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Richa Wadhawan
Professor, Department of Oral Medicine, Diagnosis & Radiology, PDM Dental College & Research Institute, Bahadurgarh, Haryana, India

Poorva Bain
Consultant Endodontist, Pearl Dental Clinic, Sagar, Madhya Pradesh, India

Srishti Mehta
Post Graduate, Department of Conservative Dentistry & Endodontics, Hitkarini Dental College and Hospital, Jabalpur, Madhya Pradesh, India

Devanshi Sharma
Senior Lecturer, Department of Conservative Dentistry & Endodontics, R.K.D.F. Dental College and Research Center, Bhopal, Madhya Pradesh, India

Mansi Raghuvanshi
Dental Surgeon, Institute of Dental Education and Advance Studies, Gwalior, Madhya Pradesh, India

Shikha Rajawat
Dental Surgeon, Institute of Dental Education and Advance Studies, Gwalior, Madhya Pradesh, India

Corresponding Author:
Richa Wadhawan
Professor, Department of Oral Medicine, Diagnosis & Radiology, PDM Dental College & Research Institute, Bahadurgarh, Haryana, India

Exacting endodontics: The evolution and precision of microsurgical techniques

Richa Wadhawan, Poorva Bain, Srishti Mehta, Devanshi Sharma, Mansi Raghuvanshi and Shikha Rajawat

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Abstract
The field of endodontics has experienced a dramatic transformation with the integration of microsurgical techniques, significantly improving precision and outcomes in root canal treatments. Traditionally, endodontic procedures were limited due to restricted visibility and access, leading to less optimal results and a higher risk of complications. The introduction of high-resolution microscopes and specialized micro-instruments has revolutionized this landscape by offering exceptional magnification and illumination. These technological advancements have reshaped endodontic practice, allowing for more accurate diagnoses, refined surgical techniques, and superior management of intricate root canal anatomy. Key advancements include the use of advanced microscopes, specialized micro-instruments, and ultrasonic technology for enhanced cleaning of canals, which has led to higher success rates, reduced patient discomfort, and more efficient procedural times. Additionally, microsurgery has transformed endodontic training and education, highlighting the need for specialized skills to master these advanced techniques. Case studies demonstrate the tangible benefits of microsurgery, such as performing smaller osteotomies, achieving precise bevels, and accurately placing filling materials. With the integration of bright illumination and magnification, endodontic surgery has evolved into a sophisticated microsurgical discipline, setting new standards for care and precision. This review explores the evolution of microsurgery within endodontics, focusing on its pivotal role in addressing complex clinical challenges and improving patient outcomes.

Keywords: Microsurgery, precision endodontics, advanced magnification, ultrasonics, endodontic innovations, anatomical complexity

Introduction

Endodontic microsurgery has transformed root canal therapy since the 1990s, leveraging high-powered microscopes, specialized instruments, and advanced materials to achieve greater precision and better outcomes. This evolution has led to improved success rates and less invasive procedures, fundamentally shifting how complex endodontic issues are managed [1]. Modern endodontic microsurgery, or "Microsurgical Endodontics," involves the use of high-powered dental microscopes and specialized tools to perform minimally invasive surgeries with enhanced accuracy [2]. Microsurgical endodontics evolved through a series of advancements rather than being the invention of a single individual, with several key figures significantly contributing to its development [3]. Dr. H. T. K. Toffel was a pioneering advocate for the use of microscopes in endodontics, establishing the importance of magnification in enhancing precision [4]. Dr. John A. S. P. Kulid further popularized microscope use through his research and clinical application of microsurgical techniques [5]. Additionally, Dr. James A. K. Hovland integrated advanced technology and microsurgical methods into endodontic practice [6]. The field's development was a collaborative effort involving various researchers, clinicians, and technological advancements, including high-powered dental microscopes and improved surgical instruments, continuously evolving through the collective contributions aimed at refining techniques and improving patient outcomes [7]. The procedure involves a small gingival incision to access the root tip, allowing for precise treatment of complex anatomical features that conventional methods might miss. This approach minimizes disruption, reduces postoperative discomfort, and supports faster recovery while preserving tooth structure for long-term dental health [8].

Historical context and evolution: Historically root canal therapy relied solely on nonsurgical methods which often fell short for certain conditions leading to the development of endodontic microsurgery as a more precise and effective solution [9]. The advent of microsurgical techniques brought significant advancements, including improved visualization with microscopes, refined tools for confined spaces, and superior root-end filling materials. These innovations have greatly enhanced the success rates and precision of endodontic surgery [10].

Principles of Microsurgery: In endodontic microsurgery, the trio of magnification, illumination, and specialized instrumentation transforms the standard of care. Surgical microscopes are game-changers, offering up to 31x magnification and intense, focused lighting [11]. This level of detail enables clinicians to navigate and treat the intricate anatomy of the root canal system with unprecedented precision. The bright, concentrated light provided by these microscopes not only enhances visibility but also ensures that every minute detail is illuminated, leading to more accurate disinfection and debridement [12]. The use of these microscopes allows for smaller, more precise osteotomies, minimizing trauma and improving patient outcomes. Specialized instruments, designed for the confined space of microsurgery, further contribute to the effectiveness of the procedure [13]. They enable fine, controlled movements within the tiny surgical field, enhancing the precision of every step. Compared to loupes, surgical microscopes offer superior magnification and ergonomic advantages, allowing for better posture and reducing operator fatigue [14]. With LED illumination and integrated digital cameras, these microscopes not only provide exceptional visualization but also support comprehensive documentation and analysis of the surgical process. Overall, the integration of advanced magnification, precise illumination, and specialized tools in endodontic microsurgery significantly elevates the ability to perform detailed, effective treatments, leading to better outcomes and improved patient care [15].

Classification of Endodontic Microsurgical Cases: Kim and Kratchman classified periradicular lesions into categories A-F. Lesion Types A, B, and C represent lesions of endodontic origin and are categorized based on the size of periradicular radiolucency. Lesion Types D, E, and F represent lesions of combined endodontic-periodontal origin and are ranked based on the degree of periradicular deterioration (Table 1 and Figure 1).

