THE FUTURE OF ENDODONTICS. A SYSTEMATIC REVIEW

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ABSTRACT

Aim of the study The main objective of this paper is to perform an updated literature review of future endodontics trends based on the available up-to-date scientific literature to identify and describe the new techniques, new materials and their benefits or their limitations. **Material and methods** Electronic databases (PubMed, Wiley Online Library, Google Scholar and Web of Science) were used to perform a literature search from 2018 to 2023 using MESH terms: Endodontics, Artificial Intelligence, Lasers. After discarding duplicates, out of 1283 results, a total of 18 articles were eligible and point out how endodontic protocol may change with the onset of new technologies and procedures. **Results** Nanoparticle, laser, regenerative treatment, guided endodontics and artificial intelligence **are the main areas that shown promising results in endodontic treatment**. New materials with biological capacities will improve the long-term results. Overall, endodontic treatment tends to became more precise and the complications can be reduced. **Conclusions** Endodontics will see many exciting developments over the coming years, some incremental, others paradigm shifting.

Key words: Endodontics, AI, Lasers, Guided Dentistry

INTRODUCTION

To understand current endodontic place in the timeline of history, it is important to look to the future, to see where the specialty may be heading in the coming decades. It is for this reason we are undertaking a systematic review on the future of endodontics. It will be beneficial to see where endodontic protocols may take a step forward, where they may leap ahead and where they may, perhaps, need to turn back completely. By synthesising all the latest research and information regarding the future of endodontics, this review should remind all clinicians that we are not at the finish line of endodontic history; rather we are just another date on its timeline.

Magnifying glasses, microscopes, and CBCT can be used for better guidance, but it is difficult for the operator—especially a novice—to interpret the CBCT images, create a mental guide, and at the same time perform the treatment manually. Guided endodontics (GE), which is based on the use of endodontic treatment planning with the help of computer technology, emerged to solve these problems. Thus, the risk of perforations and other iatrogenic complications is reduced by creating a specific pathway for root canal access and instrumentation [1,2].

OBJECTIVES

The objective of this systematic review is to collate and analyse the future trends within the field of endodontics. This

systematic review will look at all the relevant literature to see how endodontic protocol may change with the onset of new technologies and techniques.

MATERIALS AND METHODS

A search was performed in the biomedical databases PubMed, Wiley Online Library, Google Scholar and Web of Science for available literature from 2018 to 2023 using the following keywords: Endodontics, AI, Lasers, Guided Dentistry.Duplicates were discarded. Then, the titles and abstracts were manually reviewed, and those articles that did not meet the inclusion criteria were excluded. Subsequently, the remaining articles were read in full, and those that dealt with a topic other than that of interest to this literature review were excluded.

Search Strategy

The present study is designed as a systematic review based on PRISMA 2020 criteria. (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Included articles and studies are the result of a thorough literature search on all topics related to the future of endodontics. The main database used is PubMed. The time frame of the search is between spring 2018 to spring 2023, when the search was conducted. Relevant articles are collated and analysed after inclusion/ exclusion criteria has been applied.

Inclusion criteria

Articles were included according to the following criteria:

Free Full Text

Articles including information regarding future trends within endodontics.

Articles including current cutting-edge technology being used within endodontics, not yet widely adopted.

Articles no older than 5 years

English

Human research

Exclusion criteria

Articles were excluded according to the following criteria:

Articles not relevant to the topic

Articles older than 5 years

Duplicate articles

Articles not from accredited sources

Articles containing relevant information to a future trend, but not specific to a definite endodontic technique/ system/ tool.

