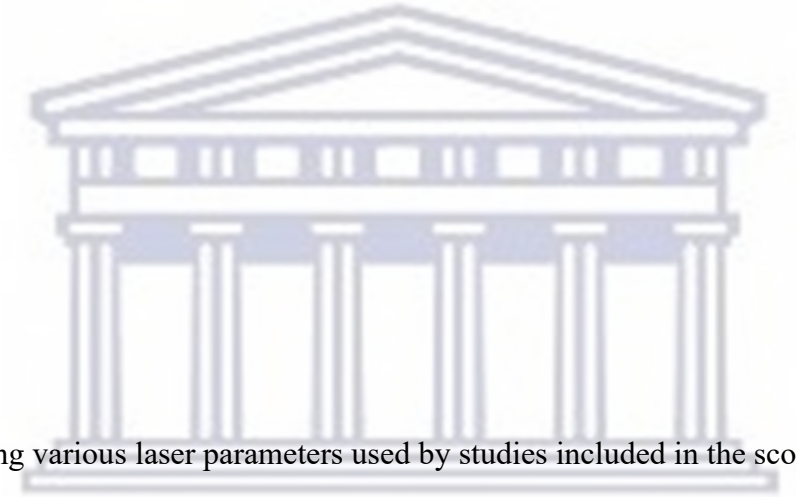


Table 6: Showing various laser parameters used by studies included in the scoping review

Name of Author, year	Laser Parameter used
Arslan et al., 2013	diode laser for. 10, 20, 30, and 40 seconds
Beltes et al., 2017	PDT laser 0.5 ,1 W
Bolhari et al., 2014	Er, Cr: YSGG laser 1.5 W,2.5 W
Braun et al., 2016	diode laser 1W
Cheng et al., 2016	Er: YAG laser 0.3, 0.5, 1.0 W; 20 or 30 s
Cheng et al., 2017	Er: YAG laser 0.3 W, 20 sec; Er: YAG laser 0.3 W ,40 and 60 sec; or 0.5 and 1.0 W for 20 sec.
da Silva et al., 2018	PDT 100 mW; 40 s 3 J; 30 s
Ghorbanzadeh et al., 2020	LAD 0.3 W, 120 J/cm (2) diode laser 2 W.
Guidotti et al., 2014	Er: YAG laser, 1 W, 5 s each,
Mehrvarzfar et al., 2011	diode laser; 2 W; 5 × 5 s.
Ozkan et al., 2014	1.5 W ,2 W laser

Rahimi et al., 2012	3-W laser; 10 sec.
Sabino et al.,2015	MB 100 mW,
Samaksamarn and Thalerngsaks, 2013	Er, Cr: YSGG laser; 1.5 W; 10 s
Samiei et al., 2016	PAD diode laser100 mW/cm (2)); 120 sec.
Schiffner et al., 2014	diode laser;200 mW ;30 s, 60 s and 90 s
Soares et al., 2016	PDT diode laser; 40mW; 150s.
Suer et al., 2020	2 W laser, 0.75 W
Yildirim et al., 2013	diode laser; 1, 2, and 4 min,
Zhou et al.,2016	Er: YAG laser; 0.5 W ,1.0 W 2.0 W

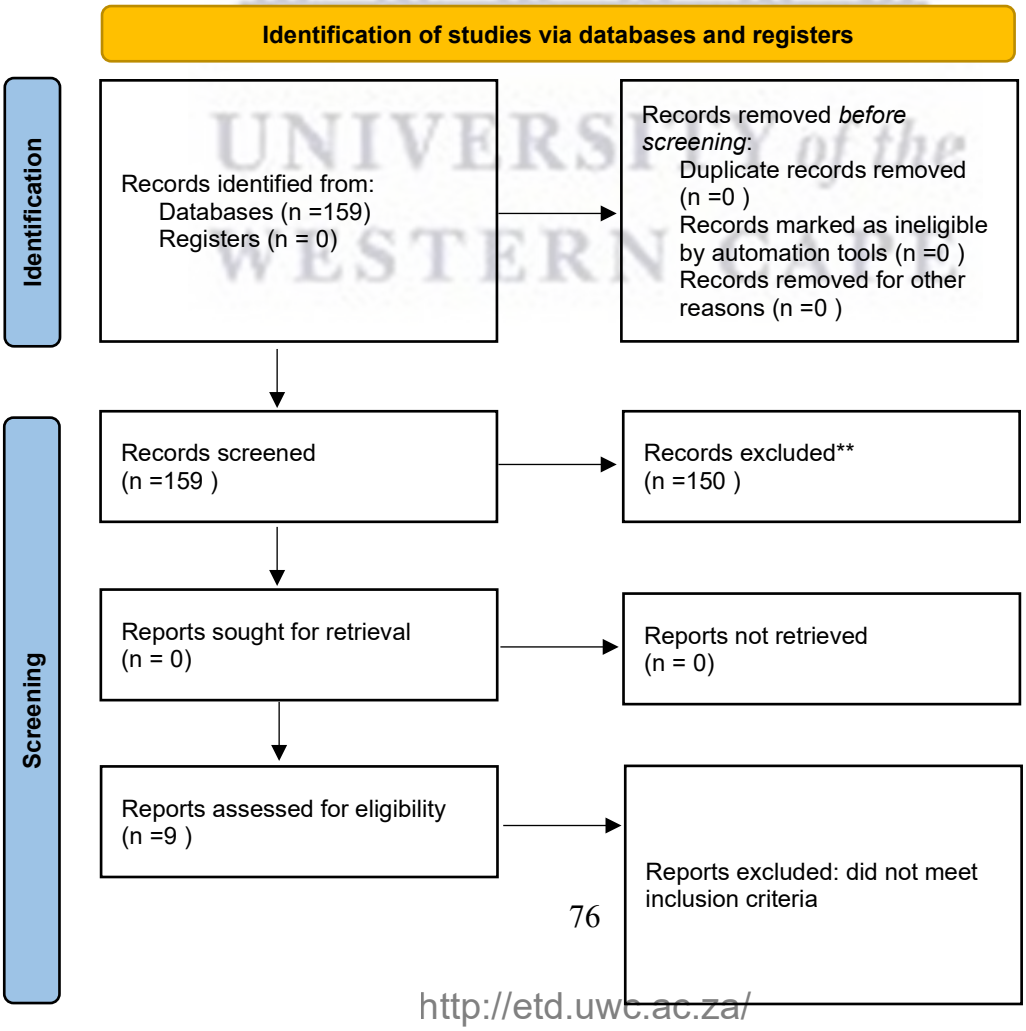
iv) Gaps in the literature

The 95 articles included in this scoping review were of different study characteristics and designs, however the majority of these studies where of weak quality and secondary research. Few clinical studies were conducted on the use of lasers as adjuncts to endodontic infection. Further high-quality clinical research needs to be conducted, to be able to make decisions to change current clinical practice regarding the incorporation of laser disinfection as a means to aid in root canal treatment success. Furthermore, standardised protocols for using lasers as adjunctive treatment modalities to aid in conventional disinfection of the root canal system need to be determined. Additionally, although the scoping review picked up several systematic review articles, the quality of those needs to be established prior to incorporating their evidence for decision making purposes and to investigate if further high-quality systematic reviews need to be conducted. hence, an overview of systematic reviews was conducted.

5.2 Overview of systematic review results

Similar to the scoping review conducted, the Arksey and O'Malley framework combined with Levac et al enhancements was used to scope the literature by searching through databases, reference lists of included studies and grey literature- Google Scholar, PubMed, Wiley Online Library, conference presentations, endodontic journals- for relevant systematic reviews matching the inclusion criteria using these keywords and Boolean operators (Laser* OR laser treatment OR "photodynamic therapy") AND (root canal treatment OR endodontic treatment) AND (disinfection) AND (systematic review OR meta-analysis) for the search strategy :

The research question for the OSR is 'What laser protocols successfully achieve disinfection of root canals amongst adult endodontic patients?' A total of 159 systematic review records were obtained and with no duplicate studies matched. All 159 records were then screened using the 3-step approach: 1st by title and then checking abstracts, and those not meeting the inclusion criteria were further excluded, leaving a total of 9 full text articles that were included in the OSR as shown in the PRISMA flow diagram (Fig 24)



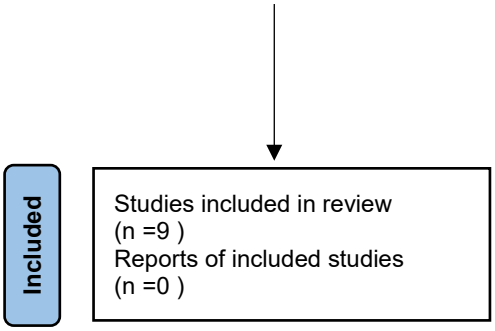


Figure 24: PRISMA flow diagram for Overview of systematic review results

Systematic reviews represent an important and valuable resource in both clinical practice and education. The quality of systematic review completed determines its ability to inform decision making and change clinical practice to improve patient care. This is especially true for high quality systematic reviews, which are conducted rigorously and are reproducible, in contrast to other research designs which do not provide valuable information or are of poor-quality designs. When searching for articles for the ScR, numerous study designs were identified, in addition to several SRs which were found related to this topic and appropriate for the OSR research question. Following the completion of the ScR, it was thus decided to evaluate these SRs further to determine if translation of outcomes could assist with changing clinical practice. The AMSTAR 2 tool to evaluate the quality of SRs, is used to critically appraising SRs of different designs on healthcare interventions, and in this case on laser use in endodontic treatment. The AMSTAR 2 tool involves answering 16 questions with 'yes', 'no', 'partially yes' answers (Table 8). To avoid disguising any critical weakness and therefore reduce confidence in the results of the review, the overall quality of the review is determined by a weighted system ranging from critically low to high. The weight is determined by the responses to the 7 critical and 9 non-critical domains of the AMSTAR 2 tool (*Shea, B.J. et al. 2017)*.

A total of 9 full text systematic review articles were included in this overview of systematic reviews. These are charted in (Table 7), where a total of 5 systematic reviews investigated the use of lasers in endodontic disinfection using photodynamic therapy. These articles found PDT to be an effective adjunct to conventional root canal therapy in the reduction of microbial load. One systematic review investigated the use of Er, Cr: YSGG, Nd:YAG, laser and also found that both lasers had an adjunctive effect in reduction of bacterial count and thus aiding in the success of root canal treatment. The remaining 3 reviews investigated lasers generally used in endodontic treatment-diode, Er:YAG, Nd:YAG, Er,Cr:YSGG and found no conclusive evidence to support the use of lasers adjunctively in endodontic treatment due to heterogeneity of included studies and low quality of evidence reviewed None of the included systematic reviews provided a clear protocol on how to successfully achieve adequate disinfection of root canals using lasers during endodontic treatments.

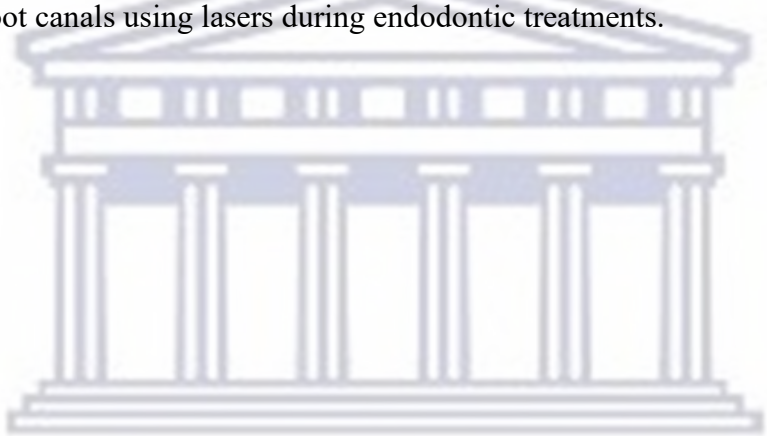


Table 7: Systematic review articles included in the overview of systematic reviews

Author, Year, Journal	Aim	Conclusion	Recommendations
Sin *et al.* (2020) ***Translational Biophotonics***	Investigate effectiveness of photosensitizers sused in laser endodontics disinfection	Photo-activated disinfection was found to be an effective adjunct to conventional root therapy	More studies are needed to assess the performance of newer photosensitizers to optimize photo-activated disinfection of the complex root canal space.
Chrepa *et al., 2014* ***The effect of photodynamic therapy in root canal disinfection: A systematic review', Journal of Endodontics,***	To investigate the effect of PDT on bacterial load reduction during root canal disinfection.	There was a positive effect of PDT in the reduction of microbial load in root canal treatment ranging from 91.3%-100%.	To optimize and standardize PDT dosimetry with the use of an appropriate photosensitizing agent that yields the most potent antimicrobial results while maintaining a high safety profile
Fransson et al., 2012 *Efficacy of lasers as an adjunct to chemo-mechanical disinfection of infected root canals: A systematic review', International Endodontic Journal*	To evaluate the efficacy of various types of lasers used as an adjunct to chemo-mechanical dis-infection of infected root canals	No conclusions can be drawn regarding the efficacy of laser as an adjunct to conventional chemo-mechanical treatment of infected root canals as included studies deemed to be of low quality of evidence	Need for high-quality studies because current knowledge of the efficacy of laser as an adjunct to chemo-mechanical disinfection of infected root canals is limited

Bordea *et al.*,2020 *Evaluation of the outcome of various laser therapy applications in root canal disinfection: A systematic review', Photodiagnosis and Photodynamic Therapy*	To answer the question "Which laser treatment protocol, among various laser applications is the most effective in root canal disinfection with optimal outcome	The effectiveness of PDT and various laser wavelengths protocols, in removing endodontic biofilms from infected root canals, remains unattainable	Due to the heterogeneity of the studies and their limitations, in terms of lack of standardised protocol or discrepancy in the methodology, authors suggest further validated approaches to achieve optimal outcomes.
Sadık *et al.*,2103 *Effects of laser treatment on endodontic pathogen enterococcus faecalis: A systematic review', Photomedicine and Laser Surgery*	To explore the antimicrobial effects of laser radiation on E. faecalis	Er, Cr:YSGG, Nd:YAG, laser significantly reduced E. faecalis count	None mentioned
Siddiqui et al., 2013 *Bactericidal efficacy of photodynamic therapy against enterococcus faecalis in infected root canals: A systematic literature review', Photodiagnosis and Photodynamic Therapy*	To review the bactericidal efficacy of PDT against Enterococcus faecalis in infected root canals	The efficacy of PDT in eliminating E. Faecalis from infected root canals remain questionable	Further well-designed studies are needed to examine the role of PDT as a bactericidal agent in infected root canals.
Vendramini *et al., 2020* *Antimicrobial effect of photodynamic therapy on intracanal biofilm: A systematic review of in vitro studies', Photodiagnosis and Photodynamic Therapy*	To analyse the antimicrobial effect of PDT on intracanal biofilm.	PDT reduced bacterial counts in most studies, especially when used as an adjunct to the conventional endodontic technique	Further controlled in vitro studies should determine the reference standard to be used in future in vivo studies
Pourhajibagher and Bahador, 2019 *Adjunctive antimicrobial photodynamic therapy to conventional chemo-mechanical debridement of infected root canal systems: A systematic review*	To investigate the efficacy of PDT adjunctive to conventional chemo-mechanical debridement of root canal system in patients with endodontic infections.	All studies found a reduction in microbial load with adjunctive use of PDT	Further high-quality RCTs focused on the standardized PDT parameters are needed

and meta-analysis', Photodiagnosis and Photodynamic Therapy,			
Anagnostaki et al., 2020 *Systematic review on the role of lasers in Endodontic therapy: Valuable adjunct treatment?' Dentistry Journal*	To evaluate which field is most strongly supported by clinical evidence, and if so, which shows more favourable results than application of the gold standard (endodontic) treatment alone.	The use of laser can be a useful adjunctive to conventional endodontic treatment.	For future directions, more studies with clear and standardized protocols should be performed in order to further confirm the evidence base of this approach.

Systematic reviews represent a high level of evidence and when done correctly and to a high degree, can inform clinical practice. The process of critical appraisal of the systematic review articles included in this study using the AMSTAR 2 tool can be seen in the table below (Table 8).

Table 8: Showing Systematic review articles with responses to AMSTAR 2 questions and quality of the studies

	Author and date								
AMSTAR 2 Questions	Sin *et al.,* 2020	Chrepa *et al,.* 2014	Fransson et al., 2012	Bordea et al., 2020	Sadık *et al..*, 2013	Siddiqui et al., 2013	Vendramini *et al..,* 2020	Pourhajibagher and bahador, 2019	Anagnostaki et al., 2020
Q 1: Did the research question and inclusion criteria for the review include the components of PICO?	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes
Q 2: Did the report of the review contain an explicit statement that review methods were established prior to the conduct of the	No	Yes	Yes	Yes	No	No	No	Yes	No

review and did the report justify any significant deviations from the protocol?									
Q 3: Did the review authors explain their selection of the study designs for inclusion in the review?	No	No	No	No	No	No	No	No	No
Q 4: Did the review authors use a comprehensive literature search strategy?	No	Yes	No	No	No	Yes	Yes	Yes	No
Q 5: Did the review authors perform study selection in duplicate?	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Q 6: Did the review authors perform data extraction in duplicate?	No	No	No	No	Yes	No	No	No	No

Q 7: Did the review authors provide a list of excluded studies and justify the exclusion?	No	Yes	Yes	Yes	Yes	No	No	No	No
Q 8: Did the review authors describe the included studies in adequate detail?	Yes	Yes	Yes	Yes	No	Yes	No	No	No
Q 9: Did the review authors use a satisfactory technique to assess risk of bias in individual studies that were included in the review?	No	No	No	No	No	No	No	Yes	Yes
Q10: Did the review authors report on the sources of funding for the studies included in the review?	No	No	No	No	Yes	Yes	No	No	Yes

Q11: If meta-analysis was performed, did the review authors use appropriate methods for statistical combination of results?	No	No	No	No	Yes	No	No	Yes	No
Q 12: If meta-analysis was performed, did the review authors assess the potential impact of risk of bias in individual studies on the results of the meta-analysis or other evidence synthesis?	No	No	No	No	No	No	No	Yes	No
Q 13: Did the review authors account for risk of bias in individual	No	No	No	No	No	No	No	No	Yes

studies when interpreting or discussing the results of the review?									
Q14: Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	No	Yes	Yes	Yes	Yes	Yes	No	Yes	NO
Q15: If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias and discuss its likely impact on the results of the review?	No	No	No	No	No	No	No	No	NO

Q 16: Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes
Quality of studies	Critically low	Critically low	Critically low	Critically low	Critically low	Critically low	Critically low	Critically low	Critically low

The results of the responses to the Amstar 2 tool questions for the included systematic reviews summarized in Table 14 are detailed further below:

Q 1: Did the research question and inclusion criteria for the review include the components of PICO?

Six out of nine articles had 'yes' response, indicating that a PICO framework was used either explicitly or by being discernable from the study, in order to generate the research question for the conduct of the review, allowing selection of the studies and the applicability of the results.

Q 2: Did the report of the review contain an explicit statement that review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?

Four out of nine articles had 'yes' indicating a protocol was followed to reduce the risk of bias in the review. Vendramini *et al*., 2020 study was registered on PROSPERO and followed PRISMA guidelines. A review that fails to provide a protocol is deemed to be of a lower quality.

Q 3: Did the review authors explain their selection of the study designs for inclusion in the review?

None of the included studies explicitly explained the reason why the types of studies involved in the study were being selected. Anagnostaki *et al*., 2020 only included RCT, however this may provide an incomplete summary of the treatment effects.

Q 4: Did the review authors use a comprehensive literature search strategy?

Four out of nine articles had 'yes' response indicating that at least two databases were searched. Ideally the more comprehensive and inclusive the search to involve more databases and grey literature and trial registries, the better selection of the studies and the less the risk of bias. Comprehensive search is considered a critical item for conducting high quality research.

Q 5: Did the review authors perform study selection in duplicate?

