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Research Article

Navigating Pathological Aberrations of Root Canals: A Review

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ABSTRACT
Management of aberrant pathological root canal morphologies poses significant challenges in endodontic therapy, affecting cleaning, shaping, and obturation, potentially compromising treatment outcomes. This review explores contemporary strategies and techniques emphasizing preoperative assessment with cone-beam computed tomography (CBCT) for accurate canal mapping. It highlights the use of dental operating microscopes for improved visualization and precision. Advanced instrumentation techniques, such as flexible nickel-titanium files and adaptive motion systems, aid in negotiating irregular canals while minimizing errors. Additionally, the role of irrigation dynamics and novel delivery systems in thorough debridement is evaluated, along with thermoplasticized obturation for optimal sealing. Emphasis is placed on personalized treatment planning and the integration of emerging technologies to enhance endodontic success.

Key words: anomalies, calcified canals, external resorption, hypercementosis, internal resorption, open apex

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INTRODUCTION

Pathological aberrations of root canals represent a significant challenge in endodontic practice, demanding a nuanced understanding of dental anatomy, pathology, and therapeutic techniques. Root canal systems can exhibit a variety of anatomical complexities and deviations from the norm, which can complicate standard treatment procedures and impact clinical outcomes[1]. These aberrations include variations in canal morphology, the presence of accessory canals, apical deltas, and developmental anomalies, as well as pathological changes like internal and external resorptive defects, calcifications, and iatrogenic errors such as perforations or instrument fractures[2].

Effective management of these aberrations is critical for the successful resolution of periapical pathology and the long-term preservation of the tooth. This requires a multidisciplinary approach that combines advanced diagnostic tools, such as cone-beam computed tomography (CBCT), with sophisticated endodontic techniques and materials. The use of magnification and illumination, alongside contemporary Nickel-Titanium(Ni-Ti) instrumentation, modern irrigation protocols and obturation techniques, enhances the clinician's ability to navigate and treat these complex cases[3].

This review outlines the fundamental concepts and challenges in managing pathological aberrations of root canals, emphasizing the importance of meticulous diagnosis, tailored treatment planning, and the integration of emerging technologies in endodontic practice. Through a detailed exploration of these aspects, this review aims to equip practitioners with the knowledge and skills necessary to tackle even the most challenging endodontic scenarios, ultimately improving patient outcomes and preserving dental health.

BLUNDERBUSS CANAL

"Open apex" refers to when the root of a tooth has not completed its development, particularly in terms of the apex. This incomplete development often results in a widened canal towards the apex, often referred as a blunderbuss canal.

Open apices can be blunderbuss (funnel shaped) which is divergent and flaring or non-blunderbuss (cylindrical shaped) which is parallel and broad[4].

An open apex can develop due to pulp death from decay or injury, root resorption from orthodontics, periapical issues, trauma, or over-instrumentation. Conditions like dens in dente and dentin dysplasia may also contribute. Clinically, these teeth have thin, fragile dentin walls, often with periapical lesions and root resorption. Shortened roots affect long-term stability, making treatment challenging, particularly in determining working length, canal preparation, and proper obturation[5,6].

Diagnosis

Clinical assessment includes history-taking, visual inspection for swelling, discoloration, caries, mobility, and periodontal probing. Traditional pulp tests are less reliable in immature teeth, especially post-trauma, but Doppler flowmetry and pulse oximetry offer alternatives to evaluate pulpal vitality. Radiographs and CBCT aid evaluation, though distinguishing pulp status remains challenging. Children's inconsistent symptoms further complicate diagnosis. Early detection and intervention support pulp preservation and root development[6].

Treatment

In 1964, Kaiser introduced calcium hydroxide for apical closure, mixing it with camphorated parachlorophenol to promote a calcified barrier[7]. Frank later popularized this approach in 1966, emphasizing direct contact with vital tissue for effectiveness. Larger apical openings require longer treatment durations, highlighting the need for patience and precision[8].

Calcium hydroxide's efficacy in apical closure varies, sometimes resulting in incomplete or thin calcified barriers. Treatment can take 5-20 months, increasing fracture risk from prolonged dressing[9]. MTA has emerged as a superior alternative, promoting healing and tissue regeneration. Its calcium ion release, alkaline pH, and hydroxyapatite formation enhance biocompatibility, sealing, and tissue repair[9,10].