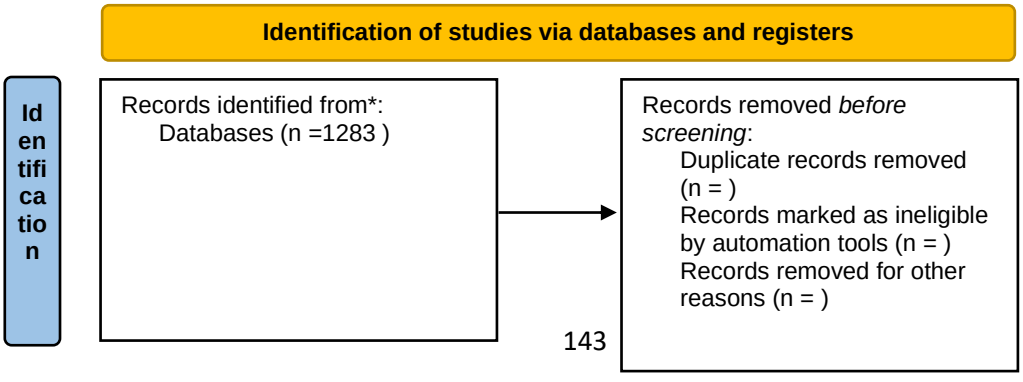
Articles containing valid information, but of small significance towards the overall topic of discussion.

Articles containing information already covered adequately in other articles.

Research on animals

Results

Once the bibliographic research was carried out, 1283 articles were obtained from the different databases (PubMed, Wiley Online Library, Google Scholar and Web of Science), which were transferred to the Mendeley Desktop reference manager software in order to facilitate their organization and storage, as well as to discard duplicates and select only those from the last 5 years. A total of 1151 articles were obtained. Subsequently, their titles and abstracts were read, and 132 articles were eligible. Finally, the remaining articles were read entirely, resulting in the 18 studies that were included in this literature review (Figure 1).



