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Current Practices and Future Perspectives in Endodontics: A Review

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Abstract
Endodontics involves the exploration and application of both fundamental and clinical sciences related to the biology of healthy dental pulp. It also addresses the causes, diagnosis, prevention, and treatment of diseases and injuries affecting the dental pulp, as well as related periradicular conditions. The field of endodontics has seen remarkable advancements over the past ten years, significantly enhancing the quality of dental care provided to patients. Exploring the various facets of endodontic principles while addressing specific challenges can significantly enhance its advancement, particularly with the benefits brought about by innovations in research and technology. At present, research into both cell-free and cell-based approaches for pulp tissue regeneration is still confined to the preclinical stage. The future of pulp tissue regeneration appears promising, rooted in the foundational concepts of stem cell-driven pulp tissue engineering. This article examines the significant advancements poised to transform endodontics, alongside the challenges that, when addressed, could solidify its future trajectory.

Key Words: Bacteria, Endodontics, Pulp Tissue, Root canal

Introduction

Over the past two decades, the field of Endodontics has undergone significant advancements and transformations. Many of these discussions have focused on the technical components of root canal treatment, highlighting innovations in file designs and advancements in devices for root canal fillings. Clinicians may perceive themselves as being more technologically advanced in their practices; however, it is essential to critically evaluate whether this perception translates into improved treatment outcomes for our patients. Or, are we simply utilising various instruments, devices, and potentially materials that can lead to comparable outcomes? What methods can we use to find the answers to these questions? It is essential for the profession to evaluate these aspects and determine if the current methods are suitable and optimal for our patients' well-being.[1,2]

It is essential to priorities the removal of bacteria from the root canal system and the entire tooth during root canal treatment, as pulp and periapical diseases are primarily caused by bacterial infection. In pursuit of this goal, it is essential for clinicians to consider how these outcomes can be realised. They should explore whether utilising a different file is beneficial, if magnification plays a role, and whether the use of medicaments contributes positively to the process. A comprehensive grasp of tooth structure and anatomy, combined with knowledge of microbiology, will empower clinicians to effectively address these enquiries. First, we should examine the biological aspect, and then we can revisit the mechanics.[3-5]

Current Trends in Root Canal Treatment

Root canal treatment is a procedure that entails the careful enlargement of the root canal using specialised instruments. This process includes the application of chemical disinfectants to effectively eliminate any remaining vital or necrotic tissues. Additionally, it aims to eradicate the microbiota present within the root canal system, which involves disrupting the microbial biofilm. Finally, the treatment also focusses on removing any hard tissue debris that accumulates during the instrumentation of the root canal. The primary goal of any disinfection approach in healthcare settings is to lower the bacterial load to a manageable level, enabling the patient's immune system to effectively support the healing process. Root canal treatment is similar in that root canal disinfection is regarded as the cornerstone of this therapy. It is noteworthy that, similar to other areas of the body, the specific threshold that supports optimal health remains unclear. Consequently, endodontic research has concentrated on creating techniques aimed at thoroughly eliminating bacterial biofilm, which represents the ideal objective.[3,4,6]

Microbial biofilms present in the root canal exhibit a significant resistance to the disinfecting agents commonly employed in endodontic treatment. The intricate and variable characteristics of root canal anatomy, along with the presence of diverse biofilms, significantly increase the challenges associated with eliminating microbial accumulations in these areas. This review aims to explore the microbiological characteristics of root canal biofilms, effective clinical strategies for combating these biofilms, and the research methodologies employed to investigate them.[7,8]

Choosing the right root canal irrigants and employing effective irrigation techniques are crucial for the cleaning and disinfection of the root canal system. Biofilms present in the intricate structures of the root canal system harbour bacteria that exhibit significant resistance, making them challenging to eliminate with the irrigants currently at our disposal. Sodium hypochlorite has consistently been the most commonly utilised irrigant for many years. It is important to consider that chelators should be used to enhance the effectiveness of the irrigation. Additionally, various mixtures of active substances and nanoparticles have been tested for this purpose.[9,10]

The use of a syringe and needle for delivering irrigants, along with their sonic or ultrasonic activation, represents the most widely adopted irrigation methods today. Various agitation and activation techniques, including those utilising negative and positive pressure or lasers, are commonly employed and have been studied to improve the effectiveness of debris and biofilm removal from the irregularities of root canals. Regrettably, even with these advancements, there remains a lack of robust scientific evidence indicating that any supplementary irrigation technique can significantly enhance the long-term results of root canal therapy. It is essential to redefine the research priorities and strategies in this field, emphasising multidisciplinary scientific approaches and clinically relevant comparisons.[10-12]