For teeth with an open apex, the treatment approach depends on the condition of the pulp.

- If the pulp is still vital (reversible pulpitis), the preferred treatment is apexogenesis, which encompasses methods like indirect pulp capping, direct pulp capping, or pulpotomy.
- However, if the pulp is necrotic (irreversible pulpitis), treatment options include apexification or pulp regeneration. Apexification can be achieved using materials like calcium hydroxide, mineral trioxide aggregate (MTA), or biodentine[11].

Apexogenesis

Apexogenesis is a vital pulp therapy aimed at fostering ongoing root development and root end formation. Its objectives include promoting root lengthening, sustaining pulp vitality for dentin deposition, facilitating natural apical constriction through root end closure, and fostering dentine bridge formation post-pulpotomy[6,12].

Indirect Pulp Capping

The stepwise caries removal technique preserves pulp vitality in immature permanent teeth with deep caries but no apical pathology. It is recommended for teeth showing normal pulp responses to vitality tests, lacking symptoms of pulpitis, or exhibiting reversible pulpitis

The procedure entails initially excavating caries, then sealing the remaining infected dentin with Calcium Hydroxide (CAOH) and Intermediate Restorative Material (IRM). After 3-8 weeks, if the tooth remains symptom-free, the temporary filling is replaced, assessing dentin hardness and color. A final restoration with hard-set CAOH, resin-modified glass ionomer (RMGIC), and composite or amalgam follows. CAOH’s high alkalinity promotes remineralization, reactionary dentin formation, and a protective dentinal barrier, making it a reliable indirect pulp capping agent[6,12].

Direct Pulp Capping

Direct pulp capping is a treatment reserved for exposed vital pulp, using materials such as mineral trioxide aggregate (MTA) or calcium hydroxide (CAOH) to promote reparative dentin and preserve vitality. It is indicated for restorable teeth with carious or traumatic exposure and reversible pulpitis. Hemostasis with 6% NaOCl precedes capping, followed by either a single-visit incorporating a resin-modified glass ionomer cement (RMGIC) base and final restoration, or in two steps, with an interim restoration for 5-10 days.

Partial pulpotomy (Cvek's pulpotomy) removes the coronal pulp while preserving healthy tissue to control inflammation and promote dentin bridge formation using CAOH or MTA.

Complete pulpotomy (cervical pulpotomy) removes the entire coronal pulp, indicated for deep caries or trauma, with CAOH or MTA stimulating hard tissue apposition[6,12].

Apexification

Apexification promotes calcific barrier formation in immature teeth with non-vital pulp, often using CAOH, MTA, Biodentine, Bioaggregate, or EndoSequence. This technique is typically employed for permanent teeth characterized by thin dentin walls or instances where standard instrumentation cannot establish an apical stop.

CAOH induces necrosis and releases bioactive molecules but requires 6-18 months for hard tissue induction, risks incomplete barrier formation, and may weaken dentin, which may lead to fractures.

MTA, introduced in 1993, sets in 3-4 hours, promotes hydroxyapatite formation, and provides a biological seal.

Biodentine (2009) sets in 45 minutes, and comprises tricalcium silicate, dicalcium silicate, calcium carbonate, and other components, aiding hard tissue formation and sealing, while Bioaggregate, with a setting time ranging from 4 to 72 hours, contains tricalcium silicate, dicalcium silicate, and tantalum pentoxide, inducing hard tissue formation upon setting[6,8,12].

EndoSequence, a bioceramic with a 30-minute working time and 4-hour setting time, composed of calcium silicates, zirconium oxide, tantalum oxide, calcium phosphate monobasic, and filler agents, it features nanosphere particles that penetrate dentinal tubules, promoting bioactive apatite crystal formation[12].

Working Length for Apexification

Different authors have different criteria for defining an open apex, often based on the minimum ISO size used. ElAyouti et al. use ISO 60, while Moore et al. use ISO 80. Various methods are employed to determine the working length, including electronic apex locators (EAL) combined with radiographs, tactile techniques using paper points, and tactile methods with a file. The paper point technique may also be used to complement initial EAL readings[6,8,12].

Revitalization/Regeneration Treatment

This procedure aims to regenerate pulp tissue and support root development in immature teeth with nonvital pulp by eliminating bacteria, providing a scaffold, and ensuring a coronal seal. Suitable cases involve permanent teeth with open apices (≥1.1mm) in patients aged 7-16.