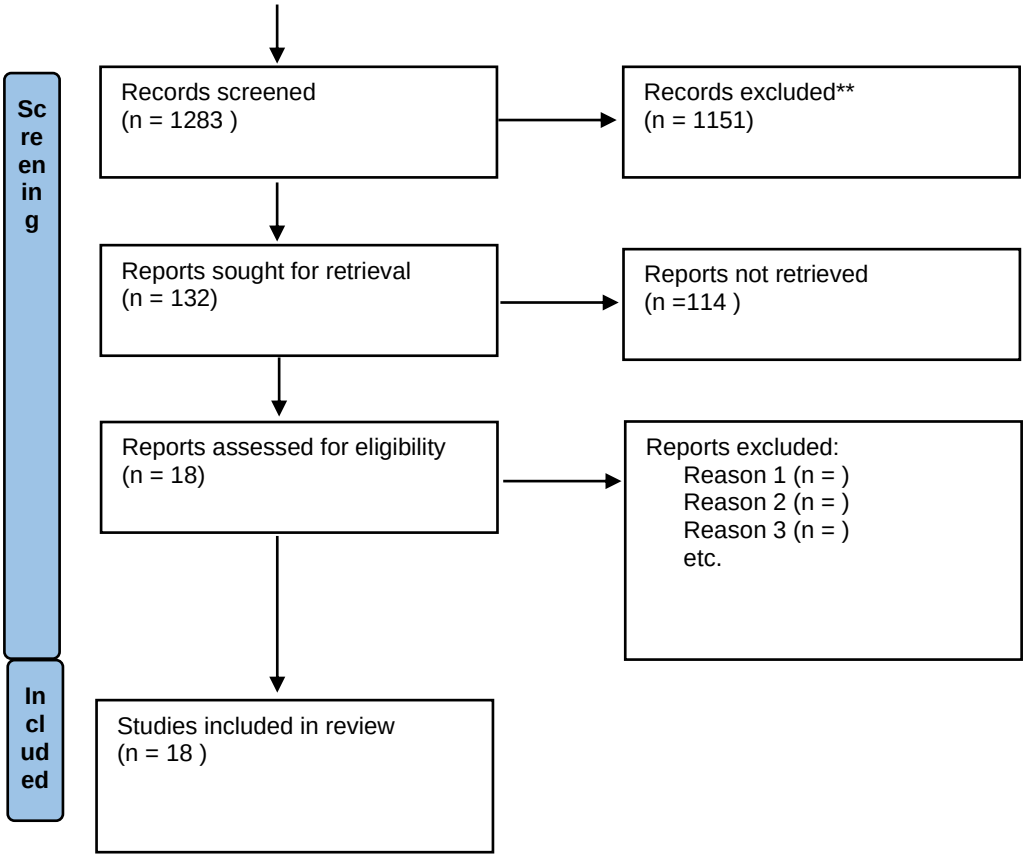


Figure 1. Study selection Flowchart

Data Extraction/ Results

Table I. Study selection article

Author/Year/Reference	**Future trend identified**	**Future protocol**	**Existing protocol**
Ronald Ordinola Zapata et al, 2022[1]	New Intra-canal medicaments	AMPS & Nanoparticles	Calcium hydroxide, biodentine, MTA
Wenjing Song et al, 2019[2]	Intra-canal medicaments	Nanoparticles	Calcium hydroxide, biodentine, MTA
Shunli Chu et al, 2021[3]	Intra-canal medicaments	Chitosan nanoparticles	Calcium hydroxide, biodentine, MTA

Qin Huang et al, 2023[4]	Laser guided endodontics	Canal shaping, dental pain, dentinal hypersensitivity, vital pulp therapy, fiber post surface treatment.	Conventional methods
Dina A. Morsy et al, 2018[5]	Laser therapy in endodontics	Disinfection; pain control	Irrigants; shaping and irrigating, drugs
Marcella Yasmin Reis Guerreiro et al, 2021[6]	Laser for pain therapy in endodontics	Pain therapy	Shaping and irrigating, drugs
Paridhi Agrawal et al, 2022[7]	Artificial intelligence	Working length determination, Root canal morphology, Root Fracture detection, Periapical lesion detection	Radiographs, CBCT data, clinical examination
F. Schwendicke et al, 2020[8]	Artificial Intelligence	Neural networks for diagnosis, treatment planning using analysis of radiographs	Clinical judgement of clinicians
T. Shan et al, 2020[9]	Artificial intelligence	Diagnosis and treatment planning in endodontics	Clinical judgement of clinicians
Sanjeev B. Khanagar, 2020[10]	Artificial intelligence	Detection of teeth; detection of caries; detection of working length; vertical root fractures;	Conventional methods
Paras Ahmed et al, 2021[11]	Dental Robots	Handing instruments during endodontic procedures; disrupting oral biofilm in root canal.	Dental assistants, normal endodontic protocols
Thomas Connert et al, 2022[12]	Guided endodontics for calcified canals	Increased range of drills (diameter & length); use of MRI in treatment planning stage; digital planning of treatment stages for all systems; Augmented reality application to overlay pathways when treating canals.	Conventional endodontic protocol

Manoj Kumar Pulyodan, 2020[13]	Regenerative endodontics	Regeneration of dental pulp using stem cells, biological scaffolding,	Pulp removal/ Pulp repair
Matthias Widbiller, 2020[14]	Regenerative endodontics	Regeneration of pulp using stem cells	Pulp removal/ Pulp repair
Zhuo Xie, 2021[15]	Regenerative endodontics	Regeneration of pulp using stem cells	Pulp removal/ Pulp repair
Tiago Reis et al, 2022[16]	3D printed teeth for Endodontic treatment practise	Production and use of printed teeth for all stages of endodontic treatment	Use of extracted teeth
Jingang Jiang et al, 2022[17]	Advancement in root canal files	Various improvements in material, function and structure	Existing root canal files
Ana Arias et al, 2021[18]	Canal Shaping	Universal standards for manufactured instruments, to prevent inferior quality copies entering the market, also to push actual innovation of future instruments	None

Selection process: three authors (A.S.P., H.U.C., A.M.) screened titles independently and compared their findings. Study selection was assessed independently by two authors (A.S.P., H.U.C.,), who performed the assessment of titles and/or abstracts of retrieved studies. In cases of disagreement, studies were included after consensus was reached through discussion between the 2 mentioned authors and a third author (A.S.P., H.U.C., A.M).