Table 1: Kim and Kratchman's Classification of periradicular lesions

Class A:	Absence of a periapical lesion, no mobility, normal pocket depth, but unresolved symptoms after nonsurgical methods. Surgery is indicated based solely on clinical symptoms
Class B:	Presence of a small periapical lesion with clinical symptoms. The tooth has normal periodontal probing depth and no mobility. These are ideal candidates for microsurgery.
Class C:	Large periapical lesion extending coronally, but without periodontal pocketing or mobility
Class D:	Similar to Class C but with deep periodontal pockets
Class E:	Deep periapical lesion with an endodontic-periodontal connection to the apex, but no evident fracture
Class F:	Apical lesion with complete exposure of the buccal plate but no mobility

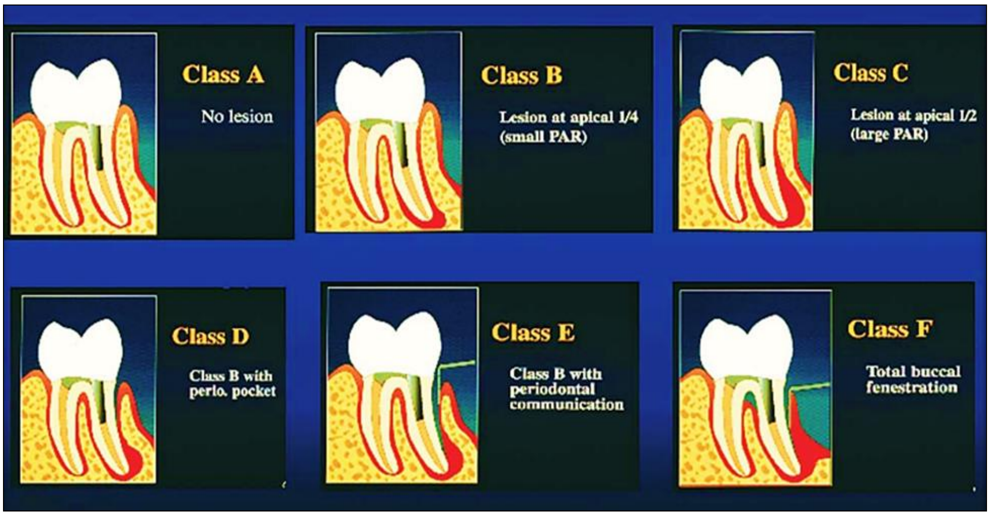


Fig 1: Classification of endodontic microsurgical cases Courtesy: Kim S, Kratchman S. Modern endodontic surgery concepts and practice: A review. J Endod. 2006; 32(7):601-23

Classes A, B, and C do not present significant treatment challenges, and these conditions do not negatively impact treatment outcomes. Conversely, Classes D, E, and F pose considerable difficulties [16].

Microsurgery is indicated for persistent apical periodontitis, anatomical challenges, and procedural errors, including cases with radiological evidence of apical periodontitis or symptoms associated with an obstructed canal where removal or displacement of the obstruction is not feasible, or the risk of damage is too high. It is also warranted when extruded material presents with clinical or radiological signs of apical periodontitis and symptoms persist over a long period, or when there is persistent or emerging disease following root canal treatment that makes root canal retreatment unsuitable. [17]. Additionally, microsurgery is necessary in situations where perforation of the root or pulp chamber floor occurs and treatment from within the pulp cavity is not viable. Contraindications for microsurgery include proximity to neurovascular bundles, endodontic-periodontic lesions, severe systemic conditions, and overall poor health.[18] Relative contraindications encompass a compromised medical status of the patient, anatomical considerations, and the surgeon's skill and clinical expertise. Additionally, microsurgery may be contraindicated for teeth that are vertically fractured, unrestorable, or have inadequate periodontal support. Nonfunctional teeth and those with short roots also present relative contraindications for the procedure [19]. Cone Beam Computed Tomography (CBCT) is essential for 3D imaging of the root canal system and surrounding structures, with future developments focusing on clearer images, reduced radiation, and real-time imaging [20]. Magnetic Resonance Imaging (MRI) offers exceptional soft-tissue contrast and may see advancements in 3D templates and imaging protocols.[21]Targeted Endodontic Microsurgery (TEMS), using 3D-printed surgical guides, has already enhanced precision and minimally invasive approaches. Future innovations might include more durable guide materials and real-time navigation systems (Figure 2) [22]. Endodontic microsurgery represents a significant advancement in root canal therapy, offering a less invasive, and more precise approach with improved outcomes. As technology continues to evolve, further enhancements in imaging, instrumentation, and surgical techniques are expected to refine these procedures, making them even more effective for managing complex endodontic issues. This progress embodies the state-of-the-art principles of endodontic microsurgery, underscoring the field's commitment to cutting-edge, minimally invasive dental care [23].

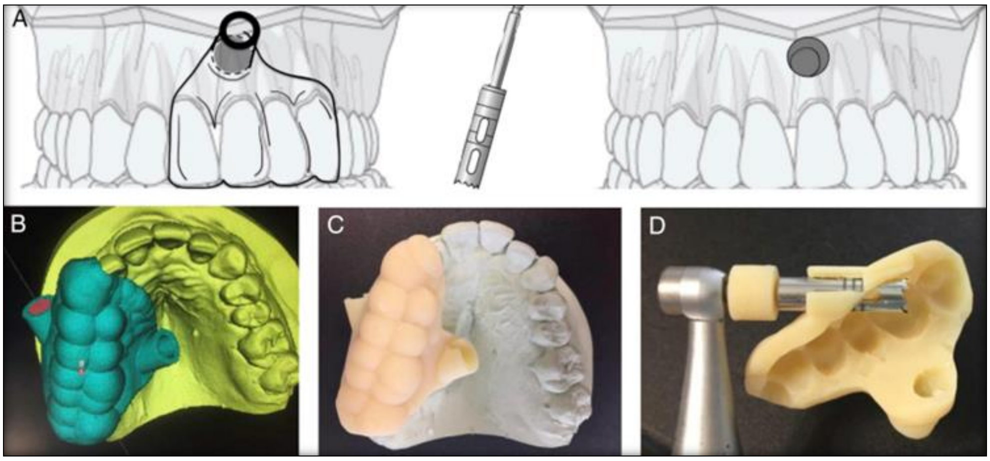


Fig 2: Targeted endodontic microsurgery Courtesy: Giacomino CM, Ray JJ, Wealleans JA. Targeted Endodontic Microsurgery: a novel approach to anatomically challenging scenarios using 3-dimensional-printed guides and Trephine Burs-A report of 3 cases. Journal Endod. 2018 Feb 14; 44(4):671-7

Discussion

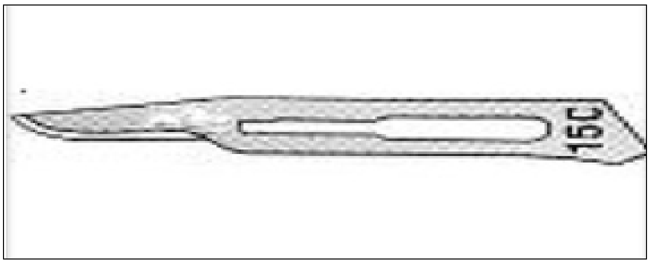
Recent advancements and techniques in endodontic surgery are often recommended for persistent or recurrent apical periodontitis, involving the exposure of the periapical lesion through an osteotomy, cleaning out the lesion, and removing the root end. Successful outcomes depend on optimal access to the tooth's root tip and the lesion. Endodontic microsurgery enhances outcomes with better magnification, illumination, and visualization, leading to a postsurgical healing rate about 35% faster compared to traditional surgery [24].

