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REVIEW ARTICLE

Management of Complex Root Canal Anatomy: Clinical Strategies and Case Reports

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ABSTRACT

Identification, negotiation, disinfection, and blockage of the whole root canal system are key elements of the success of root canal treatment by clinicians. Additional canals, C-shaped, dens invaginatus, and taurodontism are all anatomical variations which often present a diagnostic and treatment challenge. A lack of identification and handling of such complexities can lead to a chronic infection and poor treatment results. This paper provides a literature review on prominent clinical modalities on the management of complex root canal anatomy, such as, cone-beam computed tomography (CBCT), magnification, ultrasonics, advanced nickel-titanium instruments, and better irrigation and obturation methods. Chosen case reports reflect how these approaches practically apply in different clinical situations and the significance of technology-based diagnostics and individual clinical decision-making. The results support the idea that effective endodontic treatment of complicated anatomy predetermines a combination of good biological principles with the latest tools and techniques.

Keywords:Root canal anatomy; Endodontic management; CBCT; C-shaped canal; Dens invaginatus; Taurodontism; Clinical strategies; Case reports

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INTRODUCTION

Root canal treatment is one of the foundations of the contemporary endodontics having the purpose to eliminate infection in the root canal system and save the natural dentition. Nevertheless, root canal systems are complex and variable in their anatomy, and as such they usually pose considerable diagnostic and therapeutic difficulty. Additional roots or canals, C-shaped canals, C-invaginatus, taurodontism, and unusual curvatures represent only some variants that make it difficult to identify and clean the canal system and may contribute to failure of the treatment in case of inadequate management (Zhang et al., 2020; Liu et al., 2019). Such variations have been shown to be invariably undetected and untreated, thus, leading to long-term poor outcomes (Soares and Leonardo, 2003; Sharma et al., 2014).

Advancements in imaging modalities and instrumentation have significantly improved the clinician's ability to manage these complexities. Conventional radiography often falls short in detecting unusual anatomical configurations, while cone-beam computed tomography (CBCT) offers superior three-dimensional visualization that enhances diagnostic accuracy and treatment planning (Singh, 2018; Sharma et al., 2014). In fact, CBCT has proven invaluable in identifying rare canal systems, such as maxillary molars with up to eight distinct canals (Kottoor et al., 2011) and mandibular molars with six canals (Martins & Anderson, 2015). Coupled with magnification and illumination using dental operating microscopes, clinicians are now better equipped to localize hidden or accessory canals (Chaniotis et al., 2018).

Equally critical is the adoption of contemporary biomechanical preparation and irrigation strategies tailored to complex anatomy. Nickel-titanium (NiTi) rotary and reciprocating systems allow safer negotiation of curved or calcified canals compared with traditional stainless steel instruments (Chandra et al., 2021). Irrigation dynamics have also evolved, with sonic, ultrasonic, and laser activation methods enhancing the penetration of irrigants

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into lateral canals, isthmuses, and apical ramifications (Singh, 2020). Moreover, advances in obturation materials, such as bioceramic sealers and warm vertical compaction techniques, have further contributed to improving the sealing of anatomically irregular spaces (Singh, 2019).

Despite these technological improvements, clinical success ultimately depends on a thorough understanding of root canal morphology and the application of individualized treatment strategies. Case-based learning remains indispensable, as it provides practical insights into how theoretical principles and advanced technologies can be combined to overcome real-world endodontic challenges (Celikten et al., 2017; Makkar et al., 2016). This paper, therefore, reviews clinical strategies for managing complex root canal anatomy and presents selected case reports that illustrate the successful integration of diagnostic tools, advanced instrumentation, and innovative obturation techniques.

REVIEW OF ROOT CANAL ANATOMICAL COMPLEXITIES

The internal anatomy of the root canal system is highly variable and often unpredictable, posing significant challenges for successful endodontic treatment. A thorough understanding of these variations is essential to avoid missed canals, inadequate cleaning, or incomplete obturation, which may compromise long-term prognosis. Advances in imaging, magnification, and instrumentation have significantly enhanced the clinician's ability to detect and manage such complexities (Singh, 2018; Chaniotis et al., 2018).