The procedure begins with tooth anesthesia and isolation, followed by irrigation with 2.5% NaOCl, and triple antibiotic paste (TAP) application. After a month, the TAP is removed, and the canal is conditioned with 2.5% sodium hypochlorite and 17% EDTA to enhance stem cell adherence and differentiation during pulp regeneration. Bleeding is induced into the canal by passing a file beyond working length, which is left for 15minutes for the blood to clot, serving as a protein scaffold, before MTA placement followed by a moist cotton pellet and a temporary restoration. The patient is recalled after 24 hours for final restoration[6,11-13].

MTA is now preferred over glass ionomer and calcium hydroxide as an intracanal barrier (AAE 2016).

If there is no noticeable evidence of regeneration after three months, traditional treatment methods can be implemented[12].

Drawbacks of this regeneration approach include tooth discoloration, prolonged treatment duration, inadequate root development, insufficient bleeding, and canal calcification[6,10-12].

Root-end closure can be achieved with thermoplasticized obturation or customized gutta-percha, often combined with sealers or resorbable barriers. In cases where nonsurgical retreatment is unfeasible or prognosis is poor, especially in immature teeth with thin dentin or short roots prone to fracture, adapting a gutta-percha cone is challenging. MTA, known to strengthen root dentin, can be used for complete obturation in such cases[14].

Clinicians should carefully consider all treatment options for open apex cases, with regular follow-ups to monitor complete root formation.

INTERNAL AND EXTERNAL RESORPTION

Root resorption is a physiological or pathological process resulting in the deterioration of dental tissues, particularly affecting the roots of teeth.

There are diverse causes for root resorption, including trauma, orthodontic treatments, infections, and systemic conditions. Each type of resorption may stem from distinct triggers and mechanisms. For instance, external root resorption might arise from injuries or orthodontic pressures, while internal root resorption could be linked to inflammation or decay within the pulp[15,16].

Treatment approaches vary depending on the severity and nature of the resorption, alongside the underlying cause. For minor instances of external root resorption, intervention might not be necessary, whereas more extensive cases might require endodontic therapy or surgical interventions. Careful planning of orthodontic procedures is crucial to mitigate the risk of exacerbating existing resorption[17]. Comprehending the specific causes, progression, and treatment strategies associated with various types of root resorption is essential for effectively managing and conserving dental structures.

There are several ways to categorize root resorption, considering factors like histology, origin, etiology, and location.

Internal root resorption (IRR) typically initiates along the root canal wall, potentially causing damage to the dentine and dental tubules within the root. If left untreated, it can progress to the point of root perforation, which may lead to the formation of lesions if the entire root canal system becomes infected. Root resorption often occurs in teeth with infected necrotic root canals, commonly due to issues like caries and microleakage. On the other hand, external root resorption (ERR) arises from the activation of osteoclasts on the outer surface of the root, resulting in the loss of cementum[15,18].

Diagnosis

Root resorption requires prompt identification for effective management. Diagnosis relies on clinical and radiographic assessments, often complicated by asymptomatic cases.

Table 1: Characteristic features of Root Resorption

Resorption Type	Internal		External			
	Inflammatory	Replacement	Inflammatory	Replacement	Cervical	Surface
Clinical finding	Discolouration, symptoms of irreversible pulpitis and/or apical periodontitis	Discolouration, Symptoms of irreversible pulpitis and/or apical periodontitis	Discolouration, symptoms of apical periodontitis	May exhibit a metallic percussion sound. Mobility not expected	Probable periodontal defect, symptoms of (ir)-reversible pulpitis	None
Clinical appearance	Pink spot (rare), or sign of pulpitis / apical periodontitis.	Pink spot (rare), or sign of pulpitis / apical periodontitis.	Healthy, or sign of pulpitis / apical periodontitis.	Healthy	+/- pink spot, or sign of pulpitis / apical periodontitis.	Healthy
Location on root	Anywhere	Anywhere	Anywhere	Anywhere	Cervical third initially but can be seen in mid and apical third in advanced cases	Adjacent to impacted tooth, cyst or tumour. Apical in orthodontically treated teeth
Pulp sensitivity	Maybe +ve in partially vital cases, or -ve in advance necrotic cases	Maybe +ve in partially vital cases, or -ve in advance necrotic cases	-ve	+ve	Usually +ve, –ve in advanced necrotic cases	+ve
Radiological appearance	Symmetrical oval shaped (ballooning) enlargement of root canal	Oval shaped enlargement of root canal with cloudy and/ or mottled canal wall	Asymmetrical bowl shaped periradicular or periapical radiolucencies	Asymmetrical bony replacement of root surface and loss of PDL space	(A)symmetrical radiolucent (early), or radiopaque (advanced) appereance. Lesion moves on parallax views	Blunted root apex. Asymmetrical loss of root
Root canal	Canal expands into lesions	Canal expands into lesions	Intact in early EIR, perforation in advanced cases	Intact	Intact, but perforation in advanced cases	Intact

