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Research Advances in Microscopic Endodontic Therapy for the Treatment of Dental and Endodontic Diseases

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Abstract: *Microscopic Endodontic Therapy (MET) has significantly enhanced the efficacy and predictability of conventional root canal treatment through high-magnification visualization, precise illumination, and refined instrumentation, demonstrating revolutionary advantages in managing complex cases. This article systematically reviews recent advancements in MET technologies and their clinical applications, aiming to provide valuable insights for clinical practice and future research.*

Keywords: *Microscopic Endodontic Therapy (MET), Dental and Endodontic Disease, Clinical application*

Dental and endodontic diseases are common and frequently occurring conditions in oral health [1]. In recent years, their incidence has shown an increasing trend due to factors such as changes in dietary habits, trauma, and iatrogenic injuries [2]. Pulpitis, one of the most prevalent dental and endodontic pathologies, refers to inflammatory reactions in the dental pulp caused by bacterial infection, mechanical trauma, or iatrogenic stimuli. According to the diagnostic criteria proposed by the American Association of Endodontists (AAE) in 2009, "irreversible pulpitis" is defined as an inflamed pulp that cannot recover to a healthy state and requires root canal treatment (RCT) [3]. For the management of irreversible pulpitis in mature permanent teeth, RCT is often the primary treatment strategy [4].

Root canal treatment is currently recognized as the most effective method for treating pulp diseases and periapical diseases worldwide. Correct identification and complete drainage of the root canals are important factors for the success of root canal treatment, and thus, the diversity and complexity of the root canal system have become important factors influencing the success or failure of root canal treatment [5]. During clinical diagnosis and treatment, due to insufficient familiarity with the anatomical morphology of the root canal system, neglecting the possibility of root canal variations, and lacking the awareness of searching for and discovering additional root canals, root canals are often missed, which is one of the common reasons leading to the failure of root canal treatment [6]. Song et al. [7] conducted a microscopic study on 493 root tips after extraction and found that missed root canals accounted for 19.7%, which was the second leading cause of root canal failure. The number and morphology of root canals in teeth have certain patterns, but also have certain variations. Mastering the basic anatomical morphology and common types of variations of the root canal system, being vigilant of differences, correctly identifying the shape and number of root canals before treatment, carefully exploring during the treatment process, especially for the exploration of suspicious locations, having a clear understanding in mind, can maximize the success rate of root canal treatment and prolong the retention time of the affected teeth. Approximately 30%-40% of mandibular anterior teeth and premolars have multiple root canals. Bellizzi et al. found that 16.9% of mandibular central incisors have double root canals [8]. Zhao Ying et al. [9] analyzed the root canal configurations of 4674 anterior teeth using cone-beam computed tomography (CBCT) and found that 6.7% of mandibular central incisors have double root canals. Blaine et al. through literature review and statistics found that 24.2% of mandibular first premolars have multiple root canals[10]. Zhang Dan et al. [11] retrieved relevant literature on mandibular first premolars of Chinese people and found that 24.9% of mandibular first premolars have multiple root canals. Wolcott et al. [12] explored the MB2 of 3587 mandibular first molars that needed root canal treatment and root canal re-treatment. The results showed that 57.9% of the root canal-treated teeth and 66.0% of the re-treated teeth had MB2, suggesting that the omission of MB2 is the main reason for the failure of root canal treatment.

In the medical field, microscopes began to appear in the late 1950s. They were applied to oral clinical practice in the 1970s and to endodontics in the early 1980s. In 1978, the prototype of an oral surgery microscope was designed in the United States. Based on this prototype, the first oral microscope was

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introduced in 1981, and it was later applied in root canal treatment in 1986. In the late 1990s, root canal microscopes were applied in oral clinical medicine in China. Subsequently, a large number of literatures introduced and summarized the relevant equipment of microscopes and the key points of clinical operations. Microscopic root canal treatment techniques began to be recognized and learned by the dental community [13, 14].

Root canal treatment remains the cornerstone of dental and endodontic therapy. However, traditional RCT relies heavily on the operator's experience and tactile perception, posing limitations in managing complex root canal systems (e.g., calcified canals, C-shaped canals) and complications such as instrument separation or perforation. Since the 21st century, the introduction of the "Dental Operating Microscope (DOM)" has revolutionized endodontics by enabling microscopic and precision-enhanced techniques, establishing DOM as the current "gold standard" in modern endodontic practice. Root canal microscope is an extremely important and indispensable auxiliary equipment in the field of modern endodontics. A large number of clinical workers and students are learning the technique of microscopic root canal treatment, which enables the modern root canal treatment to reach a higher level of excellence.