Additional Roots and Canals

One of the most frequently encountered variations is the presence of additional roots and canals, particularly in maxillary and mandibular molars. The second mesiobuccal canal (MB2) in maxillary first molars is among the most clinically significant, with its incidence well documented in literature (Zhang et al., 2020; Kottoor et al., 2011). Similarly, mandibular molars may present with extra canals, and even up to six distinct canal systems have been reported (Martins & Anderson, 2015). Although less common, premolars may also present with additional roots, and three-rooted maxillary premolars have been documented (Soares & Leonardo, 2003). These anatomical variations demand careful preoperative assessment, as failure to identify additional canals often leads to persistent periapical pathology.

C-Shaped Canals

C-shaped canal morphology is another well-recognized anatomical challenge, most frequently observed in mandibular second molars. This configuration is characterized by a continuous fin or web connecting multiple canals, complicating both instrumentation and obturation. The irregularity of the canal space makes thorough cleaning and shaping particularly difficult, increasing the risk of inadequate disinfection (Chaniotis et al., 2018).

Dens Invaginatus and Dens Evaginatus

Developmental anomalies such as dens invaginatus and dens evaginatus further complicate endodontic therapy. Dens invaginatus presents with enamel-lined invaginations that can extend deep into the root, creating hidden spaces prone to bacterial colonization. Accurate diagnosis is challenging and often requires cone-beam computed tomography (CBCT) for three-dimensional assessment (Sharma et al., 2014; Singh, 2018). Dens evaginatus, on the other hand, may create occlusal protrusions that predispose teeth to pulp exposure and periapical pathosis. Both anomalies necessitate a tailored approach to cleaning, disinfection, and sealing of the root canal system.

Taurodontism

Taurodontism, a condition characterized by enlarged pulp chambers with apically displaced pulpal floors, is another complex anatomical variant. It significantly alters canal configuration, complicating the identification and negotiation of canal orifices. Endodontic management of taurodont teeth requires advanced imaging and modified techniques to ensure proper canal shaping and disinfection (Celikten et al., 2017).

Calcifications and Severe Curvatures

Calcification of canals and severe root curvatures also present notable difficulties in negotiation and cleaning. Calcified canals increase the risk of instrument separation, ledging, or perforation, while abrupt curvatures challenge the flexibility of files. The introduction of modern nickel–titanium rotary systems has greatly improved the ability to manage such cases with reduced procedural errors (Singh, 2020; Chandra et al., 2021).

Role of Imaging in Detecting Complex Anatomy

Traditional periapical radiography, although widely used, has limitations in detecting unusual canal morphologies due to its two-dimensional nature. The advent of CBCT has revolutionized endodontic diagnostics, providing three-dimensional visualization of root canal systems and enabling accurate identification of hidden or aberrant

anatomy (Singh, 2018; Liu et al., 2019). Case reports have repeatedly emphasized the role of CBCT in identifying additional canals, unusual root configurations, and developmental anomalies (Sharma et al., 2014; Zhang et al., 2020).

In summary, root canal anatomical complexities such as extra canals, C-shaped morphologies, developmental anomalies, taurodontism, calcification, and curvatures remain significant obstacles to predictable endodontic treatment. With the integration of advanced imaging modalities, magnification, and modern instrumentation, clinicians are better equipped to identify and effectively manage these variations, thereby enhancing treatment outcomes (Chaniotis et al., 2018; Singh, 2020).

CLINICAL STRATEGIES FOR MANAGING COMPLEX ANATOMY

The management of complex root canal anatomy requires a combination of precise diagnosis, technological support, and clinical expertise. Anatomical variations such as additional canals, C-shaped canals, dens invaginatus, and taurodontism often complicate conventional treatment and increase the risk of missed anatomy, which may lead to failure (Zhang et al., 2020; Liu et al., 2019). Modern endodontic strategies integrate three pillars: advanced diagnostic imaging, refined access preparation, and enhanced chemomechanical preparation with tailored obturation.