Seven out of nine articles had 'yes' response, this is performed to allow best practice in the conduction of the research, where the study design are checked against the research question, independently and together. Having at least to authors perform this process, allows for

credibility in the findings of the study and allows for objectivity in decision making, where any disagreements are resolved by consensus.

Q 6: Did the review authors perform data extraction in duplicate?

One of the nine articles had 'yes' response, Sadık *et al*., 2013, ideally the two authors should also perform data extraction similar to performing study selection.

Q 7: Did the review authors provide a list of excluded studies and justify the exclusion?

Four out of nine articles had 'yes' response. A list of the excluded articles along with the reasons for their exclusion is important for transparency and reduces bias, just stating that articles were excluded without providing a justified explanation biases the result findings. Performing this step is considered critical for attaining high quality research.

Q 8: Did the review authors describe the included studies in adequate detail?

Five out of nine articles had 'yes' response indicating the characteristics of the studies included were described, allowing information to make judgments related to the extent that the studies were conducted, relevancy to the study and the heterogeneity of the findings.

Q 9: Did the review authors use a satisfactory technique to assess risk of bias in individual studies that were included in the review?

Two out of the nine articles had 'yes' response. This is a critical item in systematic review appraisal to ensure that during the summary and interpretation of results, the risk of bias was accounted for, especially in non-randomized controlled trial studies. The results are more reliable when this ROB is performed. Anagnostaki et al., 2020 used the Cochrane ROB tool as the study included only RCT.

Q10: Did the review authors report on the sources of funding for the studies included in the review?

Three out of nine articles had 'yes' response. This is to prevent bias in the results, where those funded studies may lean towards the funded product more favorably in the description and results of the study. Declaring lack of funding indicates transparency in the undertaking of the study.

Q11: If meta-analysis was performed, did the review authors use appropriate methods for statistical combination of results?

Two out of nine articles had ‘yes’ response. The statistical analysis performed and accounting for heterogeneity especially in NRSI is important to reach correct results for use in influencing decision making. Pourhajibagher and Bahador, 2019 conducted the meta-analysis based on the Cochrane Collaboration recommendations for RCT. This item is also considered a critical item which needs to be fulfilled to ensure high quality research is being conducted.

Q 12: If meta-analysis was performed, did the review authors assess the potential impact of risk of bias in individual studies on the results of the meta-analysis or other evidence synthesis?

One out of nine articles had ‘yes’ response. Pourhajibagher and Bahador, 2019 all studies had low ROB

Q 13: Did the review authors account for risk of bias in individual studies when interpreting or discussing the results of the review?

One out of nine articles had ‘yes’ response. The impact of the ROB on a study is important in the interpretation of the results as it could account for differences between the results which may impact the research findings and thereby affect decision making for clinical practice. This is therefore considered a critical item in the AMSTAR 2 tool. The one study with the YES response was Anagnostaki *et al*., 2020 study which concluded that lasers can be suggested as useful adjunctive treatment modalities.

Q14: Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?

Six out of nine articles had ‘yes’ response. Heterogeneity was observed in the study designs and intervention methods.

Q15: If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias and discuss its likely impact on the results of the review?

None of the articles confirmed doing so. This is the last critical item that is needed to satisfy high quality research being conducted.

Q 16: Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?

Six out of nine articles had ‘yes’ response, however they all indicated no conflict of interest in the studies being conducted.

Based on the responses shown in table 14, rating the **overall confidence** in the result of the review can be performed:

A **high score** is given when no or one non-critical weakness is reported. This indicates that the systematic review provided a comprehensive, accurate summary of the results of the studies.

A **moderate score** denotes that more than one non-critical weakness was found in the review; however, no critical flaws are present. This means that although the review may provide an accurate summary of the results of the studies, this still diminishes confidence in the review.

Scoring low means that one critical flaw with or without non-critical weakness are present, that the review suffers from a critical flaw, and may be unable to provide comprehensive and accurate summaries.

Lastly, a **critically low score**, signifies that more than one critical flaw with or without non-critical weakness are associated with the articles included in the systematic review and as such these systematic review findings should not be relied upon to provide accurate and comprehensive summaries of the available studies. All the included systematic reviews in this overview of systematic reviews were found to have critically low scores.

The AMSTAR 2 tool is used to critically appraise a wide range of study designs in systematic reviews used for healthcare implications. The systematic reviews in table 14 were broadly assessed for their quality to determine if any flaws were present or if there was poor conduct of these reviews. This reduces bias and establishes reliability of results through rigorous methodology testing. This was determined by the responses generated to the critical domain (Q2, Q4, Q7, Q9, Q11, Q13, Q15) and non-critical domain questions. Obtaining a ‘YES’ answer to all critical domain items indicates that the study is of high quality and the results can be relied upon, which determines the validity and confidence of the study. However, none of the 9 systematic review studies answered ’YES’ to all the critical domain

questions. All the systematic reviews showed more than one critical flaw deeming them all to have a critically low level of confidence, thus the use of lasers in the disinfection of root canals during endodontic treatment is not associated with strong evidence and as such lasers cannot be recommended as being adjuncts to endodontic root canal treatments without further high-quality evidence being provided.

CHAPTER 6
DISCUSSION

6.1 Discussion

This study was conducted to determine if the use of lasers as an adjunct to endodontic treatment yielded better results than conventional treatment alone. Endodontics has evolved and as such the treatment modalities have improved. Lasers as an adjunct to conventional treatment methods have been explored, and even included by many researchers and clinicians, but how effective these really are, has not been stated emphatically. The importance of correct procedures and protocols have to be addressed as endodontics not only deals with studying the pulp and the peri-radicular region of the teeth, it also explores ways to prevent and to treat disease, thereby maintaining health, form, and function of these teeth ('Quality guidelines for endodontic treatment: Consensus report of the European Society of Endodontology' (2006). Microbial penetration plays a crucial role in the development and progression of pulp disease (Abbot, 2004). Untreated and persistent endodontic infection leads to apical periodontitis (Nair, 2006). Thus, the primary aim of root canal treatment is to remove inflamed and or infected pulpal tissues. This is accomplished by using the different evidence-based procedures available, that will guide you to eradicate the microbial infections and further preventing microorganisms from re-penetrating the root canal system by creating aseptic intra-radicular conditions (Wong *et al*., 2021).

This aseptic root canal system is achieved by chemical irrigation and mechanical preparation. Mechanical preparation is needed however before chemical disinfection can act on the bacteria occupying the root canal system (Wong *et al*., 2021). However, anatomical challenges due to the complexities within the root canals pose difficulties to mechanical preparation, which include lateral and accessory canals, apical delta and isthmi (Wong *et al*., 2021). Resistant microbial species like Enterococcus which is a Gram-positive facultative anaerobe poses a chemical challenge to be removed from inside the root canal system (Good and Hussey, 2012).

The most common chemical irrigant used in disinfection of the root canal system remains NaOCl, which is the gold standard root canal irrigant, with concentrations of NaOCl ranging between 0.5% and 6 % (Basrani *et al*., 2017). The antimicrobial and tissue dissolution actions are concentration specific, therefore, these increase with higher concentrations of microbes

(Basrani *et al*., 2017). Despite its benefits in performing as an ideal root canal disinfectant, sodium hypochlorite use as an irrigant in endodontic treatments is associated with many risks and complications (Spencer and Brennan, 2007). The use of 15%-17% EDTA alongside NaOCl has the added advantage of opening the sclerosed canals and removing the smear layer (Good and Hussey, 2012). The smear layer, formed as a byproduct of mechanical preparation of the root canal system, consists of a mixture of bacteria, dentine debris, pulp remnants and endotoxins (Bago and Anić, I, 2014). Hence, removal of all organic and inorganic contaminants is necessary in ensuring success of root canal treatment.

The incorporation of laser treatment to conventional root canal treatment, aims to further aid in the reduction of bacterial load by reaching inaccessible areas of the root canal system (Borse *et al*., 2017). The lasers been reported for use in endodontic disinfection include PDT in the presence of MB or TB (Siddiqui *et al*., 2013), and diode which have good bactericidal effects in dentine, Er: YAG laser and Er, Cr: YSGG that have high absorption rates in water (George and Walsh, 2017). Nd: YAG lasers were found to be adjunctive endodontic therapies by Akyuz *et al*., 2015; Cheng *et al*., 2012; Rahimi *et al*., 2012 in their in vitro studies, while Granevik *et al*., 2017 found it to be ineffective when used with low concentrations of NaOCl at 1% in his in vivo study. Zhou *et al*., 2016, Henninger *et al*., 2019, Guidotti *et al*., 2014; Cheng et al., 2016; Cheng *et al*., 2017 all conducted in vitro studies and found that the use of Er: YAG laser had additive effect to root canal treatments.

Nevertheless, preclinical research compromising in vitro studies represents the lowest level of scientific evidence available, giving an idea regarding the potential impact of the area under investigation. While studies conducted on human subjects are regarded as a higher level of evidence. Hence, randomized controlled clinical trials, especially when done with double blinding are the best methodological clinical trials. Superior to those, are high quality systematic reviews and meta-analyses, providing the best knowledge, allowing clinicians to make decisions affecting clinical practice (Varoni *et al*., 2014).

The scoping review identified 95 various types of studies conducting on determining whether using lasers as adjuncts to root canal treatment aided in reducing bacterial load or enhanced the success of the treatment. Fifty three of the ninety-five of these studies were in vitro

studies while only fourteen of them were conducted on dental patients. The majority of studies conducted on the use of lasers in endodontics have been conducted in simulated laboratory settings (Pourhajibagher and Bahador, 2019).

In this review study conducted, evidence indicates that both NaOCl and EDTA have been used as the irrigants of choice alongside laser treatment to aid in the successful disinfection of the root canal system. In vitro studies conducted by Akyuz *et al*., 2015 used 2.5% NaOCl and 17% EDTA to evaluate the efficiency of different irrigation activation techniques by diode laser, Nd:YAG laser, Er:YAG laser, and Er:YAG on smear layer removal. Their study concluded that all but diode lasers, have an adjunctive effect on removing the smear layer and aiding root anal disinfection.

Soares *et al*., 2016, used 5.25% NaOCl and 17% EDTA alongside a diode laser with methylene blue photosensitiser to eradicate enterococci, namely enterococcus faecalis, from inside the root canal system. Their results found adjunctive effects of photodynamic therapy performed with the aid of diode laser and methylene blue in root canal disinfection. The most commonly used photosensitizer dyes are methylene blue, and toludine blue; methylene blue is effective against gram positive microorganisms like enterococcus faecalis and toludine blue is effective against gram negative microorganisms (Sin *et al*., 2020). Wang *et al*.,2017 also used a combination of 5.25% NaOCl and 17% EDTA, instead of using PDT therapy, the study used Er:YAG and Er,Cr:YSGG lasers for activation of the irrigants and found an adjunctive effect as well using this combination. Batinić *et al*., 2018, on the other hand found no difference between irrigation using 2.5% NaOCl with EDTA and adjunctive photodynamic therapy. However, all these studies were conducted in a simulated laboratory setting, which is where the majority of studies were performed.

The study by Rabello *et al*.,2017, on the other hand, was a randomised control trial conducted on patients attending a dental clinic for root canal treatment. The irrigation protocol used was 2.5% NaOCl with 17% EDTA aided by photodynamic therapy using methylene blue as the photosensitiser. The study concluded that lasers are an adjunctive means to conventional root canal treatment. Similarly, Jurič *et al*.,2014 aimed to evaluate the efficacy of photodynamic therapy used as an adjunct to the endodontic retreatment, using 2.5% NaOCl, and 17% EDTA activated by a diode laser on anterior teeth in a dental setting. The results indicated that the

PDT used as an adjunct to the conventional endodontic therapy achieved a significant further reduction of intracanal microbial load.

On the contrary, Kalyoncuoğlu *et al*.,2013, attempted to evaluate the efficacy of smear layer removal from teeth during root canal treatment in the dental clinic, following using Er:YAG and Nd:YAG lasers adjunctively with 5.25% NaOCl and 17% EDTA. He concluded that the combination of EDTA and NaOCl still remains an effective technique. This may be due to the high concentration of NaOCl irrigant used for disinfection of root canals in this study.

The use of NaOCl as a sole irrigant, in various concentrations, was mostly researched alongside lasers in enhancing root canal disinfection. The concentrations of NaOCl used ranged from 0.5% to 5.25%. The in vitro study by Betancourt *et al*., 2019 to evaluate the antibacterial effectiveness of NaOCl at low concentrations (0.5%) activated by the Er,Cr:YSGG laser, tested NaOCl concentration ranging from 0.5% to 5%, the study showed that Er,Cr:YSGG laser proved to be able to improve the intracanal distribution of 0.5% NaOCl, reaching the same level of effectiveness than 2.5% NaOCl. Sohrabi *et al*., 2016 on the other hand, in attempting to evaluate the disinfection ability of 980-nm diode laser in comparison with NaOCl, being a common root canal irrigant, found that the 5.25% NaOCl seems to reduce E. faecalis more effectively than the diode laser. Sonarkar *et al*.,2018 in his study involving 35 patients receiving endodontic treatment, investigated the effect of using 5% NaOCl with photoactived diode laser adjunctively and found lasers to be an effective adjunct to conventional endodontic treatment.

PDT used with a diode laser and a photosensitiser was the most common type of laser adjunctive technique involved in all the different types of studies being investigated. In vitro studies by Afkhami *et al*., 2020; Bumb *et al*., 2014; da Silva *et al*., 2018; de Oliveira *et al*., 2015; Poggio *et al*., 2011; Prażmo *et al*., 2017; Rios *et al.*, 2011; Rödig *et al.*, 2017; Sard *et al*., 2019; Schiffner *et al*., 2014; Soares *et al*., 2016; Susila *et al*., 2016; where all these studies found that PDT had adjunctive benefits to conventional root canal disinfection. Similarly, the same results were found in in vivo studies mainly researching PDT adjunctive effects, studies by Asnaashari *et al*., 2016; Jurič *et al*., 2014; Lane *et al*., 2019; Pourhajibagher *et al*., 2017; Rabello *et al*., 2017; Sonarkar *et al*., 2018; Tennert *et al*., 2014.

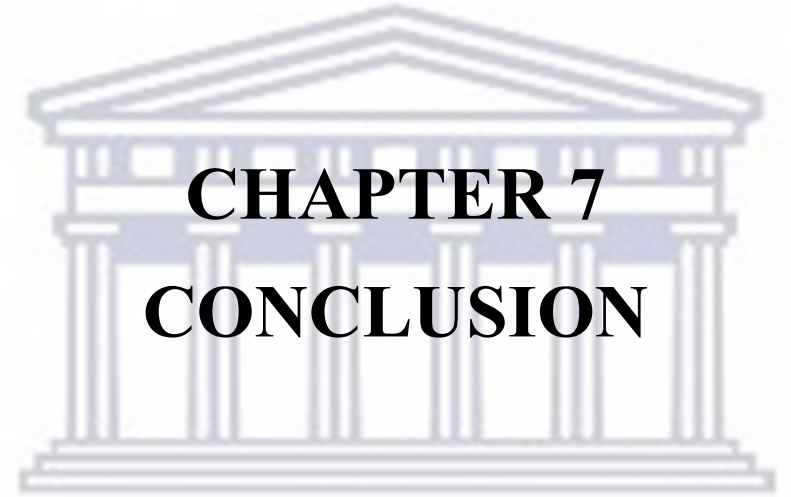
The systematic reviews on the use of lasers as an adjunctive aid to conventional root canal debridement, mainly investigated PDT as well. The findings of the studies revealed that PDT can be an effective adjunct to conventional root canal therapy, leading to reduction of microbial load in root canal treatment (Sin *et al*.,2020; Chrepa *et al*., 2014; Vendramini *et al*., 2020; Pourhajibagher and Bahador, 2019; Anagnostaki *et al*., 2020). PDT is regarded as a safe adjunct to conventional root canal treatment in terms of reducing secondary tissue damage due to an increase in intracanal temperature during laser use, whereas PDT produce a change in temperature of only about 0.5 °C (Sin *et al*.,2020).

Another advantage of the use of laser as an adjunct to sodium hypochlorite irrigation is the reduction in the percentage of NaOCl irrigant solution used, Betancourt *et al*., 2019 showed that the use of Er,Cr:YSGG activation of NaOCl showed similar bactericidal effects as 2.5% NaOCl. This allows for lower concentrations of NaOCl to be used thus reducing the chances of potential side effects and risks associated with using the irrigant while at the same time achieving adequate results (Spencer and Brennan, 2007). Christo *et al*., 2011 also showed that 0.5% and 1% NaOCl irrigant solutions when laser activated are as effective as 4% NaOCl. Suer *et al*., 2020, mentioned that when the toxic effects of high percentage of NaOCl was considered, the combination of low-powered laser and low concentration of NaOCl can be used as an effective disinfection method in root canal treatment. This, the effectiveness of the different methods were adequately researched, though more rigorous clinical studies, such as RCTs, can be conducted that will guide clinical practitioners to the use of specific lasers.

But it is important to highlight that all the studies included in both the scoping review and systematic review did not have a clearly defined protocol for using any type of laser as an adjunct during root canal disinfection. This was echoed in the systematic review by Bordea et al., 2020 who determined that the effectiveness of PDT and various laser wavelengths protocols, in removing endodontic biofilms from infected root canals, remains unattainable. All the studies included in the overview of systematic review were found to have critically low evidence after being appraised by the AMSTAR 2 tool. The evidence pertaining to the use of lasers as adjuncts to conventional root canal treatment from these reviews should not be relied upon to reflect the accuracy of the results shown, even though there seems to be potential benefit from using lasers as adjunctive modalities to aid in root canal disinfection

and improve the success rates of root canal treatment. Having knowledge of what appraisal tools include, conducting proper RCTs with these in mind, is a sure way of ensuring study outcomes will be more reliable and valid and can be translated into clinical practice.

CHAPTER 7
CONCLUSION



7.1 Conclusion

Since the introduction of lasers and their use in dentistry decades ago, the majority of the research being conducted on the use of lasers as adjuncts in root canal treatment has been carried out using in vitro studies. Regardless of the study design involved, no success rates or clear protocol defining the exact parameters for the use of lasers in root canal disinfection has been proposed in terms of the best laser type, laser wavelength, treatment time and power settings. In addition, there is lack of high-quality evidence to support the use of lasers as adjunctive methods to conventional endodontic treatment, to change clinical practice in the field of endodontics.

CHAPTER 8

LIMITATIONS RECOMMENDATIONS

8.1 Limitations and Recommendations

There is a need for standardisation in the way the studies are being conducted in the use of lasers in root canal disinfection. There is also a need for high quality research studies that determine whether the use of lasers can be considered an adjunctive modality to conventional endodontic treatment and whether this will increase the success rates of endodontic treatments. If so, there needs to be a clear protocol in place for the best laser type and the laser parameters that will enhance the success of root canal treatments

The limitations of this thesis, should also be noted, these aree:

-Limiting the search to English language articles

-Limiting the search to 10 years

-Not searching relevant databases or trial registries

. The following are recommended:

1. Conducting more rigorous clinical studies to determine the effectiveness of already acceptable lasers -diode lasers or Er,Cr:YSGG lasers or Nd:YAG laser or Er:YAG lasers.
2. Developing a clinical protocol for laser use in terms of type, laser wavelength, treatment time and power

REFERENCES

Abbott, P.V. (2004) 'Classification, diagnosis and clinical manifestations of apical periodontitis', *Endodontic Topics*, 8(1), pp. 36–54. doi:10.1111/j.1601-1546.2004.00098.x.

Alapati, S., Brantley, W., Svec, T., Powers, J., Nusstein, J. and Daehn, G., 2004. Proposed Role of Embedded Dentin Chips for the Clinical Failure of Nickel-Titanium Rotary Instruments. Journal of Endodontics, 30(5), pp.339-341.