Discussions

Intra-canal medicaments are used in conjunction with normal endodontic protocols as a means to prevent or cure apical periodontitis. One of the most promising are anti-microbial peptides, or AMPs. AMPs have a good biocompatibility, low microbial resistance and, importantly, high anti-microbial potency. When tested against conventional calcium hydroxide, AMPs have shown to have an increased ability in removing biofilms. Significantly, AMPs have also shown an increased ability in eradicating E.Faecalis, a strain of bacteria found commonly in secondary endodontic infections.[3]

Nanoparticles are another promising innovation within the field of intracanal medicaments. Composed of metal, polymers or even ceramic, nanoparticles are commonly used as additives to calcium hydroxide, to enhance its anti-microbial efficacy. Silver nanoparticles have been the most studied for their efficacy against E. faecalis, due to their broad-spectrum anti-microbial properties. Chitosan nanoparticles are a type of polymeric nanoparticle, which can be used directly as anti-microbial agents, or as biodegradable nanocarriers for antimicrobial drugs. Ceramic nanoparticles are also able to act as nanocarriers for antimicrobial drugs, such as mesoporous calcium silicate nanoparticles. As innovation and refinement continues, nanoparticles will be a likely candidate for adoption as a key intra-canal medicament of the future.[4,5]

Laser guided endodontics is an exciting avenue of exploration when considering the future of endodontics; in improving on

and even replacing current endodontic protocols.[6]

Studies have proven the efficacy of Er:YAG lasers in shaping root canals via dental hard tissue ablation, dental tubule opening and smear layer removal. By reducing the risk of dentine suture formation, ER:YAG lasers can also help reduce the risk of root fractures. Similarly, Nd:YAG lasers have also proven their effectiveness in root canal shaping; studies have shown the increased effectiveness of root canal shaping when combining Ni-Ti instruments with Nd:YAG lasers, when compared with only Ni-Ti instruments, or lasers alone.[6]

Positive research has been published regarding the effects of lasers on enhancing the lifespan of fibre posts in endodontically treated teeth. A major cause of fibre post failure is debonding which occurs between fibre posts and their corresponding root canals. Roughening fibre post surfaces via laser irradiation is one possible solution to this problem. Research has shown that glass fibre posts pre-treated with Er,Cr:YSGG lasers significantly improve their push-out bond strength. Pre-treated quartz fibre posts also see an improvement in push-out bond strength with both Er,Cr:YSGG and Er:YAG lasers.[6,7]

Lasers are able to reach bacteria in deeper layers of dentine, eliminating them without harming surrounding tooth structure. Lasers have also been found to reduce pain-inducing substances such as: dopamine, histamine, prostaglandins and substance P; at the same time, they have also been shown to stimulate: anti-inflammatory prostaglandins, beta-endorphins, immunoglobulins, lymphokines. The effects of lasers could lead to an inhibition of neural activity and a dampening of signals from nociceptors, leading to potentially a significant reduction in pain.[8]

Artificial intelligence shows great promise for the future of all Dentistry work, endodontics included. The aim of AI is to reproduce human intelligence; it has advanced much in the last 10 years, with signs of exponential growth in the next decade. AI can be ‘educated’ with hundreds of thousands of cases, to become more ‘experienced’ than any one clinician. By integrating AI with a Clinician’s own experience, it is certain diagnoses will become more accurate and efficient. [9,10]