Ergonomics and Positioning (Patient/Surgeon): A primary challenge in microscopic surgery is positioning the dental operating microscope relative to the patient and the surgical field. Typically, the patient is placed in a supine or slightly Trendelenburg position to optimize visibility of the surgical site [25]. This may involve rotating the patient's head or positioning them on their side, stabilized with rolled surgical towels, "donut" headrests, or memory foam pillows. The surgeon should be positioned at the 11-12 o'clock orientation (Figure 3), with their chair adjusted so the angle between the thigh and lower leg is at least 90°, and maintaining a straight back [26]. The patient's chair should be adjusted to keep the surgeon's elbows close to their body and bent at a neutral 90°.This ergonomic positioning helps achieve optimal dexterity and control while minimizing fatigue and strain. The microscope's visual axis should be perpendicular to the soft tissue field of the intended flap, with binocular eyepieces adjusted for comfort [27]. Inclinable optics allows the microscope to assume various vertical angles, enhancing visibility of the hand piece or resected root end. The microscope's visual axis must be parallel to the root's long axis at the resection level to avoid deviations in the resection angle. Overall, endodontic microsurgery provides a refined and less invasive approach for addressing complex cases that cannot be resolved through traditional root canal treatment alone [28]. It offers a more precise and less disruptive solution to challenging endodontic issues by utilizing advanced technology and techniques, thereby enhancing accuracy, reducing postoperative discomfort, and promoting long-term dental health [29].

Courtesy: https://rootcanalcentre.co.uk/endodontic-surgery/

Fig 3: Ergonomic Position of dentist and patient

Microsurgical Instruments: Traditional surgical instruments are often too large for use at magnifications of ×10 and ×25 [30]. Dr. Garry Carr pioneered the design and production of micro-instruments, which include examination tools such as mirrors, periodontal probes, explorers, and micro explorers. Incision and elevation tools feature the 15 and 15 C blades (Figure 4), mini scalpels, Periosteal Molt 9 (Figure 5), and various Prichard and P series elevators (Figure 6) [31].



Courtesy:https://www.dentalku.com/Products/AILEE_2139b49/Blade/BladeNo15C.html

Fig 4: 15 C Blade

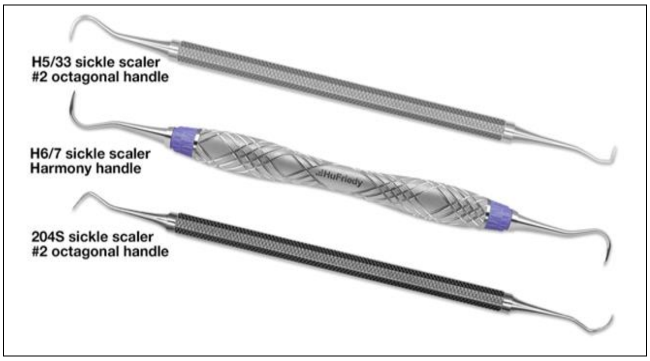
Courtesy: https://www.hufriedygroup.com/en/periosteals/9-molt-periosteal-elevator-black-line

Fig 5: Periosteal Molt 9

Courtesy:https://www.dentaltrademart.com/image/cache/catalog/Brands/GDC/Periosteal%20Elevator/prichard-periosteal-elevator-ppr3-486-550x550h.jpg

Fig 6: Prichard and P series elevators

Curettage instruments include mini Jacquette 34/35 scalers (Figure 7), Columbia 13-14 curettes (Figure 8), and mini molten and mini-endodontic curettes (Figure 9). For inspection, micro-mirrors are utilized, while retro filling requires carriers and plugging instruments. Additional tools like a large ball burnisher, bone file, and microrongeur (Figure 10) aid the procedure. Osteotomy involves using the Impact Air 45 hand piece (Figure 11) and the H 161 Lindemann Bone Cutting Bur (Figure 12) to remove cortical bone and access the root end [32]. Start by taking radiographs from two perpendicular angles to evaluate root length, curvature, and proximity to structures like the mental foramen and mandibular nerve. After raising the flap, align the radiographic image with the cortical plate for guidance. Remove the cortical bone slowly with copious water spray and low magnification (×4 to ×6) [33]. The H 161 Lindemann bone cutter is beneficial due to its fewer flutes, which reduce frictional heat, while the hand piece directs water and air to minimize splatter and associated risks. Smaller osteotomies heal faster; lesions <5 mm typically heal in 6.4 months, 6-10 mm lesions in about 7.25 months, and those >10 mm in approximately 11 months [34]. Microsurgical techniques can reduce osteotomy size to 3-4 mm in diameter, accommodating a 3 mm ultrasonic tip for vibration within the bone cavity. For resection, after exposing the lesion and root tip, use Columbia #13 and #14 curettes and Jacquette 34/35 curettes under medium magnification (×10 to ×16) to remove granulation tissue. For larger lesions, consider larger curettes like the 33 L spoon excavator (Figure 13) or #86 Lucas bone curette (Figure 14), with specific tools aiding access to various root aspects [35].