1. Core Advantages of Microscopic Technology

1.1 High-Resolution Visualization

The basic structure and technical principles of the microscope include the optical magnification system, illumination system, image acquisition and data storage system, and related auxiliary equipment (rubber barrier system, microscopic ocular mirror, microscopic probe, ultrasonic system, etc.) [15]. The optical system is composed of a large objective lens, a small objective lens for imaging, a relay prism for image transfer, a condenser lens, an eyepiece, and optical fibers. It can change the magnification and is commonly used in clinical practice to select medium magnification for root canal treatment. The operator can choose the appropriate magnification according to the treatment content and purpose [16]. The light source of the illumination system is halogen lamps and xenon lamps, and it adopts coaxial illumination, so that the light is parallel to the root canal and avoids shadow formation [17]. The camera and display connected to the microscope can obtain real-time operation data, providing important materials for later communication, learning, teaching training and so on. The related auxiliary equipment is integrated throughout the microscopic endodontic treatment. The dental operating microscope consists of three core components: support arm, main optical unit, and illumination system, along with auxiliary accessories. The support arm provides structural stability, while the main optical unit (including eyepieces, binocular head, and objective lenses) magnifies the target field of view, offering 6× to 40× continuous magnification. Combined with a coaxial cold light source, it enables clear visualization of root canal orifices, lateral/accessory canals, isthmus structures, and microcracks (<50 μm), significantly reducing the risk of missed canals and diagnostic errors [18]. Studies demonstrate that microscopically assisted root canal orifice detection rates improve by 20–30% compared to conventional methods, particularly in identifying the second mesiobuccal (MB2) canal [19].

1.2 Precision and Minimally Invasive Performance

The application of root canal microscope has broken through the limitations of traditional root canal treatment, providing a good light source and an appropriate magnification factor for the surgical area. This enables the operator to clearly see the complex anatomical structures of the tooth and the root canal system under a precise field of vision, locate the lesion area and variations, and carry out precise and complete operation procedures. It reduces the uncertainty and damage during the operation process, while maximizing the preservation of healthy tooth tissues. As a result, it simplifies complex cases and enables marginal teeth to be retained for a long time, thereby increasing the preservation rate of affected teeth.Micro-endodontic instruments (e.g., micro-files) facilitate submillimeter-level manipulation, effectively minimizing procedural complications such as ledge formation, canal transportation, and perforations. The perforation rate decreases from 10% in traditional root canal therapy to ≤3% under microscopic guidance [20]. Additionally, minimally invasive access cavity preparation preserves more intact dentin structure, thereby enhancing the long-term biomechanical resistance of the tooth.

1.3 Accessibility to Complex Cases

Microscopic technology has expanded treatment possibilities for challenging scenarios, including root canal retreatment, negotiation of calcified canals, apical microsurgery, and retrieval of foreign bodies

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(e.g., fractured instruments, posts). Clinical success rates in these complex cases are markedly superior to those achieved with conventional techniques [21].

2. Clinical Applications and Research Advances

2.1 Diagnosis and Preoperative Assessment

Integration of Microscopic Imaging with CBCT: Combining microscopic imaging with three-dimensional cone beam computed tomography (CBCT)reconstruction enables precise identification of root canal variations (e.g., C-shaped canals, S-shaped curvatures) and the extent of periapical lesions [22]. Early Diagnosis of Microcracks: Microscopy serves as a critical tool for detecting cracked teeth. Due to the difference in refractive index between dental cracks and surrounding tissues, light reflects at crack interfaces, rendering fracture lines clearly visible under magnification. A magnification range of 14× to 18× (with 16×being optimal) is recommended for evaluating enamel crack extent. Furthermore, staining techniques (e.g., methylene blue) and optical enhancement modes under microscopy enhance the detection of vertical root fractures (VRFs) at early stages, reducing misdiagnosis rates [23].

2.2 Innovations in Therapeutic Techniques

2.2.1 Negotiation of Calcified Root Canals

With increasing age-related changes and the rising proportion of “population aging”, pulp calcification has become increasingly prevalent [24]. Calcified root canals pose significant clinical challenges, often leading to tooth extraction due to suboptimal treatment outcomes. Currently, “micro-ultrasonic technology” integrated with microscopic systems has been widely adopted in endodontic therapy and has demonstrated promising clinical outcomes. The failure rate in managing calcified canals ranges from 20% to 70%, primarily attributed to complications such as lateral perforation, ledge formation, instrument separation, and root fracture during procedures [25]. Therefore, the key to successful treatment lies in precise localization of calcified canals and establishing adequate access pathways for instrumentation. Micro-ultrasonic technology, which combines the magnification and illumination of the operating microscope with the cutting and oscillatory effects of specialized instruments, has gained increasing clinical adoption in recent years. With this technology, the success rate of calcified canal negotiation has improved significantly to 85.29%–100% [26].