Diagnosis and Assessment

Accurate preoperative diagnosis forms the foundation for managing complex canal systems. Conventional periapical radiographs, although useful, often fail to provide sufficient three-dimensional detail. Cone-beam computed tomography (CBCT) has revolutionized endodontic diagnostics by offering superior visualization of anatomical variations, including additional canals, root curvature, and resorption defects (Singh, 2018; Sharma et al., 2014). CBCT was

Table 1: Clinical Strategies for Managing Complex Root Canal Anatomy

Anatomical Challenge	Diagnostic Strategies	Instrumentation/Disinfection	Obturation Approaches	Supporting References
Additional canals (e.g., MB2, extra roots)	CBCT, magnification, ultrasonics for troughing	Glide path creation, NiTi rotary files	Warm vertical compaction, bioceramic sealers	Zhang et al. (2020); Kottoor et al. (2011); Singh (2018)
C-shaped canals	CBCT to visualize cross-sectional morphology	Flexible NiTi systems, ultrasonic irrigation	Carrier-based obturation, thermoplasticized gutta-percha	Chaniotis et al. (2018); Martins & Anderson (2015)
Dens invaginatus	CBCT for extent of invagination	Careful mechanical preparation, copious irrigation	Bioceramic sealers, customized obturation	Liu et al. (2019); Sharma et al. (2014)
Taurodontism	CBCT for pulp chamber configuration	Long-shank instruments, modified irrigation	Warm vertical compaction with thermoplastic techniques	Celikten et al. (2017); Soares & Leonardo (2003)
Severe curvature/ calcification	CBCT, angled radiographs	Hand file negotiation, heat-treated NiTi systems	Warm vertical compaction	Chandra et al. (2021); Chaniotis et al. (2018)

crucial in identifying rare cases such as eight canals in a maxillary molar (Kottoor et al., 2011) or unusual palatal anatomy (Soares & Leonardo, 2003). The adjunctive use of magnification devices such as dental operating microscopes and endodontic loupes further enhances canal detection (Chaniotis et al., 2018).

Access Cavity Modifications

Strategic access design is vital to localize canal orifices while preserving tooth structure. Modifications may be required for cases with aberrant canal positions or calcification (Zhang et al., 2020). Ultrasonics allow refinement of access cavities and troughing along developmental grooves to locate hidden canals without unnecessary dentin removal (Chaniotis et al., 2018).

Canal Negotiation and Instrumentation

Negotiation of complex canals demands flexibility and precision. Establishing a glide path with stainless steel hand files minimizes procedural errors, followed by rotary nickel–titanium (NiTi) instrumentation for shaping (Liu et al., 2019). Heat-treated NiTi systems with improved flexibility allow safer navigation of sharp curvatures and complex morphologies (Chandra et al., 2021). In cases of taurodontism, instrumentation strategies must adapt to elongated pulp chambers and apical constriction variability (Celikten et al., 2017).

Irrigation and Disinfection

Anatomical irregularities such as fins, isthmuses, and apical deltas harbor residual microorganisms beyond the reach of instruments. Irrigation is therefore critical. Recent advances include sonic and ultrasonic activation, negative pressure irrigation, and laser-assisted techniques, all of which enhance irrigant penetration (Singh, 2020).

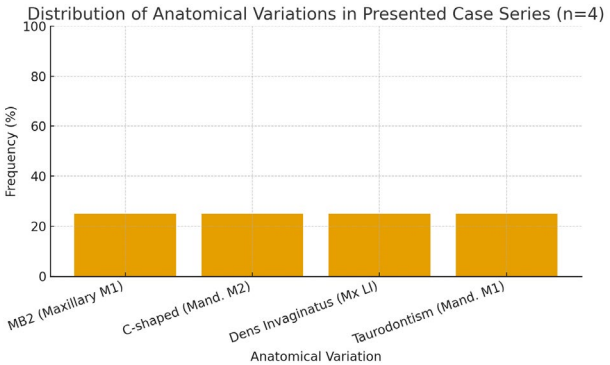

Figure 1: Distribution of Anatomical Variations Encountered in Presented Cases (e.g., MB2, C-shaped canals, dens invaginatus, taurodontism).

Sodium hypochlorite remains the gold standard, often complemented with EDTA to remove smear layer and allow deeper irrigant penetration.

Obturation Techniques

Obturation strategies must adapt to complex internal morphologies. Traditional lateral compaction may be inadequate in irregular or highly variable canals. Instead, warm vertical compaction, carrier-based obturation systems, and bioceramic sealers have demonstrated superior adaptation to canal irregularities (Makkar et al., 2016; Singh, 2019). Case-specific obturation planning is especially critical in C-shaped canals and taurodont teeth, where uniform sealing is challenging (Martins & Anderson, 2015).