Courtesy:https://k-dental.ca/hu-friedy-sickle-scaler-jacquette-34-35-7-handle-12353-00.html

Fig 7: Mini jacquette 34/35 scalers

Courtesy:https://www.pearsondental.com/catalog/product.asp?majcatid=4240&catid=13829&subcatid=50226&pid=60621

Fig 8: Mini-molten and mini-endodontic curettes

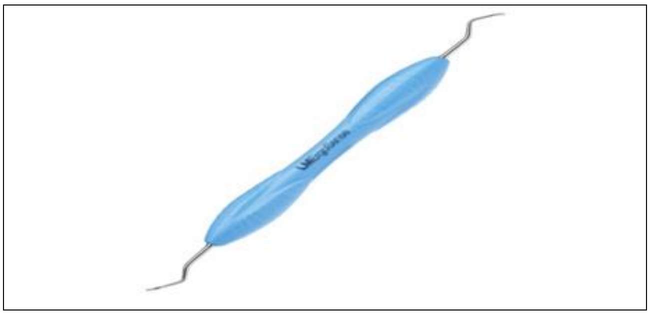


Fig 9: Columbia 13-14 curette

Courtesy: https://lm-dental.com/products/handinstrumentation/periodontics/universal-curettes/columbia-curettes/columbia-13-14/

Fig 10: Microrongeur

Courtesy:https://orthomedinc.com/surgical instruments/rongeurs/rongeurs/micro-friedman-rongeur-30-angled

Fig 11: Impact Air 45 hand piece

Courtesy: https://unicorndenmart.com/tealth-45-degree-high-speed-air-rotor-handpiece/

Fig 12: Lindemann bone cutter

Courtesy:https://www.dentalstation.co/en/product/special-cutter-h161-fg-oral-surgery

Suturing employs Laschal microscissors (Figure 15) or small-beaked scissors and the Castroviejo needle holder (Figure 16).[33]

Fig 13: Laschal micro scissors

Courtesy:https://www.dit-usa.com/media/catalog/product/n/-/n-103f.jpg

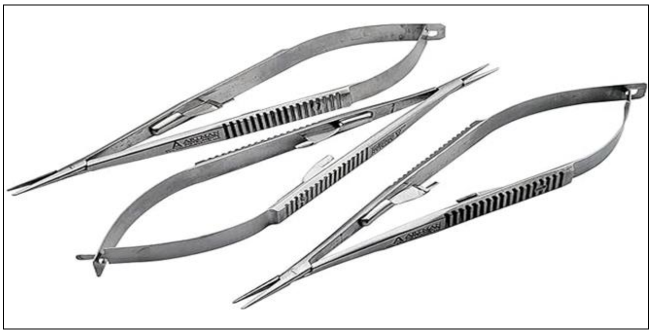


Fig 14: Castroviejo needle holder

Courtesy: https://www.amazon.in/castroviejo-needle-holder-straight-Linkers/dp/B06XH3X3S5

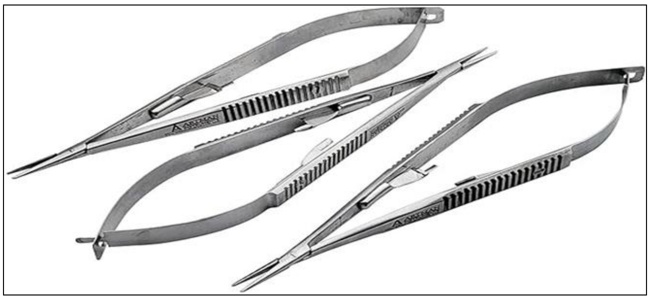


Fig 15: 33 L spoon excavator

Courtesy:https://www.crosstex.com.pk/en/product-category/excavators/endodontics-excavators

Fig 16: Lucas curette

Courtesy: https://www.medesy.it/en/products/lucas-curette/

Tissue retraction is achieved using Kim-Pecora, Rubinstein, and Prichard retractors. A compact, all-in-one dental cart, equipped with a sterilized water tank, high and low-speed hand piece ports, an ultrasonic unit, and a Stropko irrigator/drier, is essential in modern microsurgery practice.[34] Microsurgical blades provide precision with bidirectional cutting and a round handle for a pen-like grip. Tissue elevators, such as the small and sharp Buser elevator (Figure 17) combined with the Molt 9, facilitate atraumatic periosteum elevation [35]. Retractors like the Minnesota and Edge Bowdler Henry retractors (Figure 18) are ideal for retracting small flaps, and micro-explorers are suitable for probing cortical plates and root-ends [36].

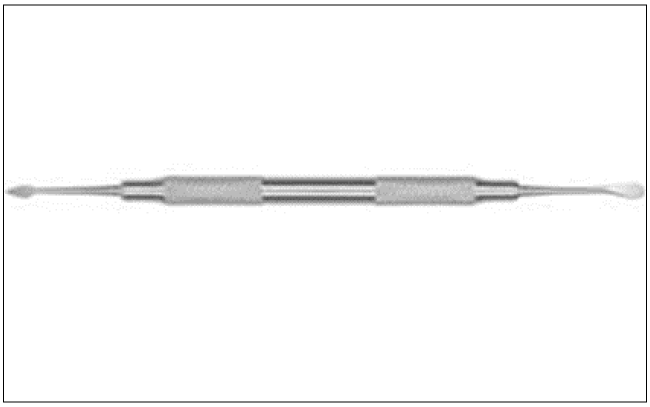


Fig 17: Buser elevator

Courtesy: https://orchiddentalsupply.com/product/buser-periosteal-elevator-4-2-3-5-mm-hollow-handle/

Fig 18: Minnesota and Edge Bowdler Henry retractors

Courtesy: https://www.fizzasurgical.com/wp-content/uploads/2018/11/Bowdler-Henry%C2%B4s-19cm-Retractor.jpg

Ultrasonic units and tips

Here is a summary of the ultrasonic tips and their key features:

1. Carr Tips (CTs) (Figure 19)

- **CT 1:** Suitable for maxillary and mandibular anterior teeth. It is 1/4 mm in diameter
- **CT 5:** Similar to CT 1 but with a more sharply pointed tip, also used for anterior teeth
- **CT 2 and CT 3:** Feature a double angle for better access to posterior teeth
- **Back-action (CK) Tip:** Hook-shaped, effective for cleaning the buccal wall of a canal[37]

Fig 19: Carr ultrasonic tips

Courtesy: Plotino G, Pameijer CH, Grande NM, Somma F. Ultrasonics in endodontics: A review of the literature. J Endod. 2007; 33(2):81-95.