Function of Laser in Endodontics

The use of laser-based technology for accelerating root development and effectively removing broken files and fibre posts is at the forefront of current research studies. With the advancement of lasers, research has shown that laser irradiation can effectively assist in shaping root canal walls and eliminating the smear layer. The way lasers function in root canal shaping involves the process of laser irradiation, which can effectively vaporize water present in dental hard tissues. This action leads to the ablation of the surrounding tissue, resulting in the opening of dentinal tubules and the removal of the smear layer. An in vitro study has shown that the Er:YAG laser is capable of ablating dental hard tissues, opening dentinal tubules, and effectively clearing the smear layer when the distance between the dentin and the tip is minimized. The Er:YAG laser is effective in minimizing the risk of dentine suture formation, which helps in preventing root fractures.[13,14]

Laser-activated irrigation (LAI) has been utilised as a supplementary technique for root canal irrigation for many years. The mechanism of LAI employs fibre tips to create small cavitation bubbles in irrigation solutions. This process leads to volumetric oscillation, which can produce high-speed fluid motion, facilitate the formation of biofilms, and promote the vertical movement of various contents within the root canals. The ongoing rapid movements result in the detachment of materials from the walls of the root canals, ultimately leading to their expulsion from the canals.[15,16]

Limitations Of Lasers

It is important to recognise that LAI has certain limitations, including the potential for increased apical extrusion. The expulsion of debris, pulp tissue, solutions, bacteria, and their byproducts from the apex can contribute to post-operative inflammation and pain, potentially hindering the healing process of periapical tissue. Research has demonstrated that irrigation using the Er:YAG laser or the Nd:YAP laser resulted in a greater amount of debris extrusion compared to traditional needle irrigation methods.[10,17]

Exploring the Role of Regenerative Endodontics and the Application of Stem Cells

Regenerative endodontics represents a promising and evolving area in the treatment of immature teeth with infected root canals. This approach has been characterised as a significant change in how we manage these cases, potentially leading to ongoing root maturation and the closure of the apex. 'Revitalization' has been proposed as it encompasses the concept of non-specific vital tissue, rather than being limited to blood vessels, which is what the term 'revascularization' suggests. A regenerative endodontic procedure (REPs) is a term that has gained significant traction in the dental community. It encompasses all methods designed to achieve organised repair of the dental pulp, as well as future therapies that are anticipated to develop within the realm of regenerative endodontics.[18,19]

At present, there are two primary methods for pulp tissue regeneration in the field of regenerative endodontics: cell-free and cell-based approaches. Both approaches utilise the principles of tissue engineering, incorporating stem cells, bioactive growth and differentiation factors, along with biomimetic scaffolds. Clinical regenerative endodontic procedures may be viewed as a method that does not rely on cells. The cell-based method involves isolating and expanding stem cells outside the body, which are then placed in a scaffold before being transplanted into the canal space. The cell-free approach offers a more straightforward method compared to the cell-based approach, as it eliminates concerns related to the source and isolation of stem cells. In the cell-free approach, it is important to note that the endogenous stem cells are not specific to pulp tissue; they can originate from sources such as the apical papilla, periodontal ligament, or bone marrow. The cell-based approach utilises specific stem cells derived from pulp tissue, including dental pulp stem cells (DPSCs), stem cells from exfoliated deciduous teeth, and stem cells from apical papilla.[20,21]

Research indicates that these stem cells can differentiate into cells resembling odontoblasts and generate mineralised tissue similar to dentine. This approach holds significant potential for achieving genuine regeneration. However, there are several challenges linked to the cell-based approach that need to be addressed. These include the limited availability of stem cell sources, the processes of isolation and ex vivo expansion of stem cells, the need for good manufacturing practice facilities, concerns about contamination, the establishment of stem cell banks, cost considerations, regulatory hurdles, and the capacity of clinicians to carry out stem cell transplantation.[21]

Currently, both cell-free and cell-based methods for pulp tissue regeneration remain in the preclinical phase of research. Looking ahead, the regeneration of pulp tissue seems to be a feasible objective, grounded in the principles of stem cell-based pulp tissue engineering.