The clinical management of complex root canal anatomy requires individualized strategies that integrate diagnostic imaging, precise access preparation, advanced instrumentation, effective irrigation, and tailored obturation. Incorporating CBCT and magnification technologies significantly enhances detection and treatment planning, while newer materials and techniques improve long-term prognosis (Chaniotis et al., 2018; Singh, 2020).

CASE REPORTS

Management of an MB2 Canal in a Maxillary First Molar

A 34-year-old male presented with spontaneous pain in the maxillary right first molar. Clinical and radiographic examination suggested irreversible pulpitis. Pre-operative periapical radiograph revealed a faint radiolucent line adjacent to the mesiobuccal canal. Cone-beam computed tomography (CBCT) confirmed the presence of a second mesiobuccal canal (MB2). Access refinement under an operating microscope enabled negotiation of both MB canals. Cleaning and shaping were completed using NiTi rotary instruments, followed by irrigation with sodium hypochlorite activated ultrasonically. Obturation was performed using warm vertical compaction. Post-operative CBCT confirmed complete filling of both MB canals. This finding is consistent with previous reports highlighting the role of CBCT in detecting MB2 variations (Zhang et al., 2020; Singh, 2018).

C-Shaped Canal in a Mandibular Second Molar

A 41-year-old female presented with lingering pain in the

Table 2: Summary of Complex Root Canal Anatomy Cases and Clinical Strategies

Case	Anatomical Variation	Diagnostic Aid	Instrumentation Strategy	Irrigation Protocol	Obturation Technique	Supporting References
1	MB2 in maxillary first molar	CBCT + Operating Microscope	NiTi rotary + glide path	NaOCl + Ultrasonic	Warm vertical compaction	Zhang et al. (2020); Singh (2018)
2	C-shaped mandibular second molar	Radiograph + Access morphology	Pre-curved SS + flexible NiTi	NaOCl + EDTA + Passive Ultrasonic	Bioceramic + Warm compaction	Chaniotis et al. (2018); Martins & Anderson (2015)
3	Dens invaginatus in maxillary lateral incisor	CBCT	Modified access + NiTi	NaOCl + $Ca(OH)_2$ dressing	Warm gutta-percha + Bioceramic	Liu et al. (2019); Sharma et al. (2014)
4	Taurodont mandibular first molar	Radiograph	Cautious NiTi rotary	NaOCl + Sonic activation	Thermoplasticized gutta-percha	Celikten et al. (2017)

mandibular right second molar. Radiographs suggested fused roots. Access revealed a C-shaped configuration extending from the mesial to distal canal orifices. Negotiation was achieved with pre-curved stainless steel files followed by flexible NiTi instruments. Copious irrigation with sodium hypochlorite and EDTA, enhanced with passive ultrasonic activation, was used to debride the isthmus. Obturation was achieved using bioceramic sealer and warm vertical compaction, ensuring sealing of irregularities. These strategies reflect recommendations for managing complex canal systems with continuous curvatures (Chaniotis et al., 2018; Martins & Anderson, 2015).

Dens Invaginatus in a Maxillary Lateral Incisor

A 19-year-old female presented with recurrent swelling in the anterior maxilla. Radiographic evaluation revealed an invagination in the maxillary right lateral incisor consistent with Oehlers Type II dens invaginatus. CBCT confirmed the extent of the anomaly. Endodontic access was modified to eliminate the invaginated portion, followed by thorough irrigation and placement of calcium hydroxide as an intracanal medicament. The canal was subsequently obturated with warm gutta-percha and bioceramic sealer. The case underlines the utility of CBCT in diagnosis and treatment planning of invagination anomalies (Liu et al., 2019; Sharma et al., 2014).

Taurodontism in a Mandibular First Molar

A 28-year-old male presented with dull pain in the mandibular left first molar. Radiographic analysis showed an enlarged pulp chamber with apical displacement of the furcation, suggestive of taurodontism. Access preparation revealed wide canals with apically positioned canal orifices. Instrumentation was performed cautiously with NiTi rotary files to maintain canal patency and prevent ledging. Irrigation was

optimized using sonic activation to reach apical areas. Obturation was completed with thermo-plasticized gutta-percha. Similar approaches for taurodontism management have been reported in the literature (Celikten et al., 2017).