2. Kim Surgical (KiS) Tips (Figure 20)

- **KiS 1:** Has an 80° angled tip, 0.24 mm in diameter, designed for mandibular anterior teeth and premolars
- **KiS 2:** Wider diameter tip for use in wider apex teeth like

maxillary anteriors

- **KiS 3:** Double-ended, 75° angled tip for posterior teeth, suitable for the maxillary left side or mandibular right side
- **KiS 4:** Similar to KiS 3 but with a 110° angle for reaching the lingual apex of molar roots
- **KiS 5:** Counterpart to KiS 3, used for the maxillary right side or mandibular left side
- **KiS 6:** Counterpart to KiS 4 for the lingual apex of molar roots

These tips are designed for different applications in dental procedures, with advancements in design and irrigation for improved performance and reduced microfractures [38].

Fig 20: Kim Surgical (KiS) Tips

Courtesy:https://guident.net/articles/endodontics/ROLE-OF-ULTRASONIC-TIPS-IN-RETROGRADE-PREPARATION-UNDER-MAGNIFICATION.html

Anesthesia and Hemostasis: For effective pain management in posterior endodontic surgeries, maxillary sites require posterior superior and middle superior alveolar nerve blocks, while mandibular sites need an inferior alveolar nerve block and a mental nerve block. Maxillary anterior teeth are best anesthetized with bilateral anterior superior alveolar or infraorbital injections, and mandibular anterior teeth with bilateral mental nerve blocks. Utilizing a long-acting anesthetic like bupivacaine (Marcaine) ensures extended pain relief [39]. Once regional anesthesia is established, administer local infiltration with lidocaine containing 1:50,000 epinephrine over the surgical site to ensure precision and hemostasis. For optimal hemostasis, inject two to three carpules of a 1:50,000 epinephrine-containing anesthetic, such as 2% xylocaine, into multiple infiltration sites across the surgical field. Effective anesthesia not only provides immediate relief but also reduces long-term pain by minimizing central sensitization. Articaine can enhance lidocaine in buccal infiltrations but is not superior for inferior alveolar blocks. Alternatives like felypressin, though useful, do not offer superior hemostatic benefits compared to adrenaline, making solutions like Scandonest and Citanest less effective. Despite its extended duration, bupivacaine's availability can be limited [40].

Surgical Phase: Insert an epinephrine pellet into the bone cavity, followed by dry, sterile cotton pellets until the cavity is filled. Apply pressure for 2 minutes, then place a cotton pellet soaked in ferric sulfate solution [41]. It is essential to thoroughly rinse away all ferric sulfate residues with a saline flush, as they can be highly irritating to the tissues if left behind. For larger osteotomy sites, use freshly mixed calcium sulfate paste (Figure 21). Although this paste is not typically employed for hemostasis, it is highly effective in managing bleeding in extensive bone cavities.Postsurgical/Postoperative Phase: Use damp gauze compresses on the tissues both before and after suturing [42].

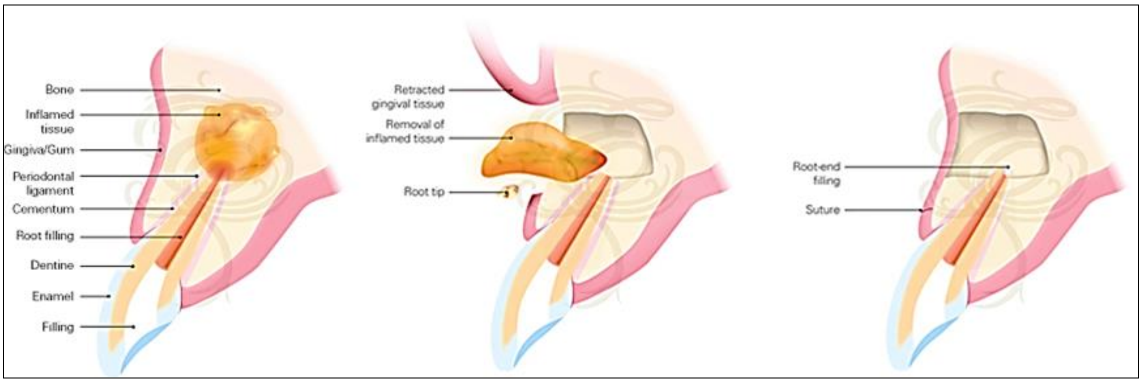


Fig 21: Procedure of endodontic microsurgery in periapical lesion

Courtesy: https://www.endodonticsolutions.com.au/patient-information/your-endodontic-treatment-solution/endodontic-microsurgery

Soft Tissue Management: Proper management of soft tissues is vital for achieving aesthetically pleasing results in treatment. Recent innovations in soft tissue management have surpassed traditional techniques. The semi-lunar incision, previously a popular flap design for anterior teeth, is now avoided due to limited access and scarring. Sutures are generally removed within 48-72 hours rather than a week, and contemporary suture materials are monofilament, size 5 × 0 or 6 × 0, to promote quicker healing [43]. The papilla base incision technique has been introduced to preserve interdental papilla height, replacing the older sulcular incisions. During surgery, flap retraction is improved by creating a resting groove in the bone, especially in mandibular posterior procedures, to ensure effective retraction [44]. Two straightforward techniques-interrupted suturing and sling suturing-is recommended. Typically, the interrupted suture technique is used for vertical releasing incisions, while the sling suture technique is employed for interproximal and sulcular incisions. Enhanced soft tissue healing is achieved through reduced tissue trauma and improved wound closure during microsurgical procedures [45].

Osteotomy and Apical Root Resection:

Root-Resection Depth: Von Arx *et al.* suggest a 3 mm apical root resection and a 3 mm deep root-end cavity, totaling a "therapeutic length" of 6 mm. [46]The required resection length depends on the presence of lateral canals and apical ramifications. Research indicates:

- **1 mm resection:** Removes 52% of apical ramifications and 40% of lateral canals
- **2 mm resection:** Removes 78% of apical ramifications and 86% of lateral canals

A 3 mm resection removes approximately 93% of apical ramifications and 98% of lateral canals, typically managing up to 6 mm of infection [47]. However, cases with significantly curved roots or resorption may necessitate deeper resections. Microsurgery allows for a minimized bevel angle, reducing tissue damage compared to traditional methods, which often employ a steep bevel angle of 45-60°, potentially harming surrounding structures like buccal bone. Apical curettage involves the removal of diseased periapical tissues but does not seal the root canal system. Effective surgery includes tissue and root tip excision, retro filling, and resealing of the root canal. High magnification (×4 to ×25) with an operating microscope (Figure 22) is essential for examining resected root surfaces. Methylene blue staining is applied with a micro applicator, followed by rinsing with isotonic saline and drying using a Stropko irrigator/drier (Figure 23) [48]. After resection, rinse the crypt with sterile saline until clear, allowing the saline to remain for optimal visualization and weak hemostatic tamponade. Carefully adjust the fluid level using a micro cannula. The Stropko device facilitates controlled introduction of air, water, or saline while minimizing the risk of air embolism by maintaining pressure below 10 psi. Under magnification (×10 to ×12), a continuous periodontal ligament line indicates complete resection, with staining differentiating between non-stained craze lines and stained microfractures [49].