Anagnostaki, E., Mylona, V., Parker, S., Lynch, E. and Grootveld, M., 2020. Systematic Review on the Role of Lasers in Endodontic Therapy: Valuable Adjunct Treatment?.Dentistry Journal, 8(3), p.63.

Arksey, H. and O'Malley, L., 2005. Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*, 8(1), pp.19-32.

Aromataris E, Munn Z (Editors). JBI Manual for Evidence Synthesis. JBI, 2020.

Atmeh, A. and Watson, T., 2016. Root dentine and endodontic instrumentation: cutting edge microscopic imaging. Interface Focus, 6(3), p.20150113.

Bago Jurić, I. and Anić, I. (2014). The Use of Lasers in Disinfection and Cleaning of Root Canals: a Review. Acta Stomatologica Croatica, 48(1), pp.6-15.

Basrani, B., Manek, S., Sodhi, R., Fillery, E. and Manzur, A., 2007. Interaction between Sodium Hypochlorite and Chlorhexidine Gluconate. Journal of Endodontics, 33(8), pp.966-969.

Baugh, D. and Wallace, J., 2005. The Role of Apical Instrumentation in Root Canal Treatment: A Review of the Literature. Journal of Endodontics, 31(5), pp.333-340.

Bhatia, S. and Kohli, S., 2013. Lasers in Root Canal Sterilization - A Review. International Journal of Scientific Study, 1(3).

Bhatia, S. and Kohli, S., 2013. Lasers in Root Canal Sterilization - A Review. International Journal of Scientific Study, 1(3).

Borse, S., Sanap, A., Mehta, V., Borse, N., Bhosale, S. and Oswal, P., 2017. Effect of different irrigation devices on removal of smear layer - a systematic review. International Journal of Contemporary Medical Research, 4(6), pp.1371-1377.

Boutsioukis, C. *et al.* (2010) 'Evaluation of irrigant flow in the root canal using different needle types by an unsteady computational fluid dynamics model', *Journal of Endodontics*, 36(5), pp. 875–879. doi:10.1016/j.joen.2009.12.026.

Carroll, L. and Humphreys, T.R. (2006) 'Laser-tissue interactions', Clinics in Dermatology, 24(1), pp. 2–7. doi:10.1016/j.clindermatol.2005.10.019.

Carrotte, P., 2004. Endodontics: Part 1 The modern concept of root canal treatment. British Dental Journal, 197(4), pp.181-183.

Carrotte, P. (2004) 'Endodontics: Part 4 morphology of the root canal system', *British Dental Journal*, 197(7), pp. 379–383. doi:10.1038/sj.bdj.4811711.

Carrotte, P., 2004. Endodontics: Part 5 Basic instruments and materials for root canal treatment. British Dental Journal, 197(8), pp.455-464.

Cheung, A.W., Lee, A.H. and Cheung, G.S. (2021) 'Clinical efficacy of activated irrigation in Endodontics: A focused review', Restorative Dentistry & Endodontics, 46(1). doi:10.5395/rde.2021.46.e10.

Coluzzi, D.J. and Parker, S. (2017) *Lasers in dentistry-current concepts*. Cham: Springer International Publishing.

Chrepa, V., Kotsakis, G., Pagonis, T. and Hargreaves, K., 2014. The Effect of Photodynamic Therapy in Root Canal Disinfection: A Systematic Review. Journal of Endodontics, 40(7), pp.891-898.

Chu, C., Wong, A. and Zhang, C., 2014. A systematic review of nonsurgical single-visit versus multiple-visit endodontic treatment. Clinical, Cosmetic and Investigational Dentistry, p.45.

Colquhoun, H.L. et al. (2014) 'Scoping reviews: Time for clarity in definition, methods, and reporting', Journal of Clinical Epidemiology, 67(12), pp. 1291–1294. doi:10.1016/j.jclinepi.2014.03.013.

Desiate, A. *et al.* (2009) '980 nm diode lasers in oral and facial practice: Current state of the science and art', *International Journal of Medical Sciences*, pp. 358–364. doi:10.7150/ijms.6.358.

Ganeshkumar, P. and Gopalakrishnan, S. (2013) "Systematic reviews and meta-analysis: Understanding the best evidence in Primary Healthcare," Journal of Family Medicine and Primary Care, 2(1), p. 9. Available at: https://doi.org/10.4103/2249-4863.109934.

Gates, A., Gates, M., Duarte, G., Cary, M., Becker, M., Prediger, B., Vandermeer, B., Fernandes, R., Pieper, D. and Hartling, L., 2018. Evaluation of the reliability, usability, and applicability of AMSTAR, AMSTAR 2, and ROBIS: protocol for a descriptive analytic study. *Systematic Reviews*, 7(1).

George, R. and Walsh, L.J. (2017) 'Laser-assisted endodontics', *Lasers in Dentistry—Current Concepts*, pp. 191–210. doi:10.1007/978-3-319-51944-9_9.

Grant, M.J. and Booth, A. (2009) 'A typology of reviews: An analysis of 14 review types and associated methodologies', *Health Information & Libraries Journal*, 26(2), pp. 91–108. doi:10.1111/j.1471-1842.2009.00848.x.

Good, M., Karim, I. and Hussey, D., 2012. Endodontic 'solutions' part 1: a literature review on the use of endodontic lubricants, irrigants and medicaments. Dental Update, 39(4), pp.239-246.

Gopikrishna, V. *et al.* (2016) 'An in vivo assessment of the influence of needle gauges on endodontic irrigation flow rate', *Journal of Conservative Dentistry*, 19(2), p. 189. doi:10.4103/0972-0707.178708.

Hunt, H., Pollock, A., Campbell, P., Estcourt, L. and Brunton, G., 2018. An introduction to overviews of reviews: planning a relevant research question and objective for an overview. *Systematic Reviews*, 7(1).

Hong, Q.N., Gonzalez-Reyes, A. and Pluye, P. (2018) 'Improving the usefulness of a tool for appraising the quality of qualitative, quantitative and mixed methods studies, the mixed methods appraisal tool (mmat)', Journal of Evaluation in Clinical Practice, 24(3), pp. 459–467. doi:10.1111/jep.12884.

Ingle, J., 1961. A standardized endodontic technique utilizing newly designed instruments and filling materials. Oral Surgery, Oral Medicine, Oral Pathology, 14(1), pp.83-91.

Jaramillo, D.E. et al. (2016) 'Root canal disinfection comparing conventional irrigation vs photon-induced photoacoustic streaming (PIPS) using a buffered 0.5% sodium hypochlorite solution', Evidence-Based Endodontics, 1(1). doi:10.1186/s41121-016-0006-6.

Kakehashi, S., Stanley, H. and Fitzgerald, R., 1965. The effects of surgical exposures of dental pulps in germ-free and conventional laboratory rats. Oral Surgery, Oral Medicine, Oral Pathology, 20(3), pp.340-349.

Kapasi, A. and Kapasi, F., 2019. When Less is More - An Update on Low Level Laser Therapy Applications in Endodontics for Predictable Outcomes - A Review Article. ACTA SCIENTIFIC DENTAL SCIENCES, 3(2), pp.83-93.

Kimura, Y., Wilder-Smith, P. and Matsumoto, K. (2000). Lasers in endodontics: A review. International Endodontic Journal, 3(33), pp.173-85.

Lee, M., Bird, P. and Walsh, L. (2004). Photo-Activated Disinfection Of The Root Canal: A New Role For Lasers In Endodontics. Australian Endodontic Journal, 30(3), pp.93-98.

León-López, M. *et al.* (2022) 'Prevalence of root canal treatment worldwide: A systematic review and meta-analysis', *International Endodontic Journal*, 55(11), pp. 1105–1127. doi:10.1111/iej.13822.

Levac, D., Colquhoun, H. and O'Brien, K., 2010. Scoping studies: advancing the methodology. *Implementation Science*, 5(1).

Liberati, A. et al. (2009) 'The prisma statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration', PLoS Medicine, 6(7). doi:10.1371/journal.pmed.1000100.

Lim, Z., Cheng, J., Lim, T., Teo, E., Wong, J., George, S. and Kishen, A. (2009). Light activated disinfection: an alternative endodontic disinfection strategy. Australian Dental Journal, 54(2), pp.108-114.

Marković, D., Rakašević, D. and Trišić, D. (2015). Application of High-Power Diode Laser and Photodynamic Therapy in Endodontic Treatment - Review of the Literature. Balkan Journal of Dental Medicine, 19(2), pp.71-74.

Marshall FJ, Papin J. A crown-down pressure-less preparation root canal enlargement technique. Technique manual. Portland 1980. Oregon Health Sciences University.

Martins, M., Franzen, R., Depraet, F. and Gutknecht, N., 2018. Rationale for using a double-wavelength (940 nm + 2780 nm) laser in endodontics: literature overview and proof-of-concept. Lasers in Dental Science, 2(1), pp.29-41.

Mittal, S., Kukreja, N., Chaudhary, D., Bansal, A., Bansal, J. and Agarwal, D., 2014. Sword of Endodontist: A Review. Dental Journal of Advance Studies, 02(03), pp.118-124.

Moher, D. et al. (2009) "Preferred reporting items for systematic reviews and meta-analyses: The Prisma statement," BMJ, 339(jul21 1). Available at: https://doi.org/10.1136/bmj.b2535.

Munn, Z., Peters, M., Stern, C., Tufanaru, C., McArthur, A. and Aromataris, E., 2018. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology*, 18(1).

Munn, Z., Stern, C., Aromataris, E., Lockwood, C. and Jordan, Z., 2018. What kind of systematic review should I conduct? A proposed typology and guidance for systematic reviewers in the medical and health sciences. *BMC Medical Research Methodology*, 18(1).

Nair, P.N. (2006) 'On the causes of persistent apical periodontitis: A review', *International Endodontic Journal*, 39(4), pp. 249–281. doi:10.1111/j.1365-2591.2006.01099.x.

Ørstavik, D. (2019) Essential Endodontology: prevention and treatment of apical periodontitis, 3rd edition. Oxford, UK: Blackwell Science, pp. 1–10

Page, M.J. et al. (2021) 'The Prisma 2020 statement: An updated guideline for reporting systematic reviews', Systematic Reviews, 10(1). doi:10.1186/s13643-021-01626-4.

Paiva, M.A. et al. (2018) 'Dental anatomical features and caries: A relationship to be investigated', Dental Anatomy [Preprint]. doi:10.5772/intechopen.71337.

Parker, S. (2007) 'Laser-tissue interaction', British Dental Journal, 202(2), pp. 73–81. doi:10.1038/bdj.2007.24.

Pawar, S., Pujar, M., Makandar, S. and Imran Khaiser, M. (2014). Post endodontic treatment pain management with low-level laser therapy. Journal of Dental Lasers, 8(2)

Pham, M., Rajić, A., Greig, J., Sargeant, J., Papadopoulos, A. and McEwen, S., 2014. A scoping review of scoping reviews: advancing the approach and enhancing the consistency. *Research Synthesis Methods*, 5(4), pp.371-385.

Peters, M., Godfrey, C., Khalil, H., McInerney, P., Parker, D. and Soares, C., 2015. Guidance for conducting systematic scoping reviews. *International Journal of Evidence-Based Healthcare*, 13(3), pp.141-146.

Pourhajibagher, M. and bahador, A., 2019. Adjunctive antimicrobial photodynamic therapy to conventional chemo-mechanical debridement of infected root canal systems: A systematic review and meta-analysis. Photodiagnosis and Photodynamic Therapy, 26, pp.19-26.

Sadık, B., Arıkan, S., Beldüz, N., Yaşa, Y., Karasoy, D. and Çehreli, M., 2013. Effects of Laser Treatment on Endodontic Pathogen Enterococcus faecalis: A Systematic Review. Photomedicine and Laser Surgery, 31(5), pp.192-200.

Saydjari, Y., Kuypers, T. and Gutknecht, N., 2016. Laser Application in Dentistry: Irradiation Effects of Nd:YAG 1064 nm and Diode 810 nm and 980 nm in Infected Root Canals—A Literature Overview. BioMed Research International, 2016, pp.1-10.

Susila, A. (2019) 'Activated irrigation vs. conventional non-activated irrigation in Endodontics – a systematic review', *European Endodontic Journal* [Preprint]. doi:10.14744/eej.2019.80774.

Schilder, H., 1974. Cleaning and Shaping the Root Canal. Dental Clinics of North America, 18(2), pp.269-296.

Selwitz, R.H., Ismail, A.I. and Pitts, N.B. (2007) 'Dental caries', *The Lancet*, 369(9555), pp. 51–59

Sharifi, R., Torabi, A., Hatam, R., Nikkerdar, N., Mozaffari, H., Safaei, M. and Amiri, S., 2018. The Effect of Gates-Glidden Drills on the Quality of Root Canal Treatment by Pre-Clinical Dental Students. Open Access Macedonian Journal of Medical Sciences, 6(11), pp.2193-2197.

Shea, B.J. et al. (2007) "Development of AMSTAR: A measurement tool to assess the methodological quality of systematic reviews," BMC Medical Research Methodology, 7(1). Available at: https://doi.org/10.1186/1471-2288-7-10.

Shea, B., Hamel, C., Wells, G., Bouter, L., Kristjansson, E., Grimshaw, J., Henry, D. and Boers, M., 2009. AMSTAR is a reliable and valid measurement tool to assess the methodological quality of systematic reviews. *Journal of Clinical Epidemiology*, 62(10), pp.1013-1020.

Shea, B., Reeves, B., Wells, G., Thuku, M., Hamel, C., Moran, J., Moher, D., Tugwell, P., Welch, V., Kristjansson, E. and Henry, D., 2017. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ*, p.j4008.

Siddiqui, S., Awan, K. and Javed, F., 2013. Bactericidal efficacy of photodynamic therapy against Enterococcus faecalis in infected root canals: A systematic literature review. Photodiagnosis and Photodynamic Therapy, 10(4), pp.632-643.

Silva, V., Grande, A., Martimbianco, A., Riera, R. and Carvalho, A., 2012. Overview of systematic reviews - a new type of study: part I: why and for whom? *Sao Paulo Medical Journal*, 130(6), pp.398-404.

Sin, J.H. et al. (2020) 'Evaluation of effectiveness of photosensitizers used in laser endodontics disinfection: A systematic review', Translational Biophotonics, 3(1). doi:10.1002/tbio.202000007.

Spencer, H.R., Ike, V. and Brennan, P.A. (2007) 'Review: The use of sodium hypochlorite in endodontics — potential complications and their management', *British Dental Journal*, 202(9), pp. 555–559. doi:10.1038/bdj.2007.374.

Tabassum, S. and Khan, F., 2016. Failure of endodontic treatment: The usual suspects. European Journal of Dentistry, 10(01), pp.144-147.

Naidu,T. A., Idris, M., I B, G., K J, N., Sahu, G., Arul, P., James, J. and Kareem, S., 2015. ROOT CANAL IRRIGANTS AND IRRIGATION TECHNIQUES: A REVIEW. Journal of Evolution of Medical and Dental Sciences, 4(27), pp.4694-4700.

Van der Sluis, L., Versluis, M., Wu, M. and Wesselink, P., 2007. Passive ultrasonic irrigation of the root canal: a review of the literature. International Endodontic Journal, 40(6), pp.415-426.

Van der Vyver, P., Vorster, M., Paleker, F. and de Wet, F., 2019. Root canal preparation: A literature review and clinical case reports of available materials and techniques. South African Dental Journal, 74(4).

Varoni, E.M., Lodi, G. and Iriti, M. (2014) 'Efficacy behind activity – Phytotherapeutics are not different from pharmaceuticals', *Pharmaceutical Biology*, 53(3), pp. 404–406. doi:10.3109/13880209.2014.923000.

Vertucci, F., Seelig, A. and Gillis, R. (1974) 'Root Canal morphology of the human maxillary second premolar', Oral Surgery, Oral Medicine, Oral Pathology, 38(3), pp. 456–464. doi:10.1016/0030-4220(74)90374-0.

Wang, C., Arnold, R., Trope, M. and Teixeira, F., 2007. Clinical Efficiency of 2% Chlorhexidine Gel in Reducing Intracanal Bacteria. Journal of Endodontics, 33(11), pp.1283-1289.

Waplington, M. and McRobert, A., 2014. Shaping the root canal system. British Dental Journal, 216(6), pp.293-297.

Young, G., Parashos, P. and Messer, H. (2007) 'The principles of techniques for cleaning root canals', Australian Dental Journal, 52(s1). doi:10.1111/j.1834-7819.2007.tb00526.x.

APPENDICES

APENDIX 1 PRISMA 2009 Checklist

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	

Appendix 2
Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	Click here to enter text.
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	Click here to enter text.
INTRODUCTION			

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	Click here to enter text.
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	Click here to enter text.
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	Click here to enter text.
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	Click here to enter text.
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	Click here to enter text.

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Click here to enter text.
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	Click here to enter text.
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	Click here to enter text.
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	Click here to enter text.
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	Click here to enter text.
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	Click here to enter text.
RESULTS			

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	Click here to enter text.
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Click here to enter text.
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	Click here to enter text.
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Click here to enter text.
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	Click here to enter text.
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	Click here to enter text.
Limitations	20	Discuss the limitations of the scoping review process.	Click here to enter text.

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	Click here to enter text.
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	Click here to enter text.

Appendix 3 MMAT tool

Part I: Mixed Methods Appraisal Tool (MMAT), version 2018

Category of study designs	Methodological quality criteria	Responses			
		Yes	No	Can't tell	Comments
Screening questions (for all types)	S1. Are there clear research questions?				
	S2. Do the collected data allow to address the research questions?				
	Further appraisal may not be feasible or appropriate when the answer is 'No' or 'Can't tell' to one or both screening questions.				
1. Qualitative	1.1. Is the qualitative approach appropriate to answer the research question?				
	1.2. Are the qualitative data collection methods adequate to address the research question?				
	1.3. Are the findings adequately derived from the data?				
	1.4. Is the interpretation of results sufficiently substantiated by data?				
	1.5. Is there coherence between qualitative data sources, collection, analysis and interpretation?				
2. Quantitative randomized controlled trials	2.1. Is randomization appropriately performed?				
	2.2. Are the groups comparable at baseline?				
	2.3. Are there complete outcome data?				
	2.4. Are outcome assessors blinded to the intervention provided?				
	2.5 Did the participants adhere to the assigned intervention?				
3. Quantitative non-randomized	3.1. Are the participants representative of the target population?				
	3.2. Are measurements appropriate regarding both the outcome and intervention (or exposure)?				
	3.3. Are there complete outcome data?				
	3.4. Are the confounders accounted for in the design and analysis?				
	3.5. During the study period, is the intervention administered (or exposure occurred) as intended?				
4. Quantitative descriptive	4.1. Is the sampling strategy relevant to address the research question?				
	4.2. Is the sample representative of the target population?				
	4.3. Are the measurements appropriate?				
	4.4. Is the risk of nonresponse bias low?				
	4.5. Is the statistical analysis appropriate to answer the research question?				
5. Mixed methods	5.1. Is there an adequate rationale for using a mixed methods design to address the research question?				
	5.2. Are the different components of the study effectively integrated to answer the research question?				
	5.3. Are the outputs of the integration of qualitative and quantitative components adequately interpreted?				
	5.4. Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?				
	5.5. Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?				