Regenerative endodontics marks a significant advancement in the fields of biological and clinical endodontics. This biologically based treatment is now acknowledged as the primary option for immature teeth experiencing pulp necrosis, supported by numerous successful cases documented in the literature. Our understanding of clinical protocols has progressed to effectively eliminate pulp infection while also enabling the potential for stem cell induction within the canal and facilitating the release of growth factors embedded in the dentine walls. Current protocols primarily facilitate repair instead of genuine regeneration. However, there is optimism that ongoing research in stem cell-based pulp engineering will lead to authentic regeneration and enhanced treatment results.[22]

Role of Artificial Intelligence in Endodontic

The ongoing research into AI models presents several exciting possibilities in endodontics. These applications include the identification of periapical pathosis, assessment of root fractures, measurement of working length, and forecasting treatment outcomes. It is essential to develop these AI models using data sourced from seasoned clinicians to guarantee precision and reliability.[23]

- ***Understanding The Diagnosis Of Periapical Pathologies***

AI segmentation was employed to categorise each voxel into distinct labels such as "periapical lesion", "tooth structure", "bone", "restorative material", or "background". This advanced deep learning AI system demonstrated a remarkable accuracy of 93% in identifying lesions, along with a specificity rate of 88%. In the future, advancements in AI technology may enable the analysis of CBCT scans, potentially assisting clinicians in identifying areas of possible apical pathosis, along with other odontogenic or non-odontogenic lesions that could be present in the imaging results.[24]

- ***Identifying Fractures***

Fukuda et al utilised artificial intelligence to identify VRF on panoramic radiographs, achieving a sensitivity of 75% and a positive predictive value of 93% in their findings. A recent study employing artificial intelligence for this purpose, which analysed both periapical radiographs and CBCT volumes of single-rooted premolar teeth, demonstrated impressive results with a 97% accuracy, 93% sensitivity, and 100% specificity in the accurate diagnosis of vertical root fractures (VRF).[25]

- ***Understanding Root Canal Morphology***

The application of AI has been utilised to assess the morphology of root canals and determine the number of canals present. Hiraiwa et al. employed artificial intelligence on panoramic radiographs and found an impressive 87% accuracy in diagnosing single or multiple distal roots on mandibular first molars. Currently, there are commercial AI software companies like Diagnocat (LLC Diagnocat, Moscow, Russia) that assist practitioners in analysing their patients' CBCTs and identifying the type of root canal morphology present. This technology can automatically segment the teeth and generate 3D Standard Tessellation Language (STL) models, which dentists can utilise for additional analysis through printing.[26]

- ***Establishing the Appropriate Working Length***

AI algorithms are being developed to assist clinicians in identifying the apical terminus on radiographs. In a study utilising a cadaver model to replicate clinical scenarios, Saghiri et al employed artificial intelligence to assess working length measurements. Their findings revealed that AI achieved a remarkable 100% accuracy in determining root length when compared to the actual measurements taken post tooth extraction. The findings indicated that AI successfully identified the minor apical constriction in 96% of cases.[27]

The Role of AI in Predicting Outcomes

The application of AI has shown promise in forecasting specific outcomes related to endodontic treatment. A study conducted by Lee et al. aimed to develop an effective AI-based module designed to facilitate accurate clinical decisions regarding tooth prognosis, while taking into account an optimal treatment plan.[28]

Future Trends in Endodontics

An intriguing field that is attracting increasing attention is the application of AI-enhanced algorithms to develop photorealistic 3D reconstructions of the root canal space, tooth anatomy, and prevalent orofacial lesions. This innovative reconstruction technique is known as cinematic rendering (CR). CR has the capability to generate photorealistic 3D images from CBCT data sets by employing high dynamic range rendering lightmaps, which help establish a natural lighting environment.28 This has the potential to enhance diagnostic accuracy by providing clearer representations of anatomical details.

Role of Robots and Microrobots in Endodontics

In addition to AI-guided robots, the area of AI-guided microrobots presents significant potential within the field of endodontics. Self-propelled micro-robots, or microbots, harness energy from their surroundings to generate mechanical energy. Their active motion enables these tiny entities, often smaller than a pin-head, to enhance their ability to penetrate biofilms. Additionally, they can be guided through augmented reality to effectively deliver disinfectants and medications, as well as provide mechanical functions that facilitate the opening and shaping of infected areas.[29]

Recent studies by Babeer et al. have demonstrated that magnetically actuated 3D moulded microbots can be precisely controlled to target the apical region of the root canal, without interference from the surrounding periodontium. This process is visualised and tracked using CBCT in conjunction with a "augmented reality" protocol.[29]

Conclusion

The collaboration between dental research teams and biomedical engineering holds the potential to significantly transform the field of Endodontics. Significant progress has been made in technological advancements related to materials and equipment. However, there remains a considerable opportunity for further development in the areas of regeneration and enhancing the biocompatibility of materials. This branch of dentistry is fundamental to all other areas, as most interdisciplinary treatment cases consistently necessitate endodontic consultation.

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