Fig 22: Surgical microscope

Courtesy:https://www.southlakeendo.com/microsurgical-root-canal-treatment-apicoectomy/

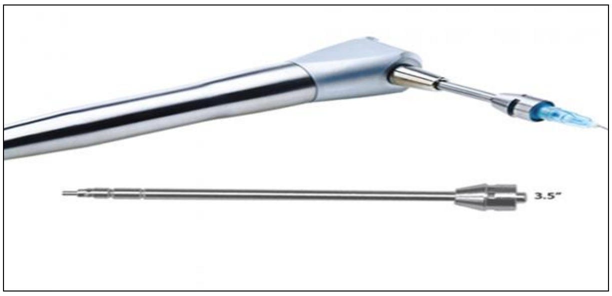


Fig 23: Stropko irrigator/drier

Courtesy: https://www.dentalforce.fr/index.php?id_product=1023&rewrite=stropko-irrigator-xl-35-length&controller=product

The Isthmus: An isthmus, a narrow connection between larger structures or cavities, must be thoroughly cleaned, shaped, and filled like other canal spaces. Types include:

- **Type I:** Two or three canals without noticeable communication.
- **Type II:** Two canals with a definite connection.
- **Type III:** Three canals with a connection or incomplete C-shapes.
- **Type IV:** Canals extending into the isthmus area.
- **Type V:** A true corridor connection throughout the section.
- Incidence: At a 3-mm resection depth, isthmuses are found in 90% of maxillary first molar mesiobuccal roots, 30% of maxillary and mandibular premolars, and over 80% of mandibular first molar mesial roots [50].

Types: There are many isthmus types (Figure 24). According to Hsu and Kim, there are five different types. Type I was defined as either two or three canals with no noticeable communication. Type II was defined as two canals that had a definite connection between the two main canals. Type III differs from the latter only in that there are three canals instead of two. Incomplete C-shapes with three canals were also included in this category. When canals extend into the isthmus area, this was named Type IV. Type V was recognized as a true connection or corridor throughout the section [51].

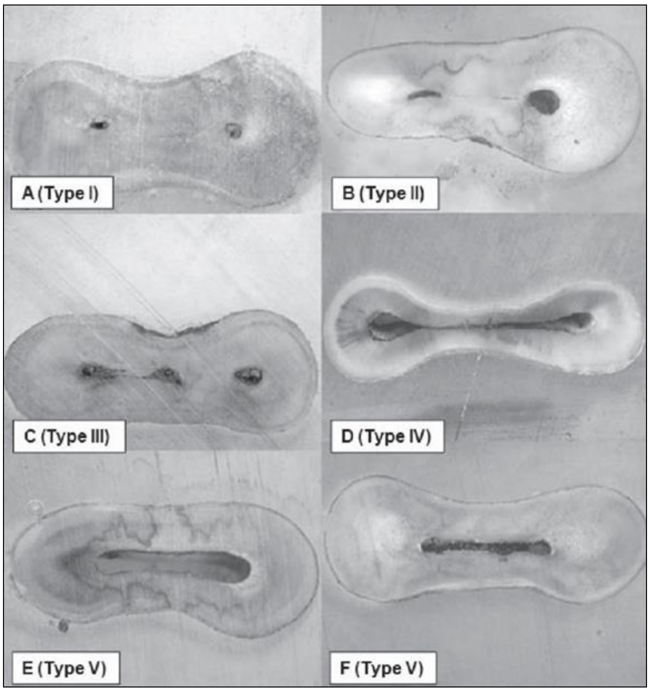


Fig 24: Types of isthmus

Courtesy: Camello de Lima, F. J., Montagner, F., Jacinto, R., Ambrosano, G., & others. (2014). An *in vitro* assessment of type, position and incidence of isthmus in human permanent molars. Journal of Applied Oral Science, 22(4), 328-333.

At the 3-mm level from the original apex, the presence of isthmuses is notable, with 90% observed in the mesiobuccal roots of maxillary first molars, 30% in maxillary and mandibular premolars, and over 80% in the mesial roots of mandibular first molars [52].

Retropreparation goals: The primary objective is to clean and shape the apical canal for an effective hermetic seal. An ideal root-end preparation is defined as a Class I cavity, at least 3 mm deep, with walls parallel to the root canal outline. Traditional rotary techniques can lead to access difficulties, increased risk of perforation, and inadequate filling retention [53].

The Ultrasonic Root-End Preparation (USREP) (Figure 25) procedure utilizes low to middle magnifications (×4 to ×16). For single canal roots, the ultrasonic tip is centered in the canal and activated to allow passive navigation. In multi-canal roots, each canal is prepared separately before addressing the connecting isthmus, ensuring care to avoid overheating [54].

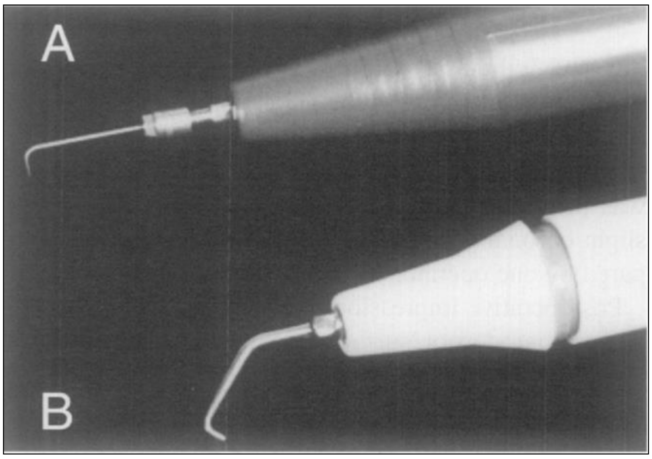


Fig 25: Ultrasonic root end cavity preparation

Courtesy: Calzonetti K, Iwanowski T, Friedman S. Ultrasonic root end cavity preparation assessed by an in situ impression technique. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998; 85(2):123-9.