Part I: Mixed Methods Appraisal Tool (MMAT), version 2018

Category of study designs	Methodological quality criteria	Responses			
		Yes	No	Can't tell	Comments
Screening questions (for all types)	S1. Are there clear research questions?				
	S2. Do the collected data allow to address the research questions?				
	Further appraisal may not be feasible or appropriate when the answer is 'No' or 'Can't tell' to one or both screening questions.				
1. Qualitative	1.1. Is the qualitative approach appropriate to answer the research question?				
	1.2. Are the qualitative data collection methods adequate to address the research question?				
	1.3. Are the findings adequately derived from the data?				
	1.4. Is the interpretation of results sufficiently substantiated by data?				
	1.5. Is there coherence between qualitative data sources, collection, analysis and interpretation?				
2. Quantitative randomized controlled trials	2.1. Is randomization appropriately performed?				
	2.2. Are the groups comparable at baseline?				
	2.3. Are there complete outcome data?				
	2.4. Are outcome assessors blinded to the intervention provided?				
	2.5 Did the participants adhere to the assigned intervention?				
3. Quantitative non-randomized	3.1. Are the participants representative of the target population?				
	3.2. Are measurements appropriate regarding both the outcome and intervention (or exposure)?				
	3.3. Are there complete outcome data?				
	3.4. Are the confounders accounted for in the design and analysis?				
	3.5. During the study period, is the intervention administered (or exposure occurred) as intended?				
4. Quantitative descriptive	4.1. Is the sampling strategy relevant to address the research question?				
	4.2. Is the sample representative of the target population?				
	4.3. Are the measurements appropriate?				
	4.4. Is the risk of nonresponse bias low?				
	4.5. Is the statistical analysis appropriate to answer the research question?				
5. Mixed methods	5.1. Is there an adequate rationale for using a mixed methods design to address the research question?				
	5.2. Are the different components of the study effectively integrated to answer the research question?				
	5.3. Are the outputs of the integration of qualitative and quantitative components adequately interpreted?				
	5.4. Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?				
	5.5. Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?				

Appendix 4 AMSTAR 1 tool

1. Was an "a priori" design provided?
The research question and inclusion criteria should be established before the conduct of the review.

□ Yes □ No □ Can't answer □ Not applicable

2. Was there duplicate study selection and data extraction?
There should be at least two independent data extractors and a consensus procedure for disagreements should be in place.

□ Yes □ No □ Can't answer □ Not applicable

3. Was a comprehensive literature search performed?
At least two electronic sources should be searched. The report must include years and databases used (e.g. Central, EMBASE, and MEDLINE). Key words and/or MESH terms must be stated and where feasible the search strategy should be provided. All searches should be supplemented by consulting current contents, reviews, textbooks, specialized registers, or experts in the particular field of study, and by reviewing the references in the studies found.

□ Yes □ No □ Can't answer □ Not applicable

4. Was the status of publication (i.e. grey literature) used as an inclusion criterion?
The authors should state that they searched for reports regardless of their publication type. The authors should state whether or not they excluded any reports (from the systematic review), based on their publication status, language etc.

□ Yes □ No □ Can't answer □ Not applicable

5. Was a list of studies (included and excluded) provided?
A list of included and excluded studies should be provided.

□ Yes □ No □ Can't answer □ Not applicable

6. Were the characteristics of the included studies provided?
In an aggregated form such as a table, data from the original studies should be provided on the participants, interventions and outcomes. The ranges of characteristics in all the studies analyzed e.g. age, race, sex, relevant socioeconomic data, disease status, duration, severity, or other diseases should be reported.

□ Yes □ No □ Can't answer □ Not applicable

7. Was the scientific quality of the included studies assessed and documented?
'A priori' methods of assessment should be provided (e.g., for effectiveness studies if the author(s) chose to include only randomized, double-blind, placebo controlled studies, or allocation concealment as inclusion criteria); for other types of studies alternative items will be relevant.

□ Yes □ No □ Can't answer □ Not applicable

8. Was the scientific quality of the included studies used appropriately in formulating conclusions?
The results of the methodological rigor and scientific quality should be considered in the analysis and the conclusions of the review, and explicitly stated in formulating recommendations.

□ Yes □ No □ Can't answer □ Not applicable

9. Were the methods used to combine the findings of studies appropriate?
For the pooled results, a test should be done to ensure the studies were combinable, to assess their homogeneity (i.e. Chi-squared test for homogeneity, I^2). If heterogeneity exists a random effects model should be used and/or the clinical appropriateness of combining should be taken into consideration (i.e. is it sensible to combine?).

□ Yes □ No □ Can't answer □ Not applicable

10. Was the likelihood of publication bias assessed?
An assessment of publication bias should include a combination of graphical aids (e.g., funnel plot, other available tests) and/or statistical tests (e.g., Egger regression test).

□ Yes □ No □ Can't answer □ Not applicable

11. Was the conflict of interest stated?
Potential sources of support should be clearly acknowledged in both the systematic review and the included studies.

□ Yes □ No □ Can't answer □ Not applicable

Appendix 5 Forms

Appendix

------DATA EXTRACTION FORM-----

A. SOURCE

Study ID…….. Date……

Reviewer ID…… Revision Date…….

Authors……

Title……..

……..

……..

B. METHODS

		Yes	No	Unclear
Study Design				
Cross-sectional Design				
Clinical Trial				
Cohort/Longitudinal				
Lab Study: Human				
Lab Study: Animal				
Narrative Reporting of Results				
Statistics				

Study Duration……..

C. PARTICIPANTS/SPECIMENS

Total N = ……..

Final N =……...

D. INTERVENTIONS (I) and OUTCOMES

	Total I	Specific I	Duration	Details
Experimental Group				
Control Group				
Laboratory Group				

Primary outcome……

……

Secondary outcome……

……

Adverse effects……

……..

E. RESULTS

	N	Missing	Summary Data	Measure Effect	Subgroup Analysis
Experimental Group					
Control Group					
Laboratory Group					
Outcomes					

F. NOTES

Conclusion……

Funding……

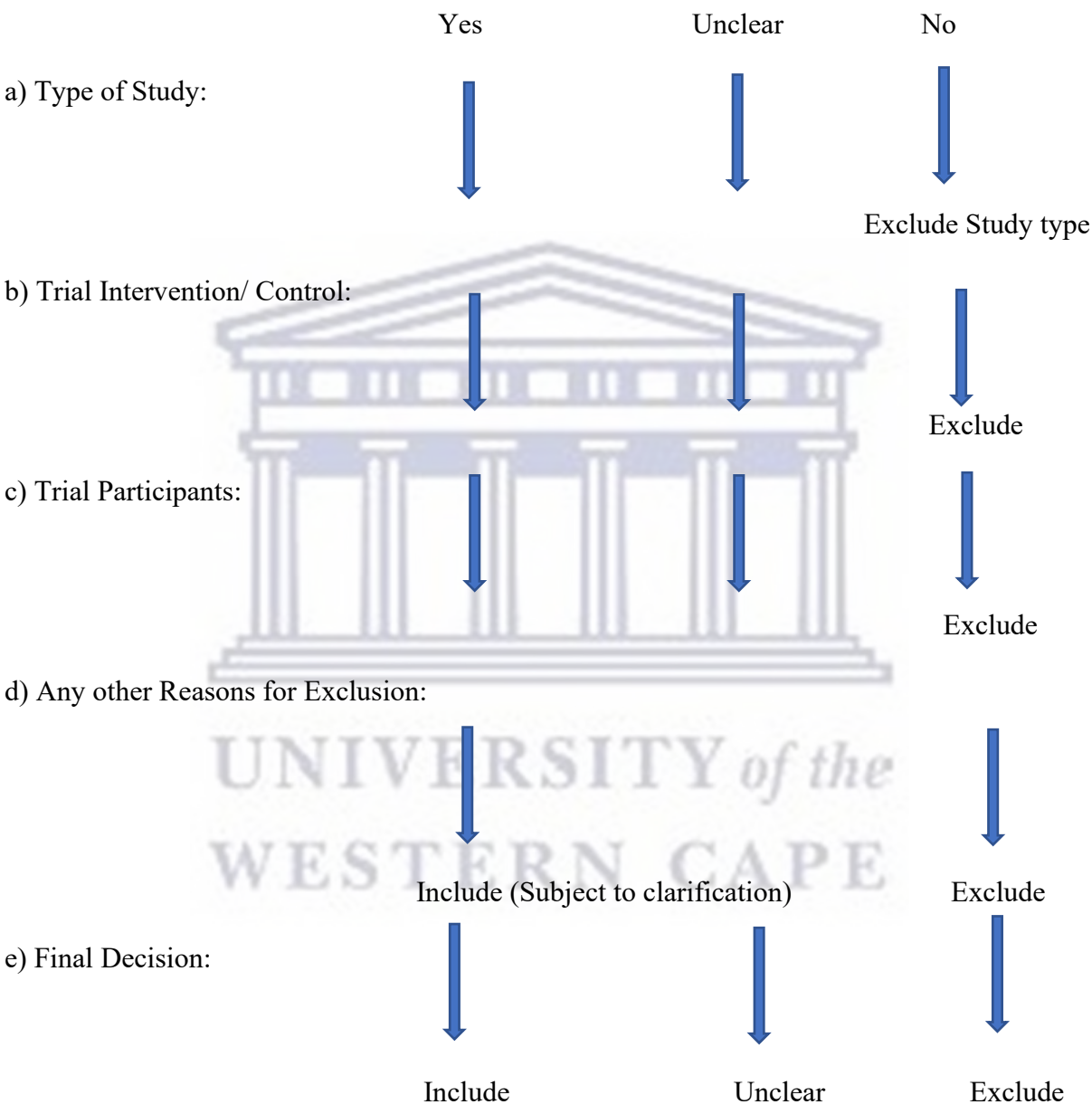
Correspondence needed……

--- STUDY ELIGIBILITY FORM ---

Reviewer ID: Date Reviewed:

Reference/ Study ID: _____

_____



Appendix 7 Ethical Approval

UNIVERSITY of the WESTERN CAPE

60 YEARS of hope, action & knowledge

27 November 2020

Dr N Hamadelneil
Faculty of Dentistry

Ethics Reference Number:	BM20/6/3
Project Title:	To Determine the efficacy of laser treatment as an adjunct to conventional endodontic treatment. An overview of systematic review.
Approval Period:	24 July 2020 – 24 July 2023

I hereby certify that the Biomedical Science Research Ethics Committee of the University of the Western Cape approved the scientific methodology and ethics of the above mentioned research project.

Any amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

Please remember to submit a progress report annually by 30 November for the duration of the project.

Permission to conduct the study must be submitted to BMREC for record-keeping.

The Committee must be informed of any serious adverse event and/or termination of the study.

Ms Patricia Josias
Research Ethics Committee Officer
University of the Western Cape

Director: Research Development
University of the Western Cape
Private Bag X 17
Bellville 7535
Republic of South Africa
Tel: +27 21 959 4111
Email: research-ethics@uwc.ac.za

BMREC Registration Number: BMREC-130410-020

FROM HOPE TO ACTION THROUGH KNOWLEDGE.

Appendix 6 Results Raw Data

Name of Author	Title,Journal and Date of Publication	Study Design	Study setting	Aim of study	Study population	Sample size	Findings of study	Recommendations from study	Intervention used	Incubation period
Afkhami, Farzaneh Karimi, Mahsa Bahador, Abbas Ahmadi, Paniz Pourhajibagher, Maryam Chiniforush, Nasim	Evaluation of antimicrobial photodynamic therapy with toluidine blue against Enterococcus faecalis: Laser vs LED-Photodiagnosis and photodynamic therapy-2020	Quantitative study	In vitro study	This study aimed to compare the antibacterial effect of antimicrobial photodynamic therapy (aPDT) by use of light emitting diode (LED) and diode laser light sources with toluidine blue (TBO) photosensitizer on Enterococcus faecalis (E. faecalis) biofilm in root canals of extracted single-canal human teeth	Eighty-five sound human single-canal teeth	(n = 15)	aPDT significantly decreased residual bacteria in the canal	aPDT can be used as an adjunct for root canal disinfection. Both diode and LED are suitable light sources for this purpose and can be used alternatively.	TBO/LED, TBO/diode laser, LED, TBO and diode laser and one negative (NaOCl)	1 week
Akyuz Ekim, Sefika Nur Erdemir, Ali	Comparison of different irrigation activation techniques on smear layer removal: an in vitro study. Microscopy research and technique. 2015	Quantitative study	In vitro study	to evaluate the efficiency of different irrigation activation techniques on smear layer removal	80 single-rooted human maxillary central teeth	(n = 10)	All experimental irrigation techniques except ANP and diode laser removed smear layer more effectively at	Irrigation activated/delivered techniques except diode laser have a positive effect on removing of smear layer.	Irrigation solutions - 2.5% NaOCl and 17% EDTA ,distilled water- were activated using passive ultrasonic irrigation,	N/A

							the coronal and middle levels compared to the apical level		EndoVac apical negative pressure , diode laser, Nd:YAG laser, Er:YAG laser, and Er:YAG laser using with photon-induced photoacoustic streaming	
Arnabat, Josep Escribano, Cesar Fenosa, Anna Vinuesa, Teresa Gay-Escoda, Cosme Berini, Leonardo Viñas, Miguel	Bactericidal activity of erbium, chromium: yttrium-scandium-gallium-garnet laser in root canals.Lasers in	Quantitative study	In vitro study	to investigate the effectiveness of the erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser by measuring its bactericidal effect inside root canals experimentally	N/A	N/A	use of NaOCl 5% was the most effective procedure, with NaOCl 0.5% being the least	laser treatment was as effective as NaOCl 5% when applied at 2 W for 60 s.	Er,Cr:YSGG and NaOCl	N/A

	medical science.2010			colonized with Enterococcus faecalis. We also determined the optimal conditions for the Er,Cr:YSGG laser to achieve the maximal bactericidal effect			effective			
Arslan, Hakan ,Ayrancı, Leyla Benan Karatas, Ertugrul Topçuoğlu, Hüseyin Sinan Yavuz, Muhammet Selim Kesim, Bertan	Effect of agitation of EDTA with 808-nanometer diode laser on removal of smear layer. Journal of endodontics.2013	Quantitative study	In vitro study	This study evaluated the efficacy of agitation of 15% EDTA with an 808-nm diode laser on removal of the smear layer.	Sixty extracted human maxillary central incisor teeth	n=10	agitation of 15% EDTA with an 808-nm diode laser for 20 seconds was effective in removing the smear layer in the apical thirds of root canals.	n/a	5% sodium hypochlorite for 120 seconds performed with the NaviTip (Dentsply Maillefer, Ballaigues, Switzerland) (control group); 15% EDTA for 120 seconds performed with the NaviTip; and agitation of 15% EDTA with an	n/a

									808-nm diode laser for 10, 20, 30, and 40 seconds.	
Azaripour, Adriano;Jacobi, Isabel;Pietsch, Michael;Willershausen, Brita	Photodynamic Therapy as an Alternative for Root Canal Disinfection. IADR-2010 IADR/PER General Session (Barcelona, Spain)2010	Quantitative study	In vitro study	aim of this study was to evaluate in vitro the antimicrobial effect of Photodynamic therapy (PDT), light activated disinfection system (LAD) and three irrigation solutions (NaOCl, CHX, H2O2) on root canals infected with Enterococcus faecalis	n/a	(n=8 x20)	The PDT and LAD could be developed as an adjunctive procedure to conventional root canal treatment.	Complete elemination of test germ was only observed in 3% sodium hypochlorite and it had the most antimicrobial effect in reduction of E. faecalis and could be regarded furthermore as the golden standard for endodontic treatments	PDT group treated with methylen blue and soft laser irradiation (λ=670 nm) for 60 seconds, (c) LAD-Group treated with toluidin blue and LED light irradiation (λ=670 nm) for 60 seconds,	24 hours

Batinić, Martina Ročan, Mia Budimir, Ana Anić, Ivica Bago, Ivona	Comparison of final disinfection protocols using antimicrobial photodynamic therapy and different irrigants after single-file reciprocating instrumentation against intracanal bacterial biofilm - An in vitro study. Photodiagnosis and photodynamic therapy.2018	Quantitative study	In vitro study	The aim of the study was to compare the efficacy of antimicrobial photodynamic therapy (aPDT) with irrigation protocols that include sodium hypochlorite (NaOCl), ethylenediaminotetraacetic acid (EDTA) or QMiX (combined irrigant: EDTA, chlorhexidine, detergent) solution after single-file reciprocating root canal instrumentation	68 extracted mandibular human single canal teeth	n/a	The aPDT used after irrigation with NaOCl and EDTA demonstrated similar antimicrobial efficacy as conventional irrigation with NaOCl.	n/a	2.5% NaOCl and EDTA followed by the application of the aPDT; Group 2. 2.5% NaOCl, EDTA and 2.5% NaOCl; Group 3. 2.5% NaOCl and QMIX solution; Group 4. 2.5% NaOCl and EDTA	n/a

Beltes, Charis Economides, Nikolaos Sakkas, Hercules Papadopoulou, Chrissanthy Lambrianidis, Theodoros	**Evaluation of Antimicrobial Photodynamic Therapy Using Indocyanine Green and Near-Infrared Diode Laser Against Enterococcus faecalis in Infected Human Root Canals. Photomedicine and laser surgery.2017**	**Quantitative study**	**In vitro study**	**aimed to assess the antimicrobial effect of PDT using indocyanine green (ICG) as photosensitizer and a near-infrared (NIR) diode laser in root canals of human teeth infected with Enterococcus faecalis**	**Ninety single-rooted teeth**	**n/a**	**ICG-mediated PDT activated by an NIR diode laser provided increased disinfection of the root canal system**	**the overall benefit in total bacterial elimination should be further investigated.**	**PDT with ICG and laser (0.5 W output power-medium-energy fluence), PDT with ICG and laser (1 W output power-high-energy fluence), only laser emission, only ICG, 2.5% sodium hypochlorite (NaOCl) as irrigant, 2.5% NaOCl and PDT with ICG and laser**	**n/a**
Betancourt, Pablo Sierra, Josep María Camps-Font, Octavi Arnabat-Domínguez, Josep Viñas, Miguel	Er,Cr:YSGG Laser-Activation Enhances Antimicrobial and Antibiofilm Action of Low Concentrations of Sodium Hypochlorite in Root Canals. Antibiotics (Basel, Switzerland).2019	Quantitative study	In vitro study	to evaluate the antibacterial effectiveness of sodium hypochlorite (NaOCl) at low concentrations activated by the Er,Cr:YSGG laser-activated irrigation (LAI) against 10-day-old intracanal	n/a	N=13	Er,Cr:YSGG LAI proved to be able to improve the intracanal distribution of 0.5% NaOCl after 60 s of activation, reaching the same level of effectiveness than 2.5% NaOCl.	working with lower concentrations may contribute to reduce undesired effects.	0.5% NaOCl + Er,Cr:YSGG; Saline + Er,Cr:YSGG; 0.5% NaOCl + syringe irrigation(SI); 2.5% NaOCl + SI; 5% NaOCl + SI	n/a

				Enterococcus faecalis biofilm						
Bolhari, Behnam Ehsani, Sara Etemadi, Ardavan Shafaq, Mohammad Nosrat, Ali	Efficacy of Er,Cr:YSGG laser in removing smear layer and debris with two different output powers. Photomedicine and laser surgery.2014	Quantitative study	In vitro study	The purpose of this study was to evaluate the effectiveness of the erbium, chromium: yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser in removing debris and the smear layer using two different output powers on the apical, middle, and coronal segments of root canal walls	Sixty extracted teeth	N=3	This study raises questions about the overall cleaning abilities of Er,Cr:YSGG lasers.	n/a	a final irrigation was performed using ethylenediaminetetraacetic acid (EDTA) and sodium hypochlorite (NaOCl), sequentially. In group 2, the samples were treated with a 2.78 µm Er,Cr:YSGG laser with an output power of 1.5 W. The same laser was used in group 3, but with an output power of 2.5 W	n/a