DISCUSSION

The successful management of root canal systems is highly dependent on the clinician's ability to identify and treat anatomical complexities. Anatomical variations such as additional canals, C-shaped configurations, and taurodontism present diagnostic and procedural challenges that, if not recognized, can compromise long-term outcomes. Literature has consistently shown that undetected or untreated canals are a leading cause of endodontic failure (Zhang et al., 2020).

The application of cone-beam computed tomography (CBCT) has significantly advanced endodontic diagnostics by enabling three-dimensional visualization of complex anatomy. Unlike traditional periapical radiographs, CBCT facilitates detection of additional roots and canals, as well as apical curvatures that may otherwise go unnoticed (Singh, 2018; Sharma et al., 2014). For instance, cases involving additional palatal canals or unusual configurations, once considered rare, are increasingly being identified with CBCT and subsequently managed with greater predictability (Kottoor et al., 2011; Liu et al., 2019).

Advanced case reports illustrate that the successful management of unusual anatomies requires the integration of diagnostic imaging with clinical expertise. For example, cases of mandibular first molars with six canals and maxillary molars with eight canals have been effectively treated with the aid of CBCT and dental operating microscopes (Martins & Anderson, 2015; Kottoor et al., 2011). Similarly, taurodont teeth, which present with elongated pulp chambers and shortened roots, require modified access and irrigation protocols to ensure thorough debridement (Celikten et al., 2017).

In addition to diagnosis, canal negotiation and cleaning strategies play a critical role in outcome success. The creation of a reproducible glide path with flexible nickel-titanium (NiTi) files helps maintain canal anatomy while minimizing the risk of procedural errors in complex curvatures (Chaniotis et al., 2018). Effective irrigation, enhanced through activation methods such as sonic or ultrasonic devices, is vital in eliminating microbial biofilms within fins, isthmuses, and lateral canals (Singh, 2020). The choice of irrigant and activation method has a direct impact on treatment success, especially in teeth with complex morphologies.

Obturation techniques are equally important when managing anatomical variations. Warm vertical compaction and bioceramic sealers provide superior adaptation to irregular spaces, minimizing microleakage and improving the prognosis of treated teeth (Singh, 2019; Chandra et al., 2021). Furthermore, restorative integrity following endodontic treatment has been highlighted as a key determinant of tooth survival. In this context, materials and restorative strategies that minimize leakage, such as resin-modified glass ionomer cements and novel alternatives, contribute significantly to treatment longevity (Makkar et al., 2016).

The importance of this case-based evidence is the need to treat individuals with unique approaches. The maxillary molars that contain accessory canals or the premolars that have three roots require changed access cavities and careful investigation (Soares and Leo, 2003; Zhang et al., 2020). Equally, dense invaginatus cases have the advantage of conservative management based on CBCT, which allows minimal invasive but effective treatment (Sharma et al., 2014). These illustrations confirm that effective endodontics cannot be purely technique based but it must be combined with diagnostic expertise, evidence based approach and new technology.

In general, the current results are consistent with the available literature in the point that thorough understanding of root canal morphology, supported by the latest diagnostic tools and sophisticated clinical guidelines can greatly enhance the prognosis of the complex endodontics cases. Ongoing use of CBCT, magnification, improved systems of delivering irrigation, and bioactive materials can be evaluated as the key to modern practice in endodontics, particularly in anatomically problematic cases (Chaniotis et al., 2018; Singh, 2018).

CONCLUSION

Complexity of root canal anatomy is one of the most significant dilemmas in endodontics. Extra canals, C-shaped, dense invaginatus and taurodontism represent anatomical differences that require careful diagnostic assessment and treatment planning. The development of better imaging modalities like CBCT, incorporation of magnification, flexible NiTi tools, improvement of irrigation guidelines, and bioceramic obturation, have significantly made the clinician be able to predict how to handle such cases.

The presented clinical cases reveal that effective results are dependent on introducing comprehensive

knowledge of root canal morphology, evidence-based approaches, and the use of technologies. In conclusion, the diagnostic accuracy, cautiously performed clinical treatment and reasonable restorative treatment guarantee positive long-term outcomes of the treatment of the anatomically complex root canal system.

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