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Sequential Treatment and Systematic Management of Vertical Root Fracture in Molars

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Abstract: Vertical root fracture (VRF) in molars is a complex and frequently encountered dental condition. Successful management relies on accurate diagnosis, sequential treatment strategies, and systematic care. This paper provides a comprehensive review of the sequential therapeutic approaches and systematic management models for molar VRF over the past five years. Particular attention is given to the diagnostic value of cone-beam computed tomography (CBCT), recent advances in tooth-preserving techniques, and the establishment of full-course management frameworks. By constructing an integrated pathway encompassing diagnostic assessment, treatment decision-making, clinical intervention, and long-term maintenance, a "dentist–nurse–patient community" model is proposed to promote standardized clinical guidance. This collaborative model aims to extend the lifespan of affected teeth and restore optimal masticatory function.

Keywords: Vertical root fracture; Sequential treatment; Systematic management; Molar; Conservative therapy; Endodontic surgery; Regenerative restoration; Clinical protocol

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1. Introduction

Vertical root fracture (VRF) of molars refers to a longitudinal crack that extends along the root and communicates between the pulp chamber and the periodontal ligament space. It is a complex dental condition that predominantly affects middle-aged and elderly patients. According to the etiology, VRF can be categorized into primary root fractures (occurring in teeth without prior endodontic treatment) and secondary root fractures (occurring after root canal therapy) [1].

In recent years, the widespread use of large-tapered endodontic instruments has led to a noticeable increase in the incidence of secondary VRF as a complication following endodontic treatment [2]. However, the clinical manifestations of VRF often resemble those of pulpitis, periapical periodontitis, and periodontal disease, which contributes to frequent misdiagnosis or delayed diagnosis in clinical practice.

Traditional clinical management has largely focused on the selection of surgical or restorative techniques, often overlooking the importance of systematic management in achieving long-term functional recovery. Given these limitations, the present study aims to establish a comprehensive framework for sequential treatment and systematic management of molar VRF. By integrating diagnostic assessment, therapeutic decision-making, and ongoing clinical follow-up, this framework is intended to provide standardized clinical guidance that supports both tooth preservation and functional rehabilitation, thereby improving clinical outcomes and patient satisfaction.

2. Disease assessment and diagnostic management

Accurate diagnosis is the cornerstone of effective management for vertical root fracture (VRF). Due to the subtle and variable clinical manifestations of VRF, its diagnosis requires comprehensive consideration of clinical symptoms, radiographic findings, and intraoperative observations.

2.1. Clinical evaluation

Clinically, patients often present with localized discomfort during mastication, sensitivity to percussion, or occasional swelling of the gingiva. In molars, VRF frequently results in narrow and deep periodontal pockets along the fracture line, accompanied by localized alveolar bone resorption. Probing in these areas frequently reveals a characteristic “sharp and narrow” periodontal defect. However, these signs can overlap with those of endodontic or combined periodontic–endodontic lesions, making a definitive diagnosis challenging.

2.2. Radiographic examination

Periapical radiographs remain a fundamental diagnostic tool, yet they often fail to reveal early or minor fractures due to projection limitations. In contrast, cone-beam computed tomography (CBCT) has emerged as a critical adjunct in detecting subtle root fractures and assessing surrounding bone morphology in three dimensions. CBCT can visualize discontinuity of root dentin, localized bone defects, and root separation, thereby improve the diagnostic accuracy and reducing the risk of misdiagnosis [3].

2.3. Diagnostic decision-making

A stepwise diagnostic approach is recommended, beginning with symptom assessment, followed by periodontal probing, radiographic evaluation, and, if needed, operative confirmation under magnification. The use of dye staining, transillumination, and endoscopic-assisted visualization further enhances detection sensitivity. When a fracture is confirmed, clinicians should promptly categorize it according to location (coronal, middle, or apical third) and extent (partial or complete) to guide appropriate treatment planning.

2.4. Diagnostic challenges and clinical implications

Despite the advancement of imaging technologies, diagnosing VRF at an early stage remains difficult. Subclinical fractures may be obscured by restorative materials or masked by secondary infection and bone loss. Therefore, the integration of multimodal diagnostic data, coupled with consistent follow-up assessments, is essential for achieving reliable and reproducible diagnostic outcomes. Ultimately, a standardized diagnostic protocol facilitates timely intervention, enhances tooth preservation potential, and forms the foundation for subsequent therapeutic decisions.