Braun, Andreas;Seifert, Tilmann;Schweizer, Robert Konstantin;Oehme, Bernd;Roggendorf, Matthias Johannes;Frankenberger, Roland;Schelle, Florian	Bacterial reduction of infected root canals with a novel 445nm diode laser. IADR-2016 AADR/CADR Annual Meeting (Los Angeles, California). 2016	Quantitative study	In vitro study	aim of the present study is to evaluate the effect of adjunctive laser irradiation with a novel 445nm laser device on Enterococcus faecalis in vitro	17 extracted human teeth	n/a	The adjunctive use of a 445nm diode laser can contribute to bacterial reduction during chemomechanical root canal treatment and therefore increase the effectiveness of conventional therapy approaches	n/a	(I) rinsing with 5 ml of a 2.65% sodium hypochlorite solution for 60 seconds, (II) laser irradiation with a 445nm diode laser (1W, 50% duty cycle, 15Hz), (III) rinsing with sodium hypochlorite and adjunctive laser irradiation	n/a
Bumb, Swapnil Sunil Bhaskar, Dara John Agali, Chandan R Punia, Himanshu Gupta, Vipul Singh, Vikas Kadtane, Safalya Chandra, Sneha	Assessment of Photodynamic Therapy (PDT) in Disinfection of Deeper Dentinal Tubules in a Root Canal System: An In Vitro Study. Journal of clinical and diagnostic research : JCDR.2014	Quantitative study	In vitro study	The basic aim of this study was assessment of the antimicrobial efficacy of Photodynamic Therapy in deeper dentinal tubules for effective disinfection of root canals using microbiological and scanning	freshly extracted 20 intact, non carious single rooted teeth	n/a	PDT can be effectively used during antimicrobial procedures along with conventional disinfection procedure for sterilization of root canals.	n/a	n/a	n/a

				electron microscopic examination inA vitro						

Cheng, X Chen, B Qiu, J He, W Lv, H Qu, T Yu, Q Tian, Y	**Bactericidal effect of Er:YAG laser combined with sodium hypochlorite irrigation against Enterococcus faecalis deep inside dentinal tubules in experimentally infected root canals-Journal of medical microbiology-2016**	**Quantitative study**	**In vitro study**	**This study evaluated the bactericidal effect of Er:YAG laser radiation combined with sodium hypochlorite (NaOCl) irrigation in the treatment of Enterococcus faecalis deep inside dentinal tubules.**	**n/a**	**n/a**	**Er:YAG laser irradiation at 0.5 W for 30 s combined with NaOCl irrigation was preferable because of the lower emission power and shorter irradiation time**	**this may serve as a new option for effective root canal disinfection.**	**The Er:YAG laser was activated, respectively, at 0.3, 0.5 and 1.0 W for either 20 or 30 s; 52.5 g l(-1) NaOCl and normal saline were used for the control groups.**	**n/a**
Cheng, Xiaogang	Evaluation of the bactericidal	Quantitative study	In vitro	The aim of this study was	Two hundred and	n/a	All the laser radiation protocols	Er:YAG/NaClO/NS/DW seems to be	(Nd:YAG, Er:YAG + 5.25% NaClO + 0.9%	n/a

Guan, Sumin Lu, Hong Zhao, Chunmiao Chen, Xingxing Li, Na Bai, Qian Tian, Yu Yu, Qing	effect of Nd:YAG, Er:YAG, Er,Cr:YSGG laser radiation, and antimicrobial photodynamic therapy (aPDT) in experimentally infected root canals- Lasers in surgery and medicine- 2012		study	to evaluate the bactericidal effect of Nd:YAG, Er:YAG, Er,Cr:YSGG laser radiation, and antimicrobial photodynamic therapy (aPDT) in experimentally infected root canals compared with standard endodontic treatment of 5.25% sodium hypochlorite (NaClO) irrigation	twenty infected root canals from extracted human teeth		tested, especially Er:YAG/NaClO /NS/DW, have effective bactericidal effect in experimentally infected root canals.	an ideal protocol for root canal disinfection during endodontic therapy.	normal saline + distilled water (Er:YAG/NaClO /NS/DW), Er:YAG + 0.9% normal saline + distilled water (Er:YAG/NS/DW), Er,Cr:YSGG, and aPDT) and two control groups (5.25% NaClO as positive control and 0.9% normal saline (NS) as negative control)	
Cheng, Xiaogang Tian, Tiantian Tian, Yu Xiang, Doudou Qiu, Jun Liu, Xiaohua Yu, Qing	Erbium:Yttrium Aluminum Garnet Laser-Activated Sodium Hypochlorite Irrigation: A Promising Procedure	Quantitative study	In vitro study	This study was to evaluate the potential of Erbium:Yttrium Aluminum Garnet laser-activated	n/a	n/a	Er:YAG + NaOCl showed a higher disinfection efficacy at each ATWW compared with NaOCl alone	The 15#/Er:YAG + NaOCl with the Er:YAG laser irradiation at 1.0 W for 20 sec may be considered a promising	The infected canals were then shaped to different apical terminal working widths (ATWW, 15#/0.04, 20#/0.04, 25#/0.04, 30#/0.04, and 40#/0.04) and	4 weeks

	for Minimally Invasive Endodontics. Photomedicine and laser surgery.2017			sodium hypochlorite irrigation (Er:YAG + NaOCl) for minimally invasive endodontics (MIE).				procedure for MIE.	treated with either Er:YAG + NaOCl (0.3 W, 20 sec) or NaOCl alone. Then, the ATWW were fixed at 15#/0.04, and the canals were treated with Er:YAG + NaOCl at 0.3 W for 40 and 60 sec, or at 0.5 and 1.0 W for 20 sec.	
Christo, J E Zilm, P S Sullivan, T Cathro, P R	Efficacy of low concentrations of sodium hypochlorite and low-powered Er,Cr:YSGG laser activated irrigation against an Enterococcus faecalis biofilm. International endodontic journal.2016	Quantitative study	In vitro study	To establish the antibacterial efficacy of low concentrations of sodium hypochlorite with and without Er,Cr:YSGG laser activation on Enterococcus faecalis biofilms in extracted teeth	96 decoronated single-rooted extracted human teeth	n/a	low-powered (0.5 W) Er,Cr:YSGG laser activation did not improve the antibacterial effect of low concentrations of sodium hypochlorite.	n/a	roots were then subjected to one of six treatment groups: group 1: syringe irrigation (SI) with saline (control) using a 27 -gauge Monoject needle 1 mm from the apex for 2 min; group 2: as for group 1 but with 1% NaOCl; group 3: as for group 1 but with 4% NaOCl; group 4: 0.5% NaOCl irrigation for 15 s followed by laser-activated irrigation (LAI) with four 15-s cycles replenishing	4 weeks

									the irrigant between cycles; group 5: as for group 4 but with 1% NaOCl as the irrigant; group 6: as for group 4 but with 4% NaOCl as the irrigant.	
Christo, Jonathan ;Zilm, Peter ;Cathro, Peter	Sodium hypochlorite and laser activation effectiveness against an E.faecalis biofilm. IADR-2011 Australian/ New Zealand Division Meeting (Melbourne, Australia).2011	Quantitative study	In vitro study	The aim of this study was to establish the effectiveness of various concentrations of NaOCl with and without laser activation, in eradicating an E. faecalis biofilm in vitro	Decoronated single rooted extracted human teeth	n/a	The study concluded that 4% NaOCl is more effective than 1% NaOCl however lower concentrations (0.5% and 1% NaOCl) when laser activated are as effective as 4% NaOCl.	n/a	There were 6 treatment groups; saline irrigation, 1% NaOCl; 4% NaOCl; 0.5% NaOCl with laser activated irrigation (LAI); 1% NaOCl with LAI; 4% NaOCl with LAI	4 weeks
Cretella, Gilda Lajolo, Carlo Castagnola, Raffaella Somma, Francesco Inchingolo, MariaTeresa	The Effect of Diode Laser on Planktonic Enterococcus faecalis in Infected Root Canals in an Ex Vivo Model. Photomedicine and laser	Quantitative study	In vitro study	This study examined the bactericidal effect of diode laser irradiation against intracanal Enterococcus faecalis	128 extracted single-rooted and single-canal teeth	N= 24	Evidence indicates that the diode laser was not more effective than sodium hypochlorite in reducing free bacteria.	n/a	Group 1 (n = 24) samples were irrigated with only saline solution (positive controls); Group 2 (n = 24) was treated with only 5.25% sodium hypochlorite;	21 days

Marigo, Luca	surgery.2017								Group 3 (n = 24) was irrigated with saline solutions activated by diode laser; Group 4 (n = 24) was treated with 5.25% sodium hypochlorite activated by diode laser; and Group 5 (n = 24) was irrigated with saline solution with methylene blue dye activated by the diode laser Fox (Sweden & Martina, Padova, Italy); additionally, eight teeth were not contaminated and their canals were irrigated with saline solution and used as a negative control	
da Silva, Caroline C Chaves Júnior, Sérgio P Pereira, Gabriela L D	Antimicrobial Photodynamic Therapy Associated with Conventional Endodontic	Quantitative study	In vitro study	This study evaluated antimicrobial photodynamic therapy (aPDT) as an adjunct	Ten uniradicular teeth	n/a	aPDT may be an effective adjunct therapy, resulting in a reduction (P = 0.0286) of the incidence of E. faecalis before root	n/a	In TG, the aPDT was performed with 100 ?g mL?1 methylene blue and irradiated with low power laser (InGaAlP,	n/a

Fontes, Karla B F da C Antunes, Lívia A A Póvoa, Helvécio C C Antunes, Leonardo S Iorio, Natalia L P P	Treatment: A Clinical and Molecular Microbiological Study. Photochemistry and Photobiology.2018			to endodontic treatment			canal obturation.		660 nm; 100 mW; 40 s) with a fiber-coupled optical laser. Another irradiation (3 J; 30 s; spot size of 3 mm2) was performed in the gingiva close to the apical foramen.	
de Oliveira, Bruna Paloma Aguiar, Carlos Menezes Câmara, Andréa Cruz de Albuquerque, Miracy Muniz Correia, Ana Cristina Regis de Barros Soares, Monica Felts de La Roca	The efficacy of photodynamic therapy and sodium hypochlorite in root canal disinfection by a single-file instrumentation technique. Photodiagnosis and photodynamic therapy.2015	Quantitative study	In vitro study	The aim of this in vitro study was to evaluate the efficacy of photodynamic therapy (PDT) and sodium hypochlorite (NaOCl) in root canal disinfection by a single-file instrumentation technique	Seventy human single-rooted mandibular premolars	N= 10	The association of 5.25% NaOCl with PDT was the most effective treatment against microorganisms from endodontic infection in root canals instrumented by a single-file instrumentation technique.	This result shows that PDT can be useful to improve the root canal disinfection.	Group 1: 1% NaOCl; Group 2: 5.25% NaOCl; Group 3: saline+PDT; Group 4: 1% NaOCl+PDT; Group 5: 5.25% NaOCl+PDT; Group 6: positive control; Group 7: negative control. For PDT, methylene blue (15µg/mL) remained in the root canal for 2min, followed by irradiation with diode laser	n/a

Dewsnup, Nathan Pileggi, Roberta	**Comparison of Bacterial Reduction in Straight and Curved Canals**	**Quantitative study**	**In vitro study**	**This study compared the reduction of Enterococcu**	**Fifty-five single-rooted extract**	**n/a**	**Traditional irrigation techniques using**	**n/a**	**NaOCl in straight canals (NS); NaOCl in curved**	**48hours at 37° in a CO2**

Haddix, James Nair, Uma Walker, Clay Varella, Claudio Herdy	**Using Erbium, Chromium:Yttrium-Scandium-Gallium-Garnet Laser Treatment versus a Traditional Irrigation Technique With Sodium Hypochlorite. Journal of Endodontics.2010**			**s faecalis in straight and curved canals using an erbium, chromium:yttrium-scandium-gallium-garnet laser and irrigation with 6.15% sodium hypochlorite (NaOCl).**	**ed teeth**		**6.15% NaOCl effectively eliminated all bacteria in straight and curved canals. Er,Cr:YSGG laser also effectively removed all bacteria from straight canals. (in three curved canals, even though there were significant bacterial reductions, they failed to render canals completely free of bacteria)**		**canals (NC); laser in straight canals (LS); laser in curved canals (LC); positive control straight canals (PCS); positive control curved canals (PCC); and negative control (NegC)**	**chamber**
Dumani, A Tanrisever, D Sihay, D Kuzu, S B Yilmaz, S	Efficacy of calcium hypoclorite with and without Er,Cr: Yttrium,	Quantitative study	In vitro study	The aim of this study was to compare the antimicrobial efficacy of	105 single-rooted premolars	N=15	Er,Cr: YSGG laser with or without an	n/a	syringe irrigation (SI) with distilled water (DW), SI with 2.5%	21 days

Guvenmez, H K	scandium, gallium, garnet laser activation on Enterococcus faecalis in experimentally infected root canals. Nigerian journal of clinical practice.2019			calcium hypochlorite (Ca(OCl)(2)) and sodium hypochlorite (NaOCl) associated with or without erbium, chromium: yttrium, scandium, gallium, garnet (Er,Cr: YSGG) laser irradiation in root canals experimentally infected with Enterococcus faecalis			irrirgation solution has antimicrobial effects on dentinal tubules infected with E. faecalis. The antimicrobial property of 2.5% Ca (OCl)(2) was effective as 2.5% NaOCl on E. faecalis with conventional or laser activated irrigation in root canals.		NaOCl, SI with 2.5% Ca (OCl)(2), laser-activated irrigation (LAI) with DW, LAI with 2.5% NaOCl and LAI with 2.5% Ca (OCl)(2) and LAI with no solution	
Er Karaoğlu, Gamze Aydın, Zeliha Uğur Erdönmez, Demet Göl, Cem Durmuş, Mahmut	Efficacy of additional antimicrobial photodynamic therapy administered using methylene blue, toluidine blue and tetra 2-mercaptopyridine	Quantitative study	In vitro study	the disinfection efficiency of additional aPDT performed using methylene blue (MB), toluidine blue (TB), and tetra 2-mercaptopyr	Forty-nine teeth with a single root and canal	N= 15	the additional aPDT protocol performed with TM-ZnPc provided similar antimicrobial efficacy, although	the use of TM-ZnPc in intra-canal disinfection in endodontics seems promising.	samples were divided into three groups according to the type of used photosensitizer (PS) (n = 15); MB (313 µM), TB (327	30 days

	substituted zinc phthalocyanine in root canals contaminated with Enterococcus faecalis. Photodiagnosis and photodynamic therapy.2020			idine substituted zinc phthalocyanine (TM-ZnPc) was compared in the roots contaminated with Enterococcus faecalis		it was used at a lower concentration compared to MB and TB		µM), and TM-ZnPc (6µM). All PSs were irradiation with a light-emitting diode (LED) lamp (630 nm, 2-4 mW/cm²) for the 60 s	
Garcia Basualdo, María Sol;Casadoumecq, Ana Clara ;Pérez, Sandra Beatriz ;Tejerina, Denise Paula;Gliosca, Laura Alejandra;Sierra, Liliana Gloria;Rodriguez, Pablo Alejandro	Efficacy of 940nm diode laser in the disinfection of ex-vivo root canals. IADR-2018 Argentine Division Meeting (Córdoba, Argentina).2018	Quantitative study	Ex vivo study	To verify the efficacy of 940 nm diode laser in the disinfection of root canals contaminated with Enterococcus faecalis ex vivo.	14 uniradicular roots with single canal	n/a	940nm diode laser application was efficient in the EF intracanal elimination	Although with this first study is not possible to conclude that its application is efficient as single treatment for final disinfection, it opens new horizons to continue the research.	Group 1: EDTA 17%+sodium hypochlorite 2.5% (final disinfection protocol) Group 2: 17% EDTA + 2.5% sodium hypochlorite + diode laser. Group 3: EDTA 17%+PBS+diode laser	37°C for 7 days
Ghorbanzadeh, Abdollah Bahador, Abbas	Ex vivo comparison of antibacterial efficacy of conventional chemomecha	Quantitative study	Ex vivo study	We aimed to assess the bactericidal effects of three disinfection	Fifty-five freshly extracted single-	N=7	All three disinfection methods were effective	n/a	the conventional chemomechanical debridemen	4 days and 4 weeks.

Sarraf, Pegah Ayar, Roya Fekrazad, Reza Asefi, Sohrab	nical debridement alone and in combination with light-activated disinfection and laser irradiation against Enterococcus faecalis biofilm. Photodiagnosis and photodynamic therapy.2020			methods on E. faecalis biofilm	rooted human teeth		for partial eliminati on of E. faecalis biofilm. But CCMD + LAD was significantly more efficacious in decreasing both mature and immature biofilms.		t (CCMD), CCMD + light-activated disinfection (LAD; 810 nm, 0.3 W, 120 J/cm(2)) with indocyanine Green (EmunDo) as photosensitizer and CCMD + diode laser irradiation (810 nm, 2 W).	
Ghorbanzadeh, Abdollah Fekrazad, Reza Bahador, Abbas Ayar, Roya Tabatabai, Siavash Asefi, Sohrab	Evaluation of the antibacterial efficacy of various root canal disinfection methods against Enterococcus faecalis biofilm. An ex-vivo study. Photodiagnosis and photodynamic therapy.2018	Quantitative study	Ex vivo study	The purpose of this study was to compare the antibacterial efficacy of different disinfection protocols against Enterococcus faecalis	Seventy-six extracted single-rooted human teeth	n/a	All the evaluated methods in this study were effective in the relative eliminati on of the E. faecalis biofilms except diode laser alone. Nevertheless, 0.2% CHX + LAD exhibited significan	n/a	Diode laser irradiation (810 nm, 2 W), Light activated disinfection (LAD) with Indocyanine Green, 0.2% Chlorhexidine gluconate (0.2% CHX), 0.2% CHX + LAD and 0.2% CHX + Diode groups.	4 days and 4 weeks.

							tly higher efficacy in reducing both 4-day and 4-week old biofilms.			
Guidotti, Rebecca Merigo, Elisabetta Fornaini, Carlo Rocca, Jean-Paul Medioni, Etienne Vescovi, Paolo	Er:YAG 2,940-nm laser fiber in endodontic treatment: a help in removing smear layer. Lasers in medical science.2014	Quantitative study	n/a	The aim of this preliminary study is to assess the effectiveness of Er:YAG laser fiber in removing the smear layer produced during root canal walls instrumentation.	Forty-eight single-rooted teeth	n/a	The Er:YAG fiber double irradiation with EDTA 17% and NaOCl 2.5% has been demonstrated to be effective in removing smear layer, even in the apical third which is described as the hardest area to clean during endodontic treatment.	n/a	three irradiations of 5 s each, with 300-µm Er:YAG endodontic fiber, 1 W and 2.5% NaOCl solution (A Group); two laser irradiations with 17% EDTA solution and 2.5% NaOCl solution (B Group); laser irradiation plus 17% EDTA solution and 2.5% NaOCl (C Group); only in the final wash of 17% EDTA (control group D)	n/a
Henninger, Eva Berto, Luciana Aranha	In Vitro Effect of Er:YAG Laser on Different Single and	Quantitative study	In vitro study	The purpose of this in vitro study was to evaluate the	n/a	n/a	Application of LAI with a 600 µm tip by	n/a	Laser-activated irrigation (LAI) with 300 or	3 days

Eick, Sigrun Lussi, Adrian Neuhaus, Klaus W	Mixed Microorganisms Being Associated with Endodontic Infections. Photobiomodulation, photomedicine, and laser surgery.2019			antimicrobial effect of activated irrigation with different modes of erbium-doped yttrium aluminum garnet (Er:YAG) laser application on microorganisms related to secondary endodontic infection.			using an Er:YAG laser might be advantageous in treatment of endodontic infections.		600 µm tips were tested with or without intermittent irrigation with 0.9% sodium chloride (NaCl) solution	
Hoedke, D Enseleit, C Gruner, D Dommisch, H Schlafer, S Dige, I Bitter, K	**Effect of photodynamic therapy in combination with various irrigation protocols on an endodontic multispecies biofilm ex vivo. International endodontic journal.2018**	**Quantitative study**	**Ex vivo study**	**To analyse the antibacterial effect of photodynamic therapy (PDT) in combination with various irrigation protocols on a multispecies biofilm in root canals ex vivo**	**160 extracted human single-rooted teeth**	**N=40**	**Adjunctive photodynamic therapy in combination with an irrigation protocol including NaOCl and CHX was an effective method for reduction of bacterial biofilm inside the root canals of extracted teeth.**	**n/a**	**G1, root canals were instrumented up to size 60 (control group),G2 to G4, instrumentation up to size 60 was performed using 0.9% sodium chloride (NaCl) (G2), 1% sodium hypochlorite (NaOCl) (G3), 1% NaOCl and a final irrigation with 2% chlorhexidine (CHX) (G4),**	**5 days**