Specifically in endodontics, AI can use ‘automated lesion segmentation’, to divide radiographs into multiple non-overlapping regions, to allow for convenient analysis. Radiographs are separated into: lesion, tooth structure, restorative material, background. This allows AI to make diagnosis of peri-apical lesions, as well as proximal lesions comparable to those of clinicians. It is not perfect, however, as it is unable to report important parameters such as volumetric deviation of lesions, affecting the reliability of results.[10,11]

AI has also shown promise in future endodontic treatments, specifically in the field of regenerative endodontics. AI has been shown to accurately predict the viability of dental pulp stem cells under various bacterial lipopolysaccharide concentrations, as well as treatment times. AI has shown, therefore, to be capable of evaluating future regenerative dentistry protocols.[10,11]

AI neural networks have proven to have practical applications during Endodontic treatments; they can determine the working length of root canals to an accuracy of between 96 percent, higher than professional endodontists. They have also shown the ability to locate the minor apical foramen to an accuracy of 93% . With such positive results, it is inevitable neural networks will be used by endodontists in the future.[11,12]

Dental robotics have been successfully utilised in other industries, removing repetitive work from the hands of humans, increasing efficacy, and lowering costs at the same time. Robotics is certain to

disrupt dental medicine, changing the way clinicians diagnose and treat patients. There are many opportunities within the field of dentistry for robotic automation to enhance, or even replace current protocols undertaken by humans. The benefits of robots lie in their ability to free a dental team to focus on more important tasks, be it interacting with patients, or concentrating on high cognitive actions beyond the purview of robotics.[13]

Specifically, within the field of endodontics, a robot assistant has been suggested as an effective use of technology, acting as a vending machine, dispensing root canal instruments when required. The robots could be designed to have a multi-nodal communication model, allowing dentists to connect to robots via speech, visual gestures or a touch screen display. Another possible application of robotics within the field of endodontics is the use of micro-robots to disrupt oral biofilms within root canals, acting as disinfectants. These same micro-robot systems could also be used to prevent dental caries, or even peri-implant infections.[13]

Guided endodontics is a relatively new sub-discipline of endodontics; its purpose is to successfully treat root canal obliterations. Published data shows promising results, with positive implications for the field.[14]

Template guided endodontics is a specific type of guided endodontics. It involves the creation of a template, or sleeve, which is placed over a tooth to help guide instruments to the calcified canal in question. The template will prevent further instrumenting of the root canal beyond the apical target point, via a mechanical stop. CBCT data is used for all virtual planning and creation of the template. The refinement of this technique in the future will involve the availability of a wider range of commercially available drills, both in diameter and length, to allow for more efficacious treatment of varied calcified root canals.[14]

Dynamic navigation is another type of guided endodontics, which allows for real-time navigation of calcified root canals, visualised on monitors. It requires data analysis from CBCT sections, along with an intra-oral surface scan. Reference marks are required before CBCT data is recorded. Future trends for this technique will involve the ability for all systems to digitally plan reference marks using existing CBCT data.[14]

Regenerative endodontics involves the use of stem cells, biomimetic scaffolds and bioactive growth factors to regenerate damaged pulp tissue. Current protocols lead to pulp repair, not regeneration; both are forms of pulp healing, but repair involves the replacement of damaged tissue not able to reproduce the original's biological functions.[15]

The future will see the advent of successful pulp regeneration; this will be achieved with cell-free and cell-based methods. A cell-based approach to regenerative therapy involves the isolation and expansion of stem cells, sourced either allogenically, or from the host. These cells are attached to scaffolds and transplanted into the root canal. Drawbacks to this method include: cost, availability, skill, government regulation and immune rejection; problems which will need to be overcome in the future.[15,16]

Another route for regenerative therapy is the 'cell-free' method. This method involves the use of signalling molecules for the migration, propagation and differentiation of endogenous stem cells. Signalling molecules which have been considered for this approach are: basic fibroblast growth factor, bone morphogenetic protein, nerve growth factor, platelet-derived growth factor, vascular endothelial growth factor. It is not actually known which growth factors are required for successful regenerative

therapy; an issue which needs addressing in the future.[16,17]