Healing Outcomes: Maddalone and Gagliani reported a 92.5% healing rate using ultrasonic tips and Super EBA root-end fillings. Bernardes *et al.* evaluated the efficacy of different ultrasonic diamond tips, finding no significant differences in apical cavity preparations [55]. During ultrasonic activation, gutta-percha is thermoplasticized, allowing it to be effectively removed in strings. This process enhances the management of gutta-percha, facilitating its removal from the root canal system. After retro preparation, the remaining gutta-percha is recondensed with a micro plugger to create a smooth base for retro filling. Effective irrigation and drying of the retro preparation are crucial for ensuring a proper seal. The Stropko instrument aids in achieving this, preventing moisture-related failures. Ideal root end filling materials should be biocompatible, bactericidal, and promote tissue regeneration [56]. Historically, amalgam was the material of choice, but newer options such as Super EBA, IRM, and mineral trioxide aggregate have become more preferred. Suturing and postoperative care involve debris clearance, followed by repositioning and suturing of the flap. Postoperative instructions should cover diet, hygiene, medications, and ice application to manage swelling. Successful periapical surgery demands careful planning of flap design, taking into account anatomical structures, healing potential, and access. An effective flap enhances visibility and reduces trauma to surrounding tissues. Modern techniques and materials have positioned periapical surgery as a favored method for treating periapical lesions. Understanding surgical factors and flap management is vital for achieving optimal long-term outcomes and patient satisfaction. The primary aim is the effective removal of periapical lesions, disinfection, and sealing of the root canal, supported by precise flap design and execution [57].

Limitations and Drawbacks of Endodontic Surgery: The limitations of endodontic surgery have become more apparent with rapid technological advancements. However, these challenges can be alleviated by integrating CBCT, Computer-Aided Design (CAD), and 3D printing technologies with microsurgery. Exploring alternative noninvasive diagnostic methods, like MRI, alongside CAD and 3D printing, could yield further improvements. A significant clinical challenge in microsurgery is accurately locating the root tip when an apical lesion has not perforated the buccal bone, complicating apex identification and increasing the risk of deviating from the original osteotomy site, which may endanger critical anatomical structures such as the maxillary sinus, mental foramen, and mandibular nerve [58]. Guided endodontic microsurgery addresses these issues by offering enhanced visualization and identification, allowing for a more precise, accurate, and minimally invasive treatment that facilitates faster postoperative recovery. Osteotomy diameters smaller than 5 mm have been shown to promote better bone healing compared to larger diameters, which often lead to fibrous tissue formation and delayed healing [59]. In apicoectomy procedures, freehand drilling shows deviations of 2 mm in 70% of cases and 3 mm in 22% of cases, whereas a guided approach limits deviation to only 0.79 mm with a standard deviation of 0.33 mm, allowing even less experienced practitioners to achieve reliable outcomes (Figure 26). This patient-centered approach has enhanced outcomes by minimizing postoperative pain and increasing comfort. However, current templates lack a water port for continuous irrigation, which could be advantageous. Guided endodontic microsurgery has proven especially effective in complex anatomical scenarios, such as those involving the maxillary sinus, greater palatine artery, mental nerve, and fused roots in posterior teeth, and has been successfully utilized in anterior teeth to ensure precise osteotomy. In guided endodontics, static and dynamic navigation techniques enhance precision during root canal procedures when using a surgical microscope. Static navigation involves preoperatively planning the root canal access using 3D imaging, allowing the placement of templates that guide the instruments during the procedure. In contrast, dynamic navigation utilizes real-time tracking technology, enabling the dentist to visualize the instrument's position relative to the tooth anatomy as they work. Both methods significantly improve accuracy and efficiency, reducing the risk of errors and enhancing treatment outcomes in complex endodontic cases [60].