									In all groups half of the specimens received adjunctive PDT using phenothiazine chloride as photosensitizer and a diode laser (wavelength 660 nm)	
Kaiwar, Anjali Usha, H L Meena, N Ashwini, P Murthy, Chethana S	The efficiency of root canal disinfection using a diode laser: in vitro study. Indian journal of dental research : official publication of Indian Society for Dental Research.2013	Quantitative study	In vitro study	The aim of this study is to verify the disinfection of diode laser, following chemo-mechanical procedures against Enterococcus fecalis.	30 extracted premolar teeth	n/a	The results of this research show that the 980 nm diode laser can eliminate bacteria that has immigrated into dentin, thus being able to increase the success rate in endodontic therapy.	n/a	Group A received no laser radiation. Specimens of group B and C were treated with diode laser (Sirona) with energy set at 1.5 and 3 W	37° C for 24 h.
Katalinić, Ivan Budimir, Ana Bošnjak, Zrinka Jakovljević, Suzana Anić, Ivica	The photo-activated and photo-thermal effect of the 445/970 nm diode laser on the mixed biofilm inside root canals of	Quantitative study	In vitro study	1) Evaluation of the photo-thermal (PT) and photo-activated (PAD) antibacterial effect of the 445/970 n	100 extracted human teeth with single straight canals	N=20	The 445 nm PAD protocol has a stronger antimicrobial effect than the 445 nm PT protocol. Prolonged exposure time to	tested laser protocols could be recommended for clinical usage but only as an adjunct to "classic" NaOCl rinse since alone they are not	Group 1 (G1) - the 445 nm photo-thermal (PT) effect, Group 2 (G2) - a combination of the 445 nm and 970 nm PT effect, Group 3 (G3) - the 445 nm	15 days

	human teeth in vitro: A pilot study. Photodiagnosis and photodynamic therapy.2019			m diode laser on E. faecalis, S. aureus and C. albicans mixed biofilms grown together inside root canals of human teeth. 2) Defining a potentially efficient clinical protocol for safe and predictable usage in endodontic procedures.			laser light and a combination of wavelengths (445/970 PT protocol) helps in the reduction of microbes	able to completely eradicate all microorganisms	photo-activated (PAD) effect with 0.1% riboflavin, Group 4 (G4) - a combination of 3% sodium hypochlorite (NaOCl) and the 445 nm PAD effect. Four samples were used as positive control (non-treated) and four as a negative control. 12 aditional samples were used as a control for the G4 (3% NaOCl rinse without the laser).	
Liu, Ting Huang, Zhiqiang Ju, Yanyun Tang, Xuna	Bactericidal efficacy of three parameters of Nd:YAP laser irradiation against Enterococcus faecalis compared with NaOCl irrigation. Lasers in medical	Quantitative study	In vitro study	We used the Nd:YAP laser in an in vitro experiment to evaluate the bactericidal effect of three parameters of Nd:YAP laser-activated irrigation	45 extracted human single-root teeth	n/a	Nd:YAP laser of 280 mJ and 360 mJ showed effective bactericidal effect in removing E. faecalis biofilm from the root canal walls and dentinal tubules.	n/a	5.25% sodium hypochlorite (NaOCl), Nd:YAP laser (180 mJ) + NaOCl, Nd:YAP laser (280 mJ) + NaOCl, and Nd:YAP laser (360 mJ) + NaOCl.	14 days

	science.2019			on biofilms of Enterococcus faecalis in root canals						

Mehrvarzfar, Payman Saghiri, Mohammad Ali Asatourian, Armen Fekrazad, Reza Karamifar, Kasra Eslami, Gita Dadresanfar, Bahareh	**Additive effect of a diode laser on the antibacterial activity of 2.5% NaOCl, 2% CHX and MTAD against Enterococcus faecalis contaminating root canals: an in vitro study. Journal of oral science.2011**	**Quantitative study**	**In vitro study**	**This in vitro study was performed to evaluate the effect of a diode laser and common disinfectants used in combination on mono-infected dental canals**	**One hundred and six single-rooted human premolars**	**N=48 (experimental group) N=5 (control group)**	**Complete eliminationon of E. faecalis was seen only for the combination of MTAD with diode laser irradiation.**	**Combination therapy with MTAD irrigation and diode laser irradiation, within the parameters used in this study, can be recommended as an effective treatment option for complete elimination of E. faecalis from the root canal system.**	**In the first group, the teeth were rinsed for 5 min with either sterile saline, 2.5% NaOCl, or MTAD, or for 1 min with 2% chlorhexidine gluconate (CHX). In the other group, samples were additionally irradiated with a 810-nm diode laser at 2 W output for 5 × 5 s.**	**Two weeks**
Mohan, Dennis Maruthingal, Sunith	Photoactivated disinfection (PAD) of	Quantitative study	Ex vivo	To investigate the efficacy	53 maxillary incisors	n/a	PAD may be an adjunctive	n/a	CET group samples were	24 hours

Indira, Rajamani Divakar, Darshan Devang Al Kheraif, Abdulaziz Abdullah Ramakrishnaiah, Ravikumar Durgesh, B H Basavarajappa, Santhosh John, Jacob	dental root canal system - An ex-vivo study. Saudi journal of biological sciences.2016		study	of photo activated disinfection (PAD) in reducing colony-forming unit (CFU) counts of Enterococcus faecalis (E. faecalis) in infected dental root canals			procedure to kill residual bacteria in the dental root canal systems after standard endodontic root canal preparation.		treated by chemo-mechanical preparation (CMP) alone, PAD samples were treated with laser alone at 2 different exposure time (4 min and 2 min). In the combination treatment, samples were treated initially by CET and then by PAD for a time period of 4 min and 2 min.	
Nunes, Maralize Ribeiro Mello, Isabel Franco, Gilson Cesar Nobre de Medeiros, João Marcelo Ferreira	Effectiveness of photodynamic therapy against Enterococcus faecalis, with and without the use of an intracanal optical	Quantitative study	In vitro study	The aim of this study was to evaluate the PDT effectiveness in reducing Enterococcus faecalis,	Extracted single-rooted teeth	n/a	results suggest that PDT was effective against E. faecalis, regardless of the use of an intracanal	n/a	one control group (untreated), one conventionally-treated group (1% NaOCl irrigation)	n/a

Dos Santos, Silvana Soléo Ferreira Habitante, Sandra Márcia Lage-Marques, José Luiz Raldi, Denise Pontes	fiber: an in vitro study. Photomedicine and laser surgery.2011			with and without the aid of an intracanal optical fiber			optical fiber.		and four PDT-treated groups. Irradiation (diode laser) was performed with (OF) or without an intracanal optical fiber (NOF) using two different irradiation times: 1 min and 30 sec (IT(90)) or 3 min (IT(180)).	
Ozkan, Leman Cetiner, Serap Sanlidag, Tamer	Effect of Er,Cr:YSGG laser irradiation with radial firing tips on Candida albicans in experimentally infected root canals. BioMed research international.2014	Quantitative study	n/a	To compare the disinfection effect of Er,Cr:YSGG laser using radial firing tips with NaOCl in root canals infected with C. albicans and to evaluate the irradiatio	seventy-six mandibular premolar teeth	N=8,n=25,n=2	According to the results of the present study, the Er,Cr:YSGG laser with radial firing tips presented less antifungal effects on C. albicans in root canals of infected teeth	n/a	Two groups were constituted as Group 1 was irradiated with 1.5 W laser (n = 8) and group 2, which was irradiated with 2 W laser (n = 8). Two more groups were	72 hours

				n effect on the dentinal surfaces.			than NaOCl solution.		formed as Group 3 (2 W laser (n = 25) and Group 4 NaOCl (5%) (n = 25). Group 5 (n = 2) did not receive any treatment	
Pérez, Sandra Beatriz ;Tejerina, Denise Paula;García Basualdo, María Sol;Casadoumecq, Ana Clara;Rodríguez, Pablo Alejandro;Molgatini, Susana Liliana;Gliosca, Laura Alejandra	Enterococcus faecalis: viable and culturable after ex vivo endodontic treatment with diode laser. IADR-2018 Argentine Division Meeting (Córdoba, Argentina). 2018	Quantitative study	Ex vivo study	To show viability of Enterococcus faecalis (Ef) kept under ecologically adverse conditions inside ex vivo endodontically-treated root canals for 12 months	Fourteen endodontically prepared and sterilized single-roots with a single canal	n/a	The results obtained under the experimental conditions used here, showed that Ef does not recover after final endodontic disinfection with sodium hypochlorite 2.5% or diode laser 940nm, or both combined successively. Ef was viable and	n/a	group 1: (Final disinfection protocoll of the Endodontics Department FOUBA): EDTA17% + sodium hypochlorite 2.5%; Group 2: EDTA17% + sodium hypochlorite 2.5% + diode laser 940nm; Group 3: EDTA17% + PBS + diode laser 940nm	12 months

							culturable after 12 months under ecologically adverse conditions inside the root canal.			
Poggio, Claudio Arciola, Carla Renata Dagna, Alberto Florindi, Filippo Chiesa, Marco Saino, Enrica Imbriani, Marcello Visai, Livia	Photoactivated disinfection (PAD) in endodontics: an in vitro microbiological evaluation. The International journal of artificial organs.2011	Quantitative study	In vitro study	the in vitro evaluation by MTT test of the antimicrobial effect of photoactivated disinfection (PAD) and, comparatively, of a conventional 5.25% NaOCl irrigating solution.	Freshly extracted single-rooted human teeth	n/a	PAD applied for a longer time (in respect to manufacturer's instructions) or PAD associated to 5% NaOCl showed the significantly higher antibacterial effects.	n/a	PAD, PAD plus 0.5% NaOCl solution, TBO, PAD for longer time and with 5% NaOCl solution (positive control).	n/a
Prażmo, Ewa Joanna Godlewska, Renata Alicja Mielczarek, Agnieszka Beata	Effectiveness of repeated photodynamic therapy in the elimination of intracanal Enterococcus faecalis biofilm: an in vitro study.	Quantitative study	In vitro study	to investigate the effectiveness of photodynamic therapy in the elimination of intracanal Enterococcus	46 single-rooted human teeth	n/a	A single PDT eliminated 45% of the initial CFU/ml. Repeated PDT eradicated 95% of the intracanal bacterial biofilm.	Photodynamic therapy has a high potential for the elimination of E. faecalis biofilm. There is a safe therapeu	single application of photodynamic therapy, two cycles of PDT, irrigation with 5.25% NaOCl solution	1 week.

	Lasers in medical science.2017			faecalis biofilm and to analyse how a repeated light irradiation, replenishment of oxygen and photosensitiser affect the results of the photodynamic disinfecting protocol				tic window where photoinduced disinfection can be used as an adjuvant to conventional endodontic treatment, which remains the most effective.	and negative and positive control.	
Rahimi, Saeed Shahi, Shahriar Gholizadeh, Seddigheh Shakouie, Sahar Rikhtegaran, Sahand Soroush Barhaghi, Mohammad Hossein Ghojazadeh, Morteza Froughreyhani, Mohammad Abdolrahimi, Majid	Bactericidal effects of Nd:YAG laser irradiation and sodium hypochlorite solution on Enterococcus faecalis biofilm. Photomedicine and laser surgery.2012	Quantitative study	In vitro study	The aim of this study was to evaluate the bactericidal effects of Nd:YAG laser on biofilm of Enterococcus faecalis.	60 extracted teeth	n/a	Based on the results of the present study, the effect of Nd:YAG laser beam on E. faecalis biofilm is less than that of sodium hypochlorite solution. A combination of laser and sodium	n/a	Group 1 samples did not undergo any interventions, to serve as controls. Group 2 samples underwent a 3-W laser beam for 10 sec. The root canals in group 3 were irrigated with 1% sodium hypochlor	n/a

							hypochlorite results in complete eliminati on of E. faecalis biofilm.		ite for 15 min and then irradiated with a 3-W laser beam for 10 sec. The root canals in group 4 were irrigated with 1% sodium hypochlorite for 15 min.	
Sabino, C P Garcez, A S Núñez, S C Ribeiro, M S Hamblin, M R	Real-time evaluation of two light delivery systems for photodynamic disinfection of Candida albicans biofilm in curved root canals. Lasers in medical science.2015	Quantitative study	In vitro study	We developed an in vitro model of bioluminescent Candida albicans biofilm inside curved dental root canals and investigated the microbial reduction produced when different light delivery methods are employed.	Root canals	n/a	APDT showed to be an effective way to inactivate C. albicans biofilms. Diffuser fibers provided optimized light distribution inside curved root canals and significantly increased APDT efficiency.	n/a	Methylene blue (90 µM) was introduced into the canals and then irradiated (λ = 660 nm, P = 100 mW, beam diameter = 2 mm) with laser tip either in contact with pulp chamber or within the canal using an optical diffuser fiber	n/a

Samaksamarn, Thalerngsaks	Antibacterial Effect On Enterococcus faecalis Of Er,Cr:YSGG Laser Irradiation. IADR-2013 IADR/AADR/ CADR General Session (Seattle, Washington). 2013	Quantitative study	In vitro study	To compare the antibacterial effect of Er,Cr:YSGG laser irradiation with two standard irrigating solutions in contaminated root canals of extracted human teeth	One hundred and twenty-five extracted single rooted teeth with straight roots	n/a	It can be concluded that Er,Cr:YSGG laser irradiation can reduce the viable colonies.	n/a	The first group was used as a negative control receiving no treatment. The second group and third group were irrigated with 2.5% NaOCl solution and 2% CHX solution for 10 min, respectively. The last group was irradiated with the Er,Cr:YSGG laser at 1.5 W output power with no air and water using four lasing cycles of 10 s each.	48 hours
Samiei, Mohammad Shahi, Shahriar Abdollahi, Amir Ardalan Eskandarinezhad, Mahsa Negahdari, Ramin Pakseresht, Zahra	The Antibacterial Efficacy of Photo-Activated Disinfection, Chlorhexidine and Sodium Hypochlorite in Infected Root Canals: An in Vitro	Quantitative study	In vitro study	This study compared the efficacy of light-activated low-power laser, 2% chlorhexidine (CHX) and 2.5% NaOCl in eliminating	60 maxillary central incisors	N= 15	Photodynamic therapy was effective in reducing the E. faecalis counts in comparison with the control	n/a	In the control group no intervention was made. In the photo-activated disinfection (PAD) group, laser therapy	24 hours

	Study. Iranian endodontic journal.2016			Enterococcus faecalis (E. faecalis) from the root canal system.			group, but 2.5% NaOCl solution was the most effective protocol.		was undertaken with diode laser beams (with an output power of 100 mW/cm(2)) for 120 sec. For the other two experimental groups, root canals were irrigated either with 5 mL of 2% CHX or 2.5% NaOCl solutions, respectively	
Sarda, R A Shetty, R M Tamrakar, A Shetty, S Y	Antimicrobial efficacy of photodynamic therapy, diode laser, and sodium hypochlorite and their combinations on endodontic pathogens. Photodiagnosis and photodynamic therapy.2019	n/a	n/a	To evaluate and compare the antimicrobial activity of diode laser, photodynamic therapy, and sodium hypochlorite along with their combinations on endodontic pathogens:	120 uniradicular teeth	n/a	PAD in combination with NaOCl can be an alternative and better option for root canal disinfection for both the endodontic pathogens, E. faecalis and S. mutans.	n/a	Ten teeth from each subgroup were disinfected with a diode laser, photo activated disinfection (PAD), sodium hypochlorite, a combination of sodium hypochlorite and diode laser, a combination of sodium hypochlorit	n/a

				Enterococcus faecalis and Streptococcus mutans.					e and photo activated disinfection respectively. Ten teeth in each group served as control without any disinfection.	
Schiffner, Ulrich Cachovan, Georg Bastian, Jochen Sculean, Anton Eick, Sigrun	In vitro activity of photoactivated disinfection using a diode laser in infected root canals. Acta odontologica Scandinavica .2014	Quantitative study	In vitro study	To investigate the lethal activity of photoactivated disinfection (PAD) on Enterococcus faecalis (ATCC 29212) and mixed populations of aerobic or anaerobic bacteria in infected root canals using a diode laser after the application of a photosensitizer (PS).	n/a	n/a	The bactericidal activity of PAD appears to be enhanced by serum proteins in vitro, but is limited to bacteria present within the root canal.	n/a	First, the bactericidal activity of a low power diode laser (200 mW) against E. faecalis ATCC 29212 pre-treated with a PS (toluidine blue) for 2 min were examined after different irradiation times (30 s, 60 s and 90 s). Second, root canals were infected with E. faecalis or with mixed aerobic or anaerobic microbial populations for 3 days	3 days

									and then irrigated with 1.5% sodium hypochlorite and exposed to PAD for 60 s	
Soares, Janir Alves Santos Soares, Suelleng Maria Cunha Santos César, Carlos Augusto de Carvalho, Maria Auxiliadora Roque Brito-Júnior, Manoel de Sousa, Gerdal Roberto Soares, Betânia Maria de Macêdo Farias, Luiz	Monitoring the effectiveness of photodynamic therapy with periodic renewal of the photosensitizer on intracanal Enterococcus faecalis biofilms. Photodiagnosis and photodynamic therapy.2016	Quantitative study	In vitro study	This study assessed the effectiveness of a PDT protocol against intracanal Enterococcus faecalis biofilms.	n/a	n/a	Our findings suggest immediate and delayed antibacterial effects using the PDT protocol tested.	n/a	The instrumentation was associated to irrigation with 0.85% saline or an alternate irrigation (AI) with 5.25% NaOCl and 17% EDTA. Complementary treatments included saline/PDT and AI/PDT. Four PDT cycles were performed using a diode laser (660nm, 40mW) delivered through a tapered optical fiber. In each cycle, the root canal was filled with 1.56µM/mL methylene	21 days

									blue and irradiated for 150s.	
Sohrabi, Khosrow Sooratgar, Aidin Zolfagharnasab, Kaveh Kharazifard, Mohammad Javad Afkhami, Farzaneh	Antibacterial Activity of Diode Laser and Sodium Hypochlorite in Enterococcus Faecalis-Contaminated Root Canals. Iranian endodontic journal.2016	Quantitative study	In vitro study	The aim of the present in vitro study was to evaluate the disinfection ability of 980-nm diode laser in comparison with sodium hypochlorite (NaOCl) as a common root canal irrigant in canals infected with Enterococcus faecalis (E. faecalis)	18 extracted single-rooted premolars	N=8	5.25% NaOCl seems to reduce E. faecalis more effectively, the diode laser also reduced the bacterial count.	980-nm diode laser could be considered as a complementary disinfection method in root canal treatment.	One specimen was chosen for the negative control, one specimen was selected as the positive control and the remaining samples were divided into two groups (n=8). The samples of the first group were irrigated with 5.25% NaOCl and the second group were treated with a 980-nm diode laser	2 weeks

Souza, Letícia C Brito, Patrícia R R Machado de Oliveira, Julio C Alves, Flávio R F	Photodynamic Therapy with Two Different Photosensitizers as a Supplement to Instrumentation/Irrigation Procedures in	Quantitative study	In vitro study	This in vitro study aimed to investigate the antibacterial effects of photodynamic therapy (PDT) with	Seventy extracted teeth	n/a	PDT with either MB or TB may not exert a significant supplemental effect to instrumentation/irrigation	Further adjustments in the PDT protocol may be required to enhance	Teeth were irrigated either with 2.5% NaOCl or with 0.85%	7 days