Internal Root Resorption (IRR):

IRR may appear as a pink discoloration ("pink spot") on the crown, progressing to a grey hue as pulp necrosis sets in. Symptoms are rare but can include reversible or irreversible pulpitis as lesions expand. Severe cases may show periapical periodontitis signs like discoloration, sinus tracts, or tenderness to touch, or sensitivity to percussion[15].

Radiographically, IRR presents as symmetrical round or oval radiolucent areas within the root canal. A small field of view, high-resolution CBCT is recommended for precise evaluation, though IRR may be mistaken for external cervical resorption (ECRR), especially in multi-rooted teeth[15].

External Root Resorption (ERR):

ERR may resolve naturally or remain localized. If it affects over 20% of the root, the tooth may lose mobility and produce a metallic percussion sound. It typically retains sensitivity, though tertiary dentin can delay responses. However, if sensibility testing yields no response and there are no other clinical signs or symptoms of endodontic infection, this alone does not necessarily warrant endodontic treatment[18].

ERR subtypes include:

- **ESRR (External Surface Root Resorption):** Uneven root loss, often due to orthodontic treatment.
- **ECRR (External Cervical Root Resorption):** Varies in radiographic appearance, making differentiation from IRR challenging.
- **EIRR (External Inflammatory Root Resorption):** Found in infected necrotic teeth, often with shortened apices.

CBCT is crucial for determining the type, location, and severity of resorption but should be used judiciously due to radiation exposure[18].

Management

Treatment selection depends on factors like age, tooth position, occlusion, root perforations, periodontal health, and existing restorations. Options include observation for asymptomatic cases, non-surgical RCT, surgical intervention, regenerative endodontics, or extraction. The choice between RCT and combined treatments depends on perforation severity. The primary goal is to eliminate bacteria, disinfect root canals, and stop resorption[15].

Nilsson et al. suggest treating root resorption (RR) with orthograde RCT, retrograde apical treatment, or extraction. Calcium hydroxide is a common intracanal medicament, while Ledermix and antibiotic pastes offer alternatives but may cause discoloration. To reduce this risk, double antibiotic pastes (ciprofloxacin and metronidazole) are recommended over triple antibiotic pastes. Orthograde RCT is preferred for removing granulation and infection, with surgical and conventional RCT using MTA or calcium silicate cement as alternative options for managing canal lesions[15].

Granulomatous lesions often cause significant bleeding upon canal access, which ceases after pulp and granulation tissue removal. Due to the complexity of resorptive defects, experts recommend energized irrigation and inter-appointment medication. Proper adaptation and compaction are crucial for obturating irregular internal root resorption (IIR). In cases of root perforation, sealing with bioactive materials like MTA or Biodentine may be necessary[18].

The treatment for internal root resorption (IRR) aligns with internal inflammatory resorption (IIR) and involves root canal therapy with energized irrigation and thermoplasticized gutta-percha. Ultrasonic tips may aid in navigating hard tissue. If the lesion is perforated but restorable, surgical intervention may be required to prevent extrusion of filling materials[17].

Altundasar et al.[19] treated perforating IRR using MTA and periodontal surgery. Various materials, including amalgam, zinc oxide/eugenol cement (such as IRM and SuperEBA), glass-ionomer, composite resin, MTA, biodentine, and bioceramics, have been studied for sealing perforations. MTA and biodentine are favoured for their biocompatibility and sealing properties, while Arifati et al[20] preferred biodentine for its ease of handling and rapid setting. CEM cement also serves as a viable alternative[15].