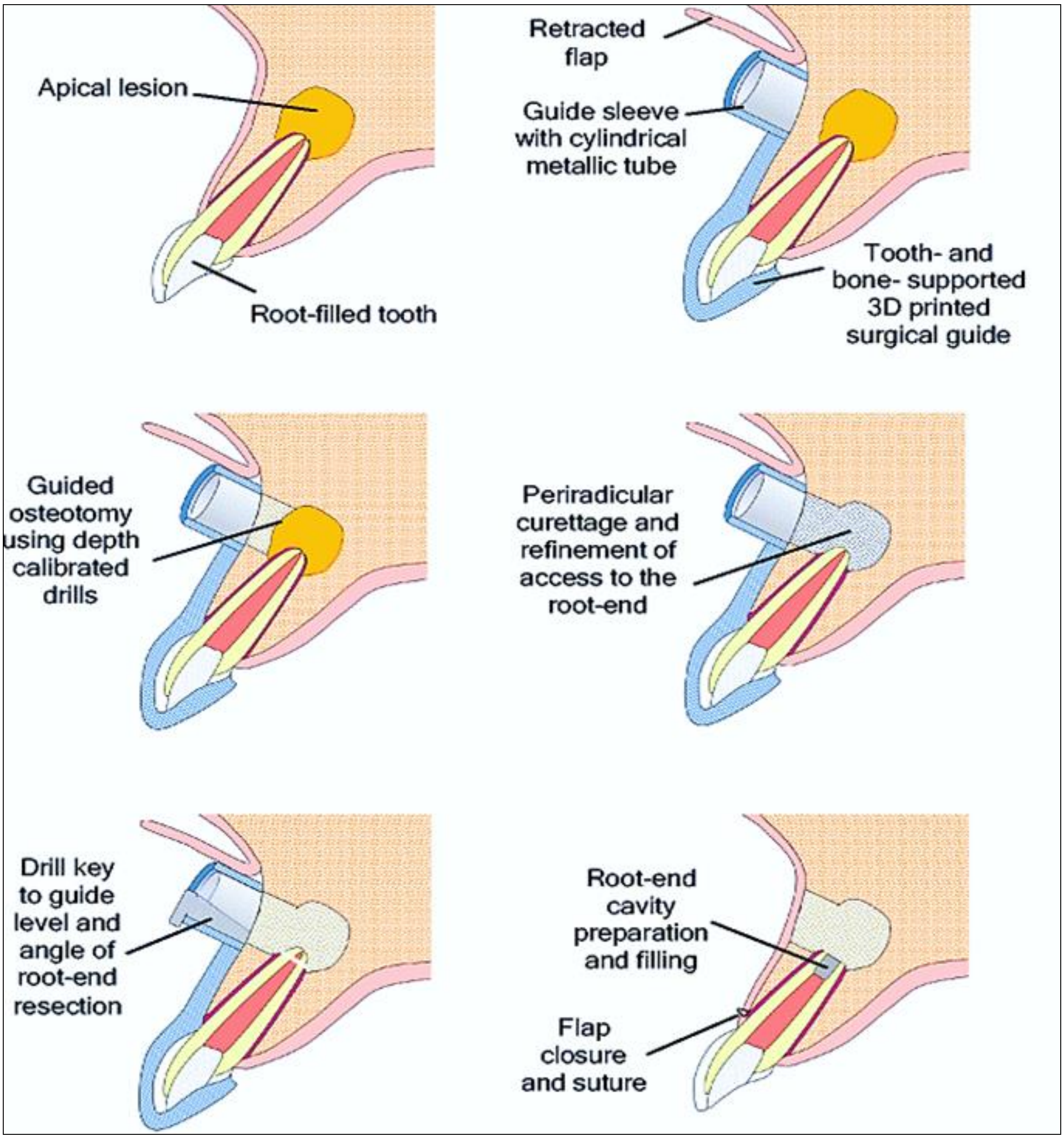


Fig 26: Guided endodontic surgery

Courtesy: Shah P, Chong BS. 3D imaging, 3D printing and 3D virtual planning in endodontics. Clinical Oral Investigations. 2018 12; 22(2):641-54

Future Directions: The integration of Artificial Intelligence (AI) into imaging has the potential to transform the field by automating the analysis of CBCT and MRI scans, enhancing the detection of subtle anatomical details and pathological changes with improved accuracy and speed. Precision-guided robotic systems could further enhance endodontic microsurgery by aiding in instrument stabilization, controlling micro-movements, and performing repetitive tasks, thereby reducing human error and improving surgical outcomes. Research is currently focused on developing advanced root-end filling materials [61]. The emergence of bioactive substances that support tissue regeneration and improve the seal between the apical root end and surrounding periradicular tissues is an evolving area. Future materials may possess intelligent properties, such as the release of growth factors or antimicrobial agents, to enhance healing and minimize infection risks. Nanotechnology could also play a role in creating new filling materials with superior adhesion, biocompatibility, and antibacterial properties, further advancing the success of endodontic microsurgery (Figure 27) [62].

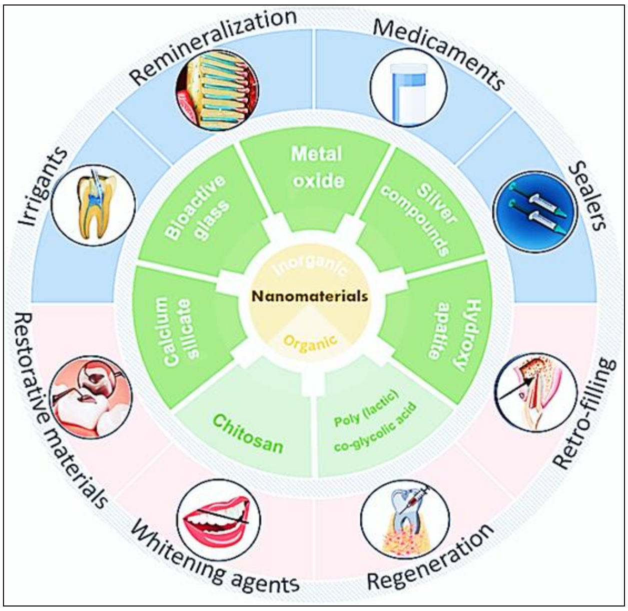


Fig 27: Nanobiomaterials used in endodontic microsurgeries

Courtesy: Afkhami F, Chen Y, Walsh LJ, Peters OA, Xu C. Application of nanomaterials in endodontics. BME Front. 2024; 5:0043

Minimally invasive techniques are progressing with advancements in ultrasonic and laser technologies, providing finer control over tissue removal and root-end preparation. These innovations could lead to less invasive procedures, reduced postoperative discomfort, and quicker recovery times. Future developments might also include integrating regenerative techniques like stem cell therapy and tissue engineering into microsurgical procedures, potentially revolutionizing the repair and regeneration of damaged dental tissues and improving outcomes for complex cases [63]. Enhancements in surgical techniques aim for greater precision in osteotomy and resection. Targeted Endodontic Microsurgery (TEMS) has shown advantages in challenging cases, and future improvements may involve real-time feedback mechanisms to optimize access and treatment [64]. Creating intra operative monitoring systems, such as real-time fluorescence imaging or digital tracking of surgical instruments, could further increase precision and enable immediate adjustments during surgery. Patient-centric approaches, including personalized treatment planning driven by advancements in digital modeling and simulation, promise more tailored strategies based on each patient's unique anatomy and pathology, potentially improving surgical planning and outcome predictions. Enhanced postoperative care may also benefit from future developments in digital tools and remote monitoring systems, which could improve recovery management, reduce complications, and offer real-time support [65]. In education and training, simulation and virtual reality (VR) technologies are set to transform endodontic training by providing immersive, risk-free environments for practicing and refining microsurgical techniques. These tools will also assist in preoperative planning and patient education. Telemedicine platforms could enhance access to expert care, facilitate remote consultations and follow-ups, and promote collaboration among specialists. Ongoing research and clinical trials will be essential for evaluating the effectiveness of new technologies and techniques in endodontic microsurgery. Collaboration among researchers, practitioners, and technology developers will be crucial for driving future innovations and ensuring that advancements are evidence-based and practical [66].

Conclusion

The evolution of endodontic microsurgery has been characterized by considerable advancements in technology, materials, and techniques. Looking ahead, ongoing progress in imaging technologies, precision-guided surgery, cutting-edge materials, and patient-focused approaches is set to further enhance the field. Endodontic microsurgery represents a major leap forward in addressing root canal failures and complex endodontic issues. By employing improved visualization, specialized tools, advanced materials, and a more comprehensive understanding of wound healing, microsurgical endodontics offers a more accurate and effective method for preserving dental health and salvaging teeth that might otherwise be lost. This shift from traditional endodontic surgery to microsurgery involves the integration of state-of-the-art technology and materials with biological principles and clinical practice. As a result, microsurgical techniques are anticipated to consistently produce favorable outcomes in the recovery from endodontic lesions. Successful endodontic surgery requires anticipating potential complications, ensuring adequate access to anatomical variations, and achieving optimal surgical results for both periodontal healing and future restorative considerations.

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