Moreira, Edson J L Sampaio-Filho, Hélio R Rôças, Isabela N Siqueira, José F	Promoting Intracanal Reduction of Enterococcus faecalis. Journal of Endodontics.2010			methylene blue (MB) or toluidine blue (TB) (both at 15 µg/mL) as a supplement to instrumentation/irrigation of root canals experimentally contaminated with Enterococcus faecalis			procedures with regard to intracanal disinfection	predictability in bacterial elimination before clinical use is recommended.	NaCl, and then randomly distributed into four experimental groups: MB/NaOCl (PDT with MB and NaOCl as the irrigant), TB/NaOCl (PDT with TB and NaOCl as the irrigant), MB/NaCl (PDT with MB and NaCl as the irrigant), and TB/NaCl (PDT with TB and NaCl as the irrigant). For PDT, the photosensitizer remained in the	

									canal for 2 minutes before exposed to red light emitted from a diode laser for 4 minutes.	
Suer, K Ozkan, L Guvenir, M	Antimicrobial effects of sodium hypochlorite and Er,Cr:YSGG laser against Enterococcus faecalis biofilm. Nigerian journal of clinical practice.2020	Quantitative study	In vitro study	The aim of this study was to investigate the antimicrobial effect of Erbium, chromium-doped yttrium, scandium, gallium, and garnet (Er,Cr:YSGG) laser with and without NaOCl solution	81 extracted human mandibular premolar teeth	N=25 ,n=6	Within the limitations of this laboratory study, NaOCl irrigation improved the antimicrobial effect of Er,Cr:YSGG laser irradiation.	When the toxic effects of high percentage of NaOCl was considered, the combination of low-powered laser and low concentration of NaOCl can be used as an effective disinfection method in root canal treatment.	The specimens were divided into 4 experimental groups. Group 1 (n = 25) was irradiated with 2 W laser, group 2 (n = 25) was irradiated with 0.75 W laser in combination with 2.5% NaOCl, group 3 (n = 25) was irrigated with 5% NaOCl and	24 hours

									group 4 (n = 6) was not treated.	
Sun, Chu-Wen Zhu, Ya-Qin	[Elimination of Entercoccus faecalis with different disinfection methods in root canals in vitro]. Shanghai kou qiang yi xue = Shanghai journal of stomatology.2017	Quantitative study	In vitro study	To compare the elimination effect against E.faecalis in root canals with different methods	Fifty extracted premolars with single root canal	n/a	Specimens treated with PUI, diode laser radiation and the combination of them showed great effect of elimination against biofilm of Enterococcus faecalis compared with saline irrigation. Irrigation with 3% NaClO was the most efficient method in this experiment.	n/a	specimens in group A were treated with saline irrigation, specimens in group B were treated with 3% NaClO irrigation (as positive control), specimens in group C were treated with PUI, specimens in group D were treated with diode laser radiation, specimens in group E were treated with	28 days

									combination of PUI and diode laser radiation	
Susila, Anand V Sugumar, R Chandana, C S Subbarao, C V	Combined effects of photodynamic therapy and irrigants in disinfection of root canals. Journal of biophotonics.2016	Quantitative study	In vitro study	In this study, the combined effects of photodynamic therapy and irrigants in eradicating common endodontic pathogens are evaluated.	80 extracted single rooted teeth	n/a	The combination of PDT and antibacterial irrigation proposed in this study can be used in all primary cases for thorough and reliable disinfection of root canals but may be highly effective in resistant cases like endodontic failures, as E. faecalis is prevalent in such cases.	n/a	teeth are divided into 2 groups (1) mechanical flushing; (2) antibacterial irrigation. After cleaning and shaping, they are inoculated with either (A) Streptococcus mutans or (B) Enterococcus faecalis and incubated. They are again subdivided and either only irrigated or	n/a

									irrigated and lased. Dentin shavings are taken from root canal walls and cultured .	
Thammasitboon, Kewalin;Kitticchokwatana, Somchai;Jitpakdeebodin, Suwanna	Antimicrobial Efficacy of Photo-Activated Disinfection on endodontic E. faecalis. IADR-2010 IADR/PER General Session (Barcelona, Spain).2010	Quantitative study	n/a	To determine the effectiveness of Photo-Activated Disinfection (PAD), 2.5% sodium hypochloride, 2% chlorhexidine and combination usage of PAD with 2.5% Sodium hypochloride and PAD with 2% Chlorhexidine in elimination of E. faecalis in human root canals.	Sixty two single rooted human teeth	N=10 ,n=2	PAD treatment did not efficiently eliminate E.faecalis whereas 2.5% NaOCl and 2% CHX significantly reduced the bacterial load in the root canal.	n/a	The experimental groups were subjected to either PAD(13 to 15 µg/ml of toloniu m chloride and laser light (633±2 nm) generated by diode laser) , 2.5% NaOCl, 2% CHX, 2.5% NaOCl followed by PAD and 2.0% CHX	24 hours

									followed by PAD.	

Tokuc, Muge Ozalp, Serife Topcuoglu, Nursen Kulekci, Guven	**Bactericidal Effect of 2780 nm Er,Cr:YSGG Laser Combined with 940 nm Diode Laser in Enterococcus faecalis Elimination: A Comparative Study. Photobiomodulation, photomedicine, and laser surgery.2019**	**Quantitative study**	**n/a**	**This study aims to compare the bactericidal efficacy of different Er,Cr:YSGG disinfection methods, particularly combined application of Er,Cr:YSGG and Diode laser**	**Ninety-five straight, single-rooted premolars with similar canal**	**n/a**	**The most successful E. faecalis elimination was obtained from laser-activated irrigation group**	**As combined application of Er,Cr:YSGG and Diode laser gives suggestive results, further studies with larger sample sizes are needed to clarify the outcome.**	**The samples were randomly divided into five groups (n = 15): 5% NaOCl, Er,Cr:YSGG, Er,Cr:YSGG +5% NaOCl, Er,Cr:YSGG + Diode, and control group.**	**n/a**
Wang, Xiaoli Cheng, Xiaogang Liu, Baogang Liu, Xin Yu, Qing He, Wenxi	Effect of Laser-Activated Irrigations on Smear Layer Removal from the Root Canal Wall. Photomedicine and laser surgery .2107	Quantitative study	In vitro study	The purpose of this study was to evaluate the effect of laser-activated irrigations (LAI) by using the Erbium: Yttrium Aluminum Garnet (Er:YAG)	Root canals of extracted human teeth	n/a	Among the treatments, the LAI+NaOCl+EDTA was the most effective protocol in removing SL from the entire root canal wall.	may be effective for root canal treatment.	(A) NaOCl, 5.25% sodium hypochlorite (NaOCl) for 60 sec; (B) EDTA, 17% ethylenediamine tetraacetic acid (EDTA) for 60 sec; (C) NaOCl+EDTA, NaOCl, and EDTA for 30 sec each; (D)	n/a

				laser and the Erbium Chromium: Yttrium Scandium Gallium Garnet (Er,Cr:YSGG) laser on removing smear layer (SL) from the root canal wall					LAI+NaOCl, LAI with NaOCl for 60 sec; (E) LAI+EDTA, LAI with EDTA for 60 sec; and (F) LAI+NaOCl+EDTA, LAI with NaOCl, and EDTA for 30 sec each	
Yildirim, Cihan Karaarslan, Emine Sirin Ozsevik, Semih Zer, Yasemin Sari, Tugrul Usumez, Aslihan	Antimicrobial efficiency of photodynamic therapy with different irradiation durations. European journal of dentistry.2013	Quantitative study	In vitro study	This study aimed to evaluate the antimicrobial efficiency of PDT and the effect of different irradiation durations on the antimicrobial efficiency of PDT	Sixty freshly extracted human teeth with a single root	n/a	PDT is as effective as conventional 5% NaOCl irrigation with regard to antimicrobial efficiency against Enterococcus faecalis.	n/a	The control group received no treatment. Group 1 was treated with a 5% sodium hypochlorite (NaOCl) solution. Groups 2, 3, and 4 were treated with methylene-blue photosensitizer and 660-nm diode laser irradiation for 1, 2, and 4 min, respectively. The root canals were instrumented and irrigated with NaOCl, ethylenediam	21 days

									ine-tetraacetic acid, and a saline solution, followed by autoclaving	
Zhou, Meng-Qi Wang, Hao-Ming Xiao, Jia-Qi Hong, Jin	[Evaluation of root canal isthmus debridement efficacy of Er:YAG laser in combination with sodium hypochlorite]. Shanghai kou qiang yi xue = Shanghai journal of stomatology.2016	Quantitative study	n/a	To histologically evaluate the efficacy of sodium hypochlorite (NaClO) in combination with Er:YAG (erbium-doped yttrium aluminium garnet) laser in dissolving necrotic tissue and cleaning root canals as well as canal isthmuses	50 well-prepared premolars	n/a	Er:YAG laser combined with 1% NaClO irrigation may be used effectively in root canal and root canal isthmus cleanliness as a new method.	n/a	group A- irrigated with 1% NaClO for 1 minute, group B- irradiated by Er:YAG laser at 0.5 W combined with 1% NaClO irrigation for 1 minute, group C- irradiated by Er:YAG laser at 1.0 W combined with 1% NaClO irrigation for 1 minute, group D- irradiated by Er:YAG laser at 2.0 W combined with 1% NaClO irrigation for 1 minute,group E- negative control	n/a

Nasher, Riman	**The effectiveness of**	**Quantitative study**	**In vitro**	**This study evaluated**	**Sixty-four**	**N=8**	**The Er:YAG**	**n/a**	**Groups a, b, c, and d**	**n/a**

Franzen, Rene Gutknecht, Norbert	**the Erbium:Yttrium aluminum garnet PIPS technique in comparison to different chemical solutions in removing the endodontic smear layer-an in vitro profilometric study.2016**			**the degree of endodontic smear layer removal using the Er:YAG PIPS technique (2.94 µm) in comparison with different irrigants**	**single-rooted teeth**		**PIPS technique did not show any improved results in removing the smear layer when compared to the irrigants alone.**		**were irrigated with (3 % NaOCl + 20 % EDTA), (0.9 % NaCl), (3 % NaOCl), and (20 % EDTA), respectively. Groups e, f, g, and h were treated with (3 % NaOCl + 20 % EDTA + PIPS), (0.9 % NaCl + PIPS), (3 % NaOCl + PIPS), and (20 % EDTA + PIPS), respectively. The settings of the Er:YAG PIPS technique were (0.3 W, 20 mJ, 15 Hz, 50 µs, no water and air)**	
Pedullà, E Genovese, C Campagna, E Tempera, G Rapisarda, E.	Decontamination efficacy of photon-initiated photoacoustic streaming (PIPS) of irrigants using low-energy laser settings: an ex vivo study.	Quantitative study	Ex-vivo study	To assess ex vivo, the antibacterial effectiveness of photon-initiated photoacoustic streaming (PIPS) of irrigants using an Er:YAG laser equipped	One hundred and forty-eight single-rooted extracted teeth	N=32	there were no significant differences in bacterial reduction between the laser and NaOCl or NaOCl alone	n/a	Infected teeth were then randomly divided into four test groups (n = 32 for each): pulsed erbium/YAG laser at nonablative settings for	15 days

	.International endodontic journal.2012			with a newly designed, stripped and tapered tip in extracted teeth with infected root canals			groups. Thus, the use of a laser did not improve microbial killing over and above use of NaOCl alone		30 s with sterile bi-distilled water (Group A) or 5% sodium hypochlorite (NaOCl) (Group B); without laser-activated sterile bi-distilled water irrigation for 30 s (Group C) or 5% NaOCl irrigation for 30 s (Group D); the positive control group received no treatment in infected teeth (n = 10)	
Cheng, Xiaogang Xiang, Doudou He, Wenxi Qiu, Jun Han, Bing Yu, Qing Tian, Yu	**PDT and diode laser 810 nm irradiation are effective methods for root canal disinfection. PDT is a suitable alternative for diode laser 810 nm irradiation, because of lower thermal**	**Quantitative study**	**In vitro study**	**This study was to evaluate the bactericidal effect of Er:YAG laser-activated sodium hypochlorite irrigation (Er:YAG + NaOCl) on biofilms of Enterococc**	**Extracted human root canals**	**N=39**	**The Er:YAG + NaOCl showed an effective bactericidal effect on biofilms of E. faecalis isolate, which may be considered an effective protocol for root canal treatment.**		**The infected canals then received treatments of syringe irrigation with normal saline (NS) or NaOCl, ultrasonic activated irrigations US + NS and US + NaOCl, and Er:YAG laser-activated irrigations**	**4 weeks**

	risk on root dentin. Photomedicine and laser surgery.2017			**us faecalis clinical isolate**					**Er:YAG + NS and Er:YAG + NaOCl**	
Ng, Raymond Singh, Fiza Papamanou, Despina A Song, Xiaoqing Patel, Chitrang Holewa, Colleen Patel, Niraj Klepac-Ceraj, Vanja Fontana, Carla R Kent, Ralph Pagonis, Tom C Stashenko, Philip P Soukos, Nikolaos S	Endodontic photodynamic therapy ex vivo.Journal of endodontics.2011	Quantitative study	Ex-vivo study	The objective of this study was to evaluate the antimicrobial effects of photodynamic therapy (PDT) on infected human teeth ex vivo	Extracted teeth	N=52	Data indicate that PDT significantly reduces residual bacteria within the root canal system, and that PDT, if further enhanced by technical improvements, holds substantial promise as an adjunct to CMD.	n/a	Twenty-six teeth with 49 canals received chemomechanical debridement (CMD) with 6% NaOCl, and 26 teeth with 52 canals received CMD plus PDT. For PDT, root canal systems were incubated with methylene blue (MB) at concentration of 50 μg/mL for 5 minutes, followed by exposure to red light at 665 nm with an energy fluence of 30 J/cm(2).	n/a
Rios, Alejandro He, Jianing Glickman, Gerald N Spears, Robert Schneiderman, Emet D Honeyman, Allen L	Evaluation of photodynamic therapy using a light-emitting diode lamp against Enterococcus faecalis in extracted human teeth. Journal of	Quantitative study	In vitro study	The aim of this study was to evaluate the antimicrobial effect of PDT using toluidine blue O (TBO) and a low-energy	Single-rooted extracted teeth	n/a	PDT using TBO and a LED lamp has the potential to be used as an adjunctive antimicrobial procedure in	n/a	n/a	2 weeks

	endodontics.2011			light-emitting diode (LED) lamp after the conventional disinfection protocol of 6% NaOCl.			conventional endodontic therapy.			

Rödig, Tina Endres, Sarah Konietschke, Frank Zimmermann, Ortrud Sydow, Hans Georg Wiegand, Annette	**Effect of fiber insertion depth on antibacterial efficacy of photodynamic-+` therapy against Enterococcus faecalis in rootcanals. Clinical oral investigations.2017**	**Quantitative study**	**In vitro study**	**This in vitro study evaluated the effect of fiber insertion depth on antimicrobial efficacy of antimicrobial photodynamic therapy (aPDT) using a photosensitizer (PS; toluidine blue) and a red light-emitting diode (LED) in root canals infected with Enterococcus faecalis.**	**Single-rooted extracted teeth**	**N=10**	**aPDT reduced E. faecalis within the root canal, whereas fiber insertion depth had a negligible influence on antimicrobial effectiveness of aPDT**	**n/a**	**Roots were randomly divided into four experimental groups: PS only, LED only, aPDT with LED in the apical third, aPDT with LED in the coronal third, as well as into infection and sterile controls (each n = 10).**	**72 hours**

Rabello, Diego G D	**Does supplemental photodynamic therapy**	**Quantitative study**	**In vivo**	**To evaluate the effectiveness of**	**n/a**	**N=12**	**The photodynamic therapy optimized**	**n/a**	**Chemo-mechanical preparation (CMP) was**	**n/a**

Corazza, Bruna J M Ferreira, Luciana L Santamaria, Mauro P Gomes, Ana P M Martinho, Frederico C	**optimize the disinfection of bacteria and endotoxins in one-visit and two-visit root canal therapy? A randomized clinical trial. Photodiagnosis and photodynamic therapy.2017**		**study**	**supplemental photodynamic therapy (PDT) in optimizing the removal of bacteria and endotoxins from primarily infected root canals after one-visit and two-visit treatments.**			**the disinfection of bacteria from root canals in one-visit but not for two visit treatment modality with the accomplishment of calcium hydroxide medication. Despite the type of treatment, the supplemental PDT was not effective against endotoxins.**		**performed by using the single-file reciprocating technique+2.5 % NaOCL and a final rinse with 17% EDTA. The photosensitizer agent (methylene blue 0.1mg/mL) was applied to root canals for 60s before application of laser with a potency of 60mW and energy density of 129J/cm(2) for 120s after CMP in the one-visit treatment and after 14-day inter-appointment medication with Ca(OH)(2)+Saline solution (SSL) in the two-visit treatment.**	
Morsy, Dina A Negm, Maged Diab, Alaa Ahmed, Geraldine	Postoperative pain and antibacterial effect of 980 nm diode laser versus conventional endodontic treatment in necrotic teeth with chronic periapical lesions: A	Quantitative study	In vivo study	this study aimed to investigate the ability of the diode laser (DL) to decrease postoperative pain and achieve root canal sterility.	Anterior teeth	N=28	The 980 nm diode laser may be a successful adjunct to conventional endodontic treatment of necrotic cases with chronic periapical lesions in	n/a	The DL group: root canals were irradiated with 200 µm fiber optic at both visits; the control group (Endo): the DL fiber was placed in root canal with no activation	n/a

	randomized control trial. F1000Research. 2018						terms of postoperative pain and root canal disinfection.			
Asnaashari, Mohammad Godiny, Mostafa Azari-Marhabi, Saranaz Tabatabaei, Fahimeh Sadat Barati, Maryam.	Comparison of the Antibacterial Effect of 810 nm Diode Laser and Photodynamic Therapy in Reducing the Microbial Flora of Root Canal in Endodontic Retreatment in Patients With Periradicular Lesions. .Journal of lasers in medical sciences.2016	Quantitative study	In vivo study	The aim of this study was to compare the antibacterial efficacy of diode laser 810nm and photodynamic therapy (PDT) in reducing bacterial microflora in endodontic retreatment of teeth with periradicular lesion	n/a	N=20	PDT and diode laser 810 nm irradiation are effective methods for root canal disinfection. PDT is a suitable alternative for diode laser 810 nm irradiation, because of lower thermal risk on root dentin.	n/a	PDT with methylene blue (MB) and diode laser (810 nm, 0.2 W, 40 seconds) was performed and in the second group diode laser (810 nm, 1.2 W, 30 seconds) was irradiated.	n/a
Granevik Lindström, Maria Wolf, Eva Fransson, Helena	The Antibacterial Effect of Nd:YAG Laser Treatment of Teeth with Apical Periodontitis: A Randomized Controlled Trial. Journal of endodontics.2017	Quantitative study	In vivo study	The aim of this blind, in vivo, randomized controlled trial was to evaluate the antibacterial effect of Nd:YAG laser irradiation in endodontic treatment of single-rooted teeth with apical	n/a	N=22/ n=23	the results failed to verify the hypothesis that Nd:YAG laser irradiation would yield significantly more negative bacterial samples than conventional irrigation with 1% unbuffered sodium	n/a	The teeth in the laser group were instrumented, irrigated with saline, and irradiated with Nd:YAG laser according to a standard protocol. The teeth in the control group were similarly instrumented but irrigated with 1% unbuffered sodium hypochlorite	n/a

				periodontitis			hypochlorite solution.		and 15% EDTA solution.	
Jurič, Ivona Bago Plečko, Vanda Pandurić, Dragana Gabrić Anić, Ivica	The antimicrobial effectiveness of photodynamic therapy used as an addition to the conventional endodontic re-treatment: A clinical study. Photodiagnosis and Photodynamic Therapy.2014	Quantitative study	In vivo study	The purpose of the study was to evaluate the efficacy of antimicrobial photodynamic therapy (aPDT) used as an adjunct to the endodontic re-treatment in the eradication of microorganisms from previously filled root canals	Anterior teeth	N=21	The results indicated that the aPDT used as an adjunct to the conventional endodontic therapy achieved a significant further reduction of intracanal microbial load.	n/a	the root canals were irrigated with 2.5% sodium hypochlorite (NaOCl), and the final irrigation protocol included 17% ethylenediaminetetraacetic acid followed by NaOCl. Root canals were filled with a phenothiazinium chloride and irradiated with a diode laser (λ=660nm, 100mW) for 1min	n/a
Tennert, Christian Feldmann, Katharina Haamann, Edwina Al-Ahmad, Ali Follo, Marie Wrbas, Karl-Thomas Hellwig, Elmar	Effect of photodynamic therapy (PDT) on Enterococcus faecalis biofilm in experimental primary and secondary endodontic infections. BMC oral health.2014	Quantitative study	In vivo study	To determine the antibacterial effect of photodynamic Therapy on Enterococcus faecalis (E. faecalis) biofilms in experimentally infected human root canals in primary infections and endodontic	One hundred and sixty single-rooted extracted teeth with one root canal	N=10	Photodynamic therapy killed E. faecalis in experimental primary endodontic infections and retreated human root canals. PDT is an effective supplement in root canal disinfection, especially in endodontic retreatments.	n/a	In the PDT group the teeth were treated using PDT, consisting of the photosensitizer toluidine blue and the PDT light source at 635 nm. In the NaOCl (sodium hypochlorite) group the root canals were rinsed with 10 mL of 3% NaOCl. In the NaOCl-PDT group the root canals were	n/a