Current research suggests that this may be achieved via transplantation of a multi-layered scaffold composite, composed of well-organised stem cells, cytokines and biomaterials. Cell homing could be an effective, simple method to recruit endogenous cells and signalling molecules. Another key challenge in precision medicine is adequate disinfection of the root canal system for successful pulp regeneration to occur. Residual micro-organisms within root canals are a potential source for unsuccessful treatment. More effective disinfection methods must be used, such as nanobubble-enhanced antimicrobial agents, to ensure treatment success; this is especially true in patients suffering with severe periapical lesions.[15,17]

3D printed teeth have the potential of solving the issues of extracted teeth. There will be no problem in acquiring the necessary number of printed teeth for students, with a potential for unlimited printed teeth to practise on. Printable files, with unique patterns beneficial for learning, could also be made available in open-source platforms. Importantly, printed teeth would allow for the possibility of learning standardisation. A tooth with a specific root canal anatomy will be available for practise and assessment for every student within a dental institution.[18]

Advances to **root canal files** will involve changes in the key components of root canal files; their shape, material and function. One of the key problems involves fatigue fracture. Graphene could be a possible solution, with its toughness and flexural strength, as well as its biocompatibility and strength. Other materials showing promise as matrixes, include ceramics, as well as Nitinol powder. Advances in 3-D printing technology, as well a breakthrough in medical grade titanium and nickel-titanium alloy powder will help the innovation of new root canal files.[18]

Innovations in root canal file structure will be achieved via three key future trends: bionic structures, foldable structures, nanostructures. Bionic structures refer to the imitation of structures found in nature to innovate human technology. The second key innovation is that of foldable structures; they can occupy spaces in a unique manner, allowing them to remove necrotic tissue without over-preparing root canals. The final key trend in the innovation of root canal structure is the introduction of nanostructures. This trend is one which is unlikely to be achieved in the near future, as it refers to the replacement of conventional root canal files with nano-robots, able to accurately remove necrotic tissue and bacteria on a miniscule scale. [18]

Innovations in root canal function will help reduce complications during root canal preparation, as well as reduce ‘blind spots’ during treatment. The first innovation will involve the implementation of ‘micro-displays’ within the root canal. By using 3-D display technology, endodontists will be able to see, in real time, the progress of their root canal treatment. This technology will be able to notify clinicians of under-preparations, over-preparations, as well as potential collisions. The second key innovation will involve effective use of previous clinical cases, with innovative artificial intelligence neural network systems.[18,19,20]

Conclusions

1.Endodontics will see many exciting developments over the coming years, some incremental, others paradigm shifting.

2.AMPs and Nanoparticles could herald a new generation of effective intracanal medicaments.

3.. The versatility of lasers, as well as their ever-increasing uses in clinical practise, will certainly pressure market forces to

produce lasers available to all modern dental practises in the future. They will also be used, in conjunction with MTA, to stimulate the apexogenesis process more effectively than MTA alone.

4.A.I will improve diagnostic accuracy and efficacy. AI automated lesion segmentation techniques will allow for computerised diagnosis of peri-apical lesions. AI will also be capable of evaluating future regenerative dentistry protocols.

5.Guided endodontics will see further refinement and evolution in its future, helping move it to a more established, widely adopted sub-speciality within endodontics.

6.Regenerative endodontics is an avenue which will lead to a paradigm shift within the field of dentistry. Pulp tissue will be regenerated using stem cells, biomimetic scaffolds and bioactive growth factors. Regeneration will be achieved using cell-free and cell-based methods.

7.3D printed teeth for use in Dental education will become a reality in the future.

8. Root canal files will continue to improve into the future. The three key components which will be advanced are material, shape and function. Innovations in root canal file structure will be achieved via three key future trends: bionic structures, foldable structures, nanostructure.

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