2.2.2 Microscopic Apical Surgery

While traditional apical surgery for apical periodontitis can partially improve occlusal function, it is often associated with significant postoperative pain and limited therapeutic efficacy. With advancements in dental microsurgical techniques, microscopic apical surgery has gained increasing clinical recognition [27]. The core advantages of the dental operating microscope lie in its enhanced illumination and magnification, enabling:

1. Clear visualization of periapical lesion boundaries.

2. Precise localization of missed canals, lateral canals, and intercanal isthmus regions.

3. Minimized surgical trauma, facilitating accurate retrograde preparation and hermetic apical sealing.

Compared to conventional approaches, microscopic apical surgery ensures more thorough debridement of pathological tissues and significantly reduces the incidence of postoperative pain [28]. Fan Cong et al. conducted a study involving 82 patients with refractory chronic apical periodontitis. The results showed that the pain incidence rate 7 days after micro-surgical apicoectomy was lower than that after traditional apicoectomy, and the success rates of follow-up examinations at 6 months and 1 year after surgery were higher than those of traditional apicoectomy. In conclusion, microscopic apex surgery has a remarkable therapeutic effect on patients with periapical periodontitis, and can significantly improve periodontal indicators, reduce pain and the incidence of complications. It is worthy of clinical promotion and application[29].

2.2.3 Retrieval of Fractured Instruments

In recent years, with the continuous increase in the types of root canal preparation instruments and the continuous improvement of techniques, the treatment of many complex root canals has been successfully completed, greatly improving the quality of root canal treatment. However, the separation of instruments during the treatment process has caused people to feel troubled. When the separated

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instruments block the root canal, the treatment becomes more difficult and affects the quality of root canal treatment. With the widespread application of post-core crowns, root canal treatment (RCT), and various endodontic instruments, instrument separation within root canals has become a common complication. Intracanal metallic obstructions hinder proper canal preparation and obturation, contributing to RCT failure. The integration of the dental operating microscope with ultrasonic instruments (micro-ultrasonic technology) provides clear visualization, minimizes procedural accidents caused by blind manipulation, and significantly improves the retrieval rate of fractured instruments. Studies report a 98% success rate for removing fractured files or foreign bodies located proximal to canal curvatures or within straight root canals [30].

2.2.4 Perforation Repair

Root canal perforation is an abnormal passage between the root canal system and the periapical tissues caused by pathological or iatrogenic factors. Due to the inability to perform a tight three-dimensional filling in perforated root canals, it may lead to the failure of root canal treatment. Preserving teeth with root canal perforations is a complex and challenging problem. The sealing performance of filling materials, the removal of infection sources, the operation technique, and the repair of periodontal bone defect tissues are all closely related to the success or failure of root canal perforation repair. Non-surgical repair of perforations in the middle and lower segments of the root canal can be performed using a surgical microscope. The surgical process can benefit from the magnification and enhanced illumination provided by the microscope, significantly improving the field of vision, reducing the blind operation, and increasing the success rate of treatment. Under real-time microscopic guidance, bioceramic materials (e.g., MTA, Biodentine) are used to repair furcation or lateral wall perforations, achieving a 5-year success rate of 75%–90% [31].

2.2.5 Root Canal Re-treatment

In cases where root canal treatment fails, the microscope can utilize its excellent lighting and magnification system, combined with specialized microsurgical instruments, to identify the reasons for re-treatment failure, eliminate the infection in the root canal system, repair complications caused by pathological and iatrogenic injuries, and promote lesion healing [32]. Song et al. used the microscope to analyze cases of failed root canal treatment. The results showed that the main reason for the failure of root canal treatment was the non-compact filling of the root canal, which led to bacterial re-infection [33]. Many studies have shown that the combination of root canal microscope and ultrasonic system has an irreplaceable role in root canal re-treatment, such as clearing calcified root canals, identifying missed root canals, removing separated instruments in the root canal, repairing root canal perforations with bio-ceramic materials, and forming root apex barrier zones. The direct vision operation makes the operation process controllable and the expected results. It has become the most beneficial auxiliary equipment in root canal re-treatment [32-36].

3. Conclusions

The root canal microscope is a root canal treatment device that integrates multiple functions. Its advantages mainly lie in the roles of the microscope, root canal treatment instrument, root canal irrigator and root canal obturator. It enables precise root canal treatment operations under the microscope. The microscope can magnify and illuminate the structure of the root canal, helping doctors handle complex root canal conditions, effectively solving problems that are difficult to overcome with traditional methods, and improving the safety and effectiveness of root canal treatment. In summary, compared with traditional root canal treatment methods, root canal treatment under the microscope has obvious advantages. It can shorten the treatment time for patients, improve the shape of the root canal, enhance the quality of apical sealing, reduce periapical inflammatory reactions, lower periapical bone resorption, promote periapical healing, and increase the success rate and long-term effect of root canal treatment. It is a root canal treatment technology worth promoting and applying. Of course, root canal treatment under the microscope also has certain limitations, such as high operation difficulty, the need for professional training and practice, high equipment cost, and complex maintenance and care. These all need to be continuously improved and perfected in future research and practice.

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