Altenburger, Markus J				retreatments					rinsed with 10 mL of 3% of sodium hypochlorite and then treated with PDT	
Pourhajibagher, Maryam Ghorbanzadeh, Roghayeh Parker, Steven Chiniforush, Nasim Bahador, Abbas	The evaluation of cultivable microbiota profile in patients with secondary endodontic infection before and after photo-activated disinfection. Photodiagnosis and photodynamic therapy.2017	Quantitative study	In vivo study	In this study, we evaluated the effect of PAD on diversity and count of microbiota related to secondary/persistent endodontic infections.	n/a	n/a	TBO-PAD is an effective approach that exhibited anti-microbial potential activity against microbiota involved in secondary/persistent endodontic infection.	n/a	PAD was performed on teeth with toluidine blue O (TBO) in combination with diode laser	n/a
Sonarkar, Snehal S Singh, Shishir Podar, Rajesh Kulkarni, Gaurav Purba, Rucheet	An in vivo comparison of the antibacterial efficacy of photoactivated disinfection, diode laser, and 5% sodium hypochlorite in root canal disinfection. Journal of conservative dentistry : JCD.2018	Quantitative study	In vivo study	n/a	Thirty-two patients	n/a	PAD, diode laser, and 5% NaOCl showed antibacterial action against aerobic and anaerobic bacteria.	n/a	four groups (photoactivated disinfection [PAD], diode laser, 5% sodium hypochlorite [NaOCl], and normal saline). The treatment was done according to groups, following manufacturer's instructions	n/a
Romeo, Umberto Palaia, Gaspare Nardo, Alessia Tenore, Gianluca	Effectiveness of KTP laser versus 980 nm diode laser to kill Enterococcus faecalis in biofilms developed in	Quantitative study	In vivo study	This study aimed to evaluate the antibacterial action of KTP (potassium-titanyl-	Fifty-six dental roots with single	n/a	This study confirms that laser systems can provide an additional aid in	n/a	Laser parameters were as follows: power 2.5 W, Ton 35 ms, Toff 50 ms (KTP laser); power 2.5 W, Ton 30	72 hours

Telesca, Vito Kornblit, Roly Del Vecchio, Alessandro Frioni, Alessandra Valenti, Piera Berlutti, Francesca	experimentally infected root canals. Australian endodontic journal : the journal of the Australian Society of Endodontology Inc.2015			phosphate) laser irradiations (compared with 980 nm diode laser), associated with conventional endodontic procedures, on Enterococcus faecalis biofilms	canals		endodontic disinfection.		ms, Toff 30 ms (980 nm diode laser)	
Mashalkar, Shailendra Pawar, Mansing G Kolhe, Swapnil Jain, Deepak T	Comparative evaluation of root canal disinfection by conventional method and laser: an in vivo study. Nigerian journal of clinical practice.2014	Quantitative study	In vivo study	The aim of this study was to comparatively evaluate in vivo the disinfecting ability of conventional method and lasers in root canals.	60 single rooted teeth	n/a	Conventional method by using sodium hypochlorite and hydrogen peroxide as irrigating solutions is highly effective in disinfecting the root canal. Lasers when used can also reduce the bacterial load of the infected root canal.	n/a	The teeth in Group A were subjected to biomechanical preparation followed by the treatment with the help of diode laser containing the gallium aluminum and arsenic, which emitted 980 nm wavelengths. The teeth in Group B were treated with routine method of biomechanical preparation along with irrigation using sodium hypochlorite and hydrogen peroxide	n/a
Licata, M E	Effectiveness of a new method of disinfecting	Quantitative study	In vivo	The aim of this in vitro study was	52 single-	n/a	The results indicated a bactericidal	n/a	In all groups, teeth were chemically	n/a

Albanese, A Campisi, G Geraci, D M Russo, R Gallina, G	the root canal, using Er, Cr:YSGG laser to kill Enterococcus faecalis in an infected tooth model. Lasers in medical science.2015		study	to determine the effectiveness of the erbium, chromium:yttrium scandium gallium garnet (Er, Cr:YSGG) laser by measuring its bactericidal effect inside the root canal experimentally colonized with Enterococcus faecalis	rooted extracted human teeth		effect of Er, Cr:YSGG laser irradiation at the settings used in this study. The highest bactericidal effect of this laser was observed at 60 s of irradiation time, using an energy pulse of 75 mJ.		irrigated with 5.25% sodium hypochlorite and 17% ethylenediaminetetraacetic acid. Groups 1 and 2 were also irradiated at 30 and 60 s, respectively, with an Er, Cr:YSGG laser at 75 mJ. Teeth of group 3 were treated with laser for 60 s at 25 mJ.	
Lageman n, Manfred George, Roy Chai, Lei Walsh, Laurence J	Activation of ethylenediaminetetraacetic acid by a 940 nm diode laser for enhanced removal of smear layer. Australian endodontic journal : the journal of the Australian Society of Endodontology Inc.2014	Quantitative study	In vivo study	This study evaluated the efficiency of EDTAC activation using a near-infrared-pulsed 940 nm laser delivered by plain fibre tips into 15% EDTAC or 3% hydrogen peroxide	4 groups of 10 single roots	n/a	Lasing EDTAC considerably improved smear layer removal, while lasing into peroxide gave minimal smear layer removal. The laser protocol used was more effective for smear layer removal than the 'gold	lasers may also provide a benefit through photothermal disinfection. Further research is needed to optimise irrigant activation protoco	laser treatment (80 mJ pulse(-1), 50 Hz, 6 cycles of 10 s),	n/a

							standard' protocol using EDTAC with sodium hypochlorite (NaOCl).	ls using near-infrared diode lasers of other wavelengths.		
Kalyoncuoğlu, Elif Demiryürek, Ebru Özsezer	A comparative scanning electron microscopy evaluation of smear layer removal from teeth with different irrigation solutions and lasers. Microscopy and microanalysis : the official journal of Microscopy Society of America, Microbeam Analysis Society, Microscopical Society of Canada.2013	Quantitative study	In vivo study	The aim of this study was to evaluate the efficacy of smear layer removal from teeth following root canals using lasers (Er:YAG and Nd:YAG), NaOCl, 17% EDTA, and MTAD by scanning electron microscopy (SEM)	n/a	n/a	Although improvement was observed in removal of the smear layer using alternative materials and techniques, application of a combination of EDTA and NaOCl remains an effective technique.	n/a	canals were irrigated with 5.25% NaOCl (Group 1, control), 17% EDTA (Group 2), or BioPure MTAD (Group 3). Laser groups were irradiated with Er:YAG laser (1.8 W, 120 mJ, 15 Hz) (Group 4) or Nd:YAG laser (1 W, 100 mJ, 15 Hz) (Group 5).	n/a

Vendramini, Yasmin Salles, Alexandre Portella, Fernando Freitas	**Antimicrobial effect of photodynamic therapy on intracanal biofilm: a systematic review of in vitro studies.**	**Qualitative study**	**n/a**	**to analyze the antimicrobial effect of PDT on intracanal biofilm.**	**n/a**	**n/a**	**PDT reduced bacterial counts in most studies, especially when used as an**	**n/a**	**Two reviewers conducted a literature search in PubMed, MEDLINE, Lilacs, SciELO, EMBASE and Google Scholar**	**n/a**

Brew, Myrian Camara Steier, Liviu de Figueiredo, José Antonio Poli Bavaresco, Caren Serra	**Photodiagnosis and photodynamic therapy.2020**						**adjunct to the conventional endodontic technique to treat refractory infection. However, PDT effects on in vitro bacterial biofilm were not accurately quantified because of the numerous biases in the studies reviewed.**		**using the following search strategy: photochemotherapy "[Mesh] OR (photodynamic therapy) AND" dental plaque "[Mesh] OR (dental biofilm) AND (root canal)**	
Lane, Jonathan Bonsor, Stephen	Survival rates of teeth treated with bacterial photo-dynamic therapy during disinfection of the root canal system. British dental journal.2019	Qualitative study	In vivo study	To ascertain the survival of teeth having undergone root canal therapy, when bacterial photo-dynamic therapy (bacterial PDT) was used as an adjunct during root canal system disinfection	n/a	n/a	The effectiveness of conventional chemo-mechanical disinfection of the root canal system may be enhanced by the adjunctive use of bacterial PDT, particularly in reRCT cases.	n/a	n/a	n/a
Trindade, Alessandra Cesar	Photodynamic therapy in endodontics: a literature	Qualitative study	n/a	to summarize the results of research	n/a	n/a	most of these studies were not	Data suggest the need for protocol	A review of pertinent literature was conducted	n/a

De Figueiredo, José Antônio Poli Steier, Liviu Weber, João Batista Blessmann	review. Photomedicine and laser surgery.2015			on photodynamic therapy in endodontics published in peer-reviewed journals.			able to confirm a significant improvement in root canal disinfection for photodynamic therapy as a substitute for current disinfection methods. Its indication as an excellent adjunct to conventional endodontic therapy is well documented	adjustments or new photosensitizer formulations to enhance photodynamic therapy predictability in endodontics.	using the PubMed database, and data obtained were categorized into sections in terms of relevant topics	
Singh, Shipra Nagpal, Rajni Manuja, Naveen Tyagi, Sashi Prabha	Photodynamic therapy: An adjunct to conventional root canal disinfection strategies. Australian endodontic journal : the journal of the Australian Society of Endodontology Inc.2015	Qualitative study	n/a	This paper explores the novel photodynamic therapy (PDT) for antimicrobial disinfection of root canals.	n/a	n/a	n/a	n/a	n/a	n/a
Sin, Jonathan Hong-Man Walsh, Laurence J	Evaluation of effectiveness of photosensitizers used in laser endodontics	Qualitative study	n/a	to investigate the effectiveness of photosensitizers used in	n/a	n/a	Photo-activated disinfection using tolonium chloride or methylene	More studies are needed to assess the performance of newer photosensiti	A comprehensive literature search is conducted to identify in vitro and in vivo	n/a

Figueredo, Carlos Marcelo George, Roy	disinfection: A systematic review. Translational Biophotonics. 2020			laser endodontics disinfection			blue can be an effective adjunct to conventional root canal therapy.	zers to optimize photo-activated disinfection of the complex root canal space.	studies involving photo-activated disinfection in endodontic treatment. Publications are selected based on predetermined eligibility criteria.	
Siddiqui, Shoaib Haider Awan, Kamran Habib Javed, Fawad	Bactericidal efficacy of photodynamic therapy against Enterococcus faecalis in infected root canals: A systematic literature review. Photodiagnosis and Photodynamic Therapy.2013	Qualitative study	n/a	The aim was to review the bactericidal efficacy of photodynamic therapy (PDT) against Enterococcus faecalis (E. faecalis) in infected root canals	n/a	n/a	Efficacy of PDT in eliminating E. faecalis from infected root canals remains questionable.	n/a	PubMed/Medline and Google-Scholar databases were searched from 1985 up to August 2013 using various combinations of the following key words: “antibacterial; “bactericidal; “endodontic; “root canal” and “photodynamic therapy”	n/a
Pourhajibagher, Maryam Bahador, Abbas. **.**	Adjunctive antimicrobial photodynamic therapy to conventional chemo-mechanical debridement of infected root canal systems: A systematic review and meta-analysis. Photodiagnosis and	Qualitative study	n/a	To investigate the efficacy of antimicrobial photodynamic therapy (aPDT) adjunctive to conventional chemo-mechanical debridement of root canal	n/a	n/a	Although the aPDT parameters may vary from one RCT to the next, all studies found a reduction in microbial load with adjunctive use of aPDT	further high-quality RCTs focused on the standardized aPDT parameters are needed.	Two independent reviewers performed an extensive literature search on electronic databases of MEDLINE, EMBASE, and SCOPUS up to January 2019. The search strategy was done from the following	n/a

	photodynamic therapy.2019			system in patients with endodontic infections					terms: antimicrobial photodynamic therapy OR photo-activated disinfection AND root canal therapy OR endodontic therapy OR root canal infection OR endodontic infection.	
Plotino, G Grande, N M Mercade, M	Photodynamic therapy in endodontics. International endodontic journal.2019	Qualitative study	n/a	to review the existing literature on PDT in the endodontic field regarding its mechanism of action, photosensitizers and light sources, limitations and clinical procedures.	n/a	n/a	Although positive results have been demonstrated in vitro, there are considerably fewer in vivo investigations	more in vivo studies are needed on the use of antimicrobial PDT in root canal treatment	n/a	n/a
Mohammadi, Zahed Jafarzadeh, Hamid Shalavi, Sousan Palazzi, Flavio	Recent Advances in Root Canal Disinfection: A Review. Iranian endodontic journal.2017	Qualitative study	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Jurič, Ivona Bago Anić, Ivica.	The Use of Lasers in Disinfection and Cleanliness of Root Canals: a Review. .Acta stomatologica Croatica.2014	Qualitative study	n/a	reviews the literature covering the effect of Er:YAG, Er,Cr:YSGG, Nd:YAG and diode laser on the root canal wall in	n/a	n/a	Certain lasers can help in removing the smear layer and debris and can modify the morphology	n/a	n/a	n/a

				the removal of smear layer and against intracanal bacteria.			of the root canal wall.			
Fransson, H Larsson, K M Wolf, E.	Efficacy of lasers as an adjunct to chemo-mechanical disinfection of infected root canals: a systematic review. .International endodontic journal.2013	Qualitative study	n/a	to evaluate the efficacy of various types of lasers used as an adjunct to chemo-mechanical disinfection of infected root canals with the outcome measures 'normal periapical condition' or 'reduction of microbial load'.	n/a	n/a	The evidence grade for whether lasers can be recommended as an adjunct to chemo-mechanical disinfection of infected root canals was insufficient.	need for future high-quality studies.	PubMed, CENTRAL and ISI Web of Knowledge literature searches with specific indexing terms and a subsequent hand search were made with stated limits and criteria	n/a
Chrepa, Vanessa Kotsakis, Georgios A. Pagonis, Tom C. Hargreaves, Kenneth M.	The Effect of Photodynamic Therapy in Root Canal Disinfection: A Systematic Review. Journal of Endodontics.2014	Qualitative study	n/a	to investigate the effect of PDT on bacterial load reduction during root canal disinfection.	n/a	n/a	All included studies showed a positive effect of PDT in the reduction of microbial load in root canal treatment ranging from 91.3%–100%.	If supported by future clinical research, PDT may have efficacy for additional root canal disinfection, especially in the presence of multi–drug-resistant bacteria.	Two reviewers independently conducted a comprehensive literature search using a combination of medical subject heading terms and key words to identify studies relevant to the Population Intervention Control Outcome question.	n/a

Chiniforush, Nasim Pourhajibagher, Maryam Shahabi, Sima Kosarieh, Emad Bahador, Abbas	Can Antimicrobial Photodynamic Therapy (aPDT) Enhance the Endodontic Treatment? Journal of lasers in medical sciences.2016	Qualitative study	n/a	To evaluate reports in the scientific literature that used different photosensitizers (PSs) for bacterial reduction	n/a	n/a	it was concluded that aPDT should be applied in combination with conventional mechanical debridement and irrigants	n/a	The literature search was conducted using databases including PubMed, Scopus, and Google Scholar with the keywords "photodynamic therapy," "antimicrobial photodynamic therapy," or "photoactivated disinfection" and "endodontic," "Enterococcus faecalis," or "root canal treatment," from 2000 to 2015	n/a
Chiniforush, Nasim Pourhajibagher, Maryam Shahabi, Sima Bahador, Abbas	Clinical Approach of High Technology Techniques for Control and Elimination of Endodontic Microbiota. Journal of lasers in medical sciences.2015	Qualitative study	n/a	to review the endodontic microbiota and their respective virulence attributes, as well as perform a literature review of the effects of disinfection procedures in the treatment of endodontic infections to	n/a	n/a	n/a	n/a	n/a	n/a

				gain best practices.						
Bordea, Ioana Roxana Hanna, Reem Chiniforush, Nasim Grădinaru, Elena Câmpian, Radu Septimiu Sîrbu, Adina Amaroli, Andrea Benedicenti, Stefano	Evaluation of the outcome of various laser therapy applications in root canal disinfection: A systematic review. Photodiagnosis and photodynamic therapy.2020	Qualitative study	n/a	to evalaute the outcome of root canal disinfection in relation to the efficacy of various treatment modalities.	n/a	n/a	Study concluded that the combination of aPDT with antimicrobial irrigants could provide a synergetic effect.	authors suggest further validated approaches to achieve optimal outcomes.	The electronic databases PubMed was searched from January 2013-January 2019. The search terms utilised various combinations as follows: photodynamic therapy or antimicrobial photodynamic therapy or photoactivated disinfection or light activated disinfection or laser activated disinfection or laser therapy, and endodontic	n/a
Asnaashari, Mohammad Safavi, Nassimeh	Disinfection of Contaminated Canals by Different Laser Wavelengths, while Performing Root Canal Therapy. Journal of lasers in medical sciences.2013	Qualitative study	n/a	n/a	n/a	n/a	use of laser energy can improve success rate of root canal treatments.	n/a	n/a	n/a
Arneiro, Ricardo A S Nakano, Ryan D Antunes, Lívia A A	Efficacy of antimicrobial photodynamic therapy for root canals infected with	Qualitative study	n/a	we compare the performance of photodynamic therapy	n/a	n/a	PDT had a better antimicrobial effect when used as an	n/a	Relevant studies were identified by searching electronic databases,	n/a

Ferreira, Gustavo B Fontes, Karla B F C Antunes, Leonardo S	Enterococcus faecalis.Journal of Oral Science,2014.			(PDT) and sodium hypochlorite (NaOCl) in reducing the amount of Enterococcus faecalis in root canals.			adjuvant endodontic treatment to NaOCl		including Web of Science, PubMed, BVS (Medline, Scielo, Lilacs and BBO), Scopus, and Cochrane, and by manually searching the references of identified studies. The terms used in the literature search were "photodynamic therapy" and "Enterococcus faecalis"	
Ali, Islam A Abdelaziz Neelakantan, Prasanna	Light Activated Disinfection in Root Canal Treatment-A Focused Review.Dentistry General,2018	Qualitative study	n/a	to systematically review the literature to evaluate the effect of LAD on dual and multispecies biofilms and demonstrate the antibiofilm effect of LAD	n/a	n/a	LAD alone may be unable to eradicate dual and multispecies biofilms, but it may enhance the effect of conventional canal debridement strategies. Novel formulations of photosensitizers with nanoparticles showed the potential to inhibit biofilm formation and/or	n/a	Two databases (PubMed and Scopus) were searched to identify eligible studies using a combination of key words.	n/a

							disrupt the biofilm architecture .			