For root perforations, bioactive hydraulic silicate cements like MTA and Biodentine are recommended[15]. Thermoplastic filling techniques improve adaptation, while surgical intervention is necessary if orthograde access is insufficient. Before proceeding with surgical repair, treatment involves establishing canal access, maintaining patency, and sealing with bioactive cement before RCT[18]. Regenerative endodontics may help halt resorption and promote hard tissue formation[15].

Restoration depends on remaining tooth structure, with options ranging from composite resins to ceramic crowns. Durability and cost also influence selection. Extensive resorption may weaken the tooth, leading to potential fracture or extraction. Further research is needed to evaluate the effectiveness of regenerative endodontic procedures[15,17].

HYPERCEMENTOSIS

Hypercementosis, or cementum hyperplasia, is the excessive, non-neoplastic deposition of cementum on the root surface[21]. Pinheiro et al[22] note that diagnosis requires cementum formation exceeding normal levels, causing abnormal root thickening and shape alterations. In 1931, Gardner and Gardnes linked infection to hypercementosis, noting it was 4.2 times more common in necrotic teeth[23]. Thoma and Goldman showed it affects both erupted and unerupted teeth, suggesting causes beyond function or occlusion[24].

Mild irritation may stimulate cementum growth, and hypercementosis is associated with Paget's disease and aging [21]. Shafer et al[25] suggested low-intensity inflammation, like apical pericementitis or chronic pulpitis, as a trigger. Prabhakar et al. linked repetitive dental abscesses to its development[25].

Diagnosis

Radiographically, hypercementosis appears as thickened, rounded apices with an enlarged root surrounded by a radiolucent periodontal ligament space. Differentiation from cementoblastoma can be challenging due to similar radiopacity of cementum and dentin. While treatment is usually unnecessary, some cases may require tooth sectioning before extraction[26].

Management

Pinheiro et al[22] observed that in hypercementosis, the dentinal canal is over 1 mm above the radiographic apex, complicating endodontic shaping and filling. Excess cementum may obstruct instruments, retaining contaminated tissue and risking treatment failure. Coolidge[27] linked pathological cementum deposition to root fractures, while Barros[28] associated hypercementosis with increased secondary and accessory canals, apical deltas, and altered canal paths, which may not be radiographically visible. These changes can harbour bacteria, contributing to chronic apical periodontitis. Additionally, hypercementosis may displace the foramen laterally, leading to endoperiodontal lesions. Kuttler[29] noted that apical anatomy varies, with hypercementosis increasing the distance between key landmarks, complicating endodontic procedures.

Root Canal Shaping and Filling Limits

Endodontists set the working length below the radiographic apex to avoid periapical damage. The apical constriction, 0.5–2 mm below the apex, is a common reference but difficult to identify, especially in cases of resorption or periapical pathology. Wu et al. suggested using the root apex as the most reliable landmark, setting the apical limit 0–3 mm below the apex based on pulp diagnosis. Ingle advocated stopping at sound dentin to preserve the pulp stump, particularly in cases of biopulpectomy. Leonardo recommended limiting instrumentation 1–2 mm below the apex in vital pulps, while necrotic cases require adjustments based on periapical conditions. In necropulpectomy cases without periapical lesions, the working length is set 1–2 mm below the radiographic apex. For cases with chronic periapical lesions and cementum resorption, it should be around 1 mm below the radiographic apex[21].

Apical Patency

Pinheiro et al.[22] found that most teeth with mild and diffuse hypercementosis had smooth apexes with multiple foramina, while moderate hypercementosis presented more irregularities and foramina, and severe hypercementosis sometimes showed apex obliteration.

Maintaining apical patency helps preserve working length and enhances irrigant effectiveness. Traditional techniques stop at the apical constriction, but cleaning the foramen is recommended in necrotic cases, as microorganisms may reside in the cementum canal and periapical tissues[21].

Conversely, in vital pulp cases, removing healthy tissue is unnecessary. Accurate working length determination prevents inadequate cleaning, shaping, and potential postoperative symptoms.

For hypercementosis cases, conventional treatment is suitable for mild forms, while moderate to severe cases may require instrumentation to the apical foramen if necrotic tissue is present. Thermoplasticized Gutta-percha can effectively seal accessory canals and apical deltas[21]. Due to limited studies, treatment guidelines for hypercementosis remain unclear, requiring case-by-case clinical assessment to optimize endodontic protocols.

CALCIFIED CANALS

The American Association of Endodontists defines Calcific Metamorphosis (CM) as "a pulpal response to trauma characterized by rapid deposition of hard tissue within the canal space." Also known as pulp canal obliteration, dystrophic calcification, diffuse calcification, and calcific degeneration.

CM results from pulp chamber calcification, causing the crown to appear darker, less translucent, and yellowish. It involves hard tissue deposition within the root canal and is often linked to trauma-induced neurovascular damage[30].

Diagnosis requires a thorough medical, dental, and trauma history, along with clinical examination. CM may appear as early as three months post-injury but often remains undetected for a year. Pulp vitality tests can produce false negatives. Other causes include dentinal dysplasia, dentinogenesis imperfecta (type 2), and rigid splinting. Common in concussion or subluxation injuries, CM may present minor or unnoticed symptoms. Its occurrence depends on the severity of luxation and root development stage[30].

Radiographically, calcific metamorphosis (CM) is classified as partial obliteration, where the pulp chamber is indistinct and the canal is significantly narrowed but visible, or total obliteration, where both structures are barely or not visible. Despite this, a narrow canal is always present, even if undetectable on radiographs[31].

Kronfeld and Boyle identified two types of pulp calcifications: diffuse or linear calcifications, common in radicular pulp, and pulp stones (denticles), more frequent in the coronal region. Denticles are categorized as true (with dentinal tubules and odontoblastic processes) or false (concentric calcified layers with a necrotic central area). They can also be classified by location as embedded, interstitial, adherent, or free[30].

Pulp obliteration may be total or partial. In total obliteration, the pulp chamber and canal are nearly or completely undetectable, though some organic material may remain. Partial obliteration significantly narrows the root canal but preserves circulation, maintaining pulp health. Obliteration can be localized (due to trauma, fractures, luxation, or replantation) or generalized (age-related, often seen with attrition). Post-traumatic pulp canal obliteration rates range from 3.8% to 24% [32].

Treating calcified canals is challenging due to difficulty in locating and shaping them, increasing the risk of instrument breakage. Widening the canal orifice aids access, while thorough cleaning and shaping ensure effective obturation. Asymptomatic calcified teeth may not require intervention, but endodontic treatment is necessary if periapical pathology is present[30].

Management

The impact of an obliterated pulp canal remains debated, with 1-16% of cases developing pulpal pathology. Regular follow-up is essential. External bleaching can address discoloration in asymptomatic cases, while irregular dentin formation may require endodontic treatment and non-vital bleaching[33]

Successful root canal treatment relies on understanding canal anatomy. Preparing the access cavity before rubber dam placement aids in evaluating the working length and root relationships. Once the canal is located, the rubber dam is applied, and treatment proceeds.

Negotiation

The use of Instruments

Navigating calcified canals requires small files, such as #8 and #10 K-files, using a gentle watch-winding motion with minimal pressure. K-files with modified tips by slicing diagonally to enhance its thinness has been developed to effectively penetrate constricted canals and also work-hardened stainless-steel instruments like Canal Pathfinder, C+ Files, and D-finder files improve rigidity and penetration. Additionally, variable regressive taper glide finder files with active tips have been recently introduced for the catheterization of calcified canals, although their efficacy needs to be evaluated. Nickel-titanium files are contraindicated for this use due to their lack of torsional strength[30,32].

Additionally, Long-shafted burs, including LN-burs, Mueller burs, and Munce Discovery burs, aid in orifice identification while improving visibility. A crown-down approach in 1 mm increments helps prevent complications. Ultrasonic tips, used with magnification and methylene blue dye, enhance canal detection. The buckling resistance activation test (BRAT) can assist with apical penetration[30,32].

Role of chelating agents And The Continuous Chelation Concept

Chelators aid in root canal preparation, especially in calcified canals. Apical dentin is often sclerosed, making liquid EDTA useful for locating canal entrances. Chelators modify the calcified substrate by acting on calcium ions, while sodium hypochlorite (NaOCl) removes organic material and alters the mechanical properties of dentin.

Continuous chelation combines a weak chelator with NaOCl, maintaining its antimicrobial and proteolytic effects. Etidronic acid (HEDP), available as "Dual Rinse HEDP," offers an all-in-one solution for deproteinizing, disinfecting, and chelating. This approach reduces irrigation time and facilitates instrument penetration in calcified canals[32].

Biomechanical Preparation

Successful management of calcified and curved canals requires careful access to the pulp chamber. As calcification progresses coronoapically, locating the initial canal is crucial for easier instrumentation. Several anatomical laws aid in identifying pulp chamber position and canal orifices.

Accessing the chamber typically involves a tapered diamond bur, followed by non-cutting carbide burs for refinement. For a deeper search of canal orifices through the pulp chamber floor, longer burs of small diameters may be beneficial.

Thin explorers (DG-16, JW-17), rhodium mirrors, and ultrasonic diamond tips improve visibility and aid in locating canals. Establishing a reproducible glide path minimizes procedural errors (Berutti et al., 2012)[34]. Initial exploration uses size 06–10 K-files with a watch-winding motion until resistance is met. Stainless steel files larger than size 15 require a balanced force technique to navigate curvatures effectively. These files are inserted using clockwise rotation and light inward pressure, with counterclockwise rotation and inward pressure being used for cutting. This sequence is repeated until the desired working depth is achieved. If the file reaches length, the canal can be enlarged in a standardized approach with hand files or rotary instruments (Ingle, 1961)[35].

Irrigation with NaOCl and EDTA softens calcified tissues and enhances disinfection (Hülsmann et al., 2003; Zehnder, 2006; Boutsioukis et al., 2010). Activation methods like sonic/ultrasonic instruments, negative pressure, laser-assisted irrigation, and machine-assisted systems (PIPS, GentleWave) improve cleaning (Haapasalo et al., 2014). While negotiating and managing calcified canals present challenges, they can be overcome by following a proper protocol. Operator skill, patience, and the right armamentarium are essential for successful treatment of these challenging canals[35].

Endodontic surgery

Root-end resection and filling are options to be considered when a canal cannot be located. Endodontic microsurgery provides direct access to the root apex but poses challenges in identifying calcified canals post-resection. Surgery is considered only if nonsurgical treatment or retreatment fails to resolve periapical disease or symptoms[30].

Guided Negotiation of Calcified Canals

Locating calcified root canals is challenging, risking tooth structure loss and complications. Traditional methods have a 20–70% failure rate in treating pulp canal obliteration (PCO). Even experienced endodontists with advanced tools may struggle. A new approach called "Guided Endodontics," using static-guided (SG) or dynamic-guided (DG) techniques, offers an alternative for complex cases. The static-guided technique uses a CBCT-based guiding template to locate calcified root canals, enhancing accuracy and preserving tooth structure. Software like coDiagnostiX 10.5 integrates CBCT and 3D intra-oral scans to create a guide directing the bur. Studies show minimal deviations, with a mean drill path error of <0.7 mm (Buchgreitz et al.), while Zehnder et al. showed low deviations between planned and prepared access cavities, with mean angle deviations of 1.81◦. Despite its accuracy, limitations include high costs, long treatment time, and challenges in curved canals. Inaccuracies stem from the loose drill fit within the sleeve, though metal sleeves can improve control. Careful irrigation during drilling is also essential to avoid heat-related injuries to the periodontal ligament and adjacent bone. While CBCT aids in preoperative planning, its radiation dose and limited intraoperative visualization remain drawbacks. The dynamic-guided technique may overcome some of these limitations[32].

While, the dynamic-guided technique uses a portable unit with an overhead light, a stereoscopic motion-tracking camera, and planning software to guide a calibrated handpiece in real time. The system monitors the position of the patient and the dental handpiece throughout the procedure. Surgeons plan the ideal drill position virtually using CBCT data, with sensors transferring 3D spatial information. It is especially beneficial for cases with limited mouth opening or posterior region treatments where a template may be impractical. Studies confirm its accuracy, but drawbacks include high cost, the need for operator proficiency, and the bulkiness of some systems[32].

CONCLUSION

Managing pathological root canal aberrations requires expertise in anatomy, advanced diagnostics, and modern therapeutic techniques. Unusual morphologies, accessory canals, and resorptive defects pose significant treatment challenges. Advancements in technologies like CBCT imaging, dental microscopes, NiTi instruments, and advanced irrigation systems enhance diagnosis and treatment precision. These innovations, combined with a thorough diagnostic approach and tailored planning are key to managing complex endodontic cases successfully.

Ultimately, the goal is to resolve periapical pathology and preserve the natural tooth. Advanced technologies and a meticulous approach help endodontists achieve optimal outcomes, enhancing patient care and dental health.

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