3. Sequential treatment strategies and clinical management

3.1. Comprehensive evaluation and treatment planning

Effective management of vertical root fracture (VRF) in molars requires a sequential and integrated approach that aims to preserve tooth vitality and maintain long-term function. Once a definitive diagnosis is established, a detailed assessment of the fracture pattern, periodontal support, occlusal stress distribution, and the patient's systemic health should be conducted. These factors critically influence therapeutic decision-making and the design of an individualized treatment plan. In cases where the fracture remains localized and the tooth retains structural stability, conservative and minimally invasive techniques are prioritized to preserve as much natural tooth tissue as possible.

3.2. Conservative and minimally invasive approaches

For partial or early fractures, conservative management can effectively restore root function and extend tooth longevity. Adhesive systems combined with fiber post reinforcement or bioceramic sealers can re-establish root integrity and enhance resistance to further stress. Additionally, careful adjustment of the occlusal scheme helps reduce masticatory overload on the affected tooth. Clinical studies have shown that combining minimally invasive repair with controlled occlusion markedly improves prognosis and patient comfort, while reducing the probability of subsequent fracture propagation.

3.3. Surgical and regenerative management

When fractures are extensive or involve the bifurcation and apical regions, surgical intervention becomes a necessary component of the treatment sequence. Procedures such as root amputation, hemisection, and intentional replantation may be employed to eliminate the fractured segment while maintaining partial tooth function. Microsurgical magnification and the use of fine instruments reduce operative trauma, ensuring more precise manipulation of the root and surrounding tissues. The incorporation of bone grafting materials and guided tissue regeneration (GTR) membranes during surgery enhances periodontal healing, promotes new bone formation, and contributes to long-term functional recovery [4].

3.4. Restorative rehabilitation and occlusal optimization

Postoperative prosthetic restoration plays a vital role in reestablishing occlusal stability and preventing recurrent fractures. Full-coverage crowns, on lays, and endocrowns distribute masticatory forces evenly across the tooth structure, thereby lowering stress concentration at the fracture site. In complex cases with weakened supporting structures, the use of occlusal splints, careful bite adjustment, and regular evaluation are essential [5]. These restorative measures ensure the harmonious integration of the treated tooth within the masticatory system and contribute to sustainable long-term outcomes.

3.5. Sequential and systematic management integration

Sequential management integrates the entire therapeutic process into a dynamic continuum encompassing diagnosis, treatment, restoration, and maintenance. Each stage is closely linked to the next, forming a standardized and reproducible clinical pathway. Regular clinical and radiographic reviews facilitate the early identification of complications such as reinfection, marginal leakage, or secondary fracture, enabling timely intervention. More importantly, a systematic management model, anchored in multidisciplinary collaboration between clinicians,

dental technicians, and patients, ensures consistent treatment quality, enhances clinical predictability, and maximizes tooth survival outcomes.

4. Construction of a systematic management model and case-based application

4.1. Concept and framework of systematic management

The systematic management model for vertical root fracture (VRF) integrates diagnostic precision, evidence-based treatment selection, and long-term follow-up into a unified clinical pathway. Rather than treating each stage as an independent therapeutic step, this model conceptualizes patient care as a continuous, interactive process that adapts dynamically to clinical feedback and healing outcomes. The framework emphasizes early detection, sequential decision-making, interdisciplinary collaboration, and patient-centered care, all essential elements for optimizing prognosis. Through structured integration, the model standardizes clinical procedures, reduces variability among practitioners, and enhances the predictability of treatment outcomes [6].

4.2. Core components of the management system

The model consists of four interrelated modules: diagnostic standardization, treatment protocol optimization, restorative-functional integration, and long-term monitoring. The diagnostic standardization module promotes consistent use of multimodal imaging and clinical examination criteria to ensure accurate identification of fracture characteristics. The treatment protocol optimization module focuses on establishing clear clinical decision thresholds between conservative and surgical approaches, improving efficiency and reducing overtreatment. The restorative-functional integration module links the surgical or conservative treatment outcome directly with restorative design, emphasizing occlusal harmony and biomechanical stability. Finally, the long-term monitoring module introduces structured follow-up intervals and digital data tracking to evaluate periodontal health, bone remodeling, and function restoration over time. Collectively, these modules form a closed-loop system that supports dynamic feedback, allowing clinicians to modify strategies according to healing progress and patient-specific risk factors.

4.3. Application in clinical case analysis

Clinical application of the systematic management framework demonstrates its practicality and flexibility. For instance, in a representative case of mandibular molar VRF, the standardized diagnostic process, comprising CBCT imaging, periodontal probing, and transillumination, enabled clear delineation of the fracture plane. Based on the assessment, a minimally invasive surgical approach was chosen, followed by intentional replantation and microsurgical reattachment of the fractured segment. The use of bone grafting combined with bioceramic sealing facilitated periodontal regeneration, while subsequent full-coverage restoration ensured functional stabilization.

During the follow-up period, the systematic management protocol guided routine imaging assessments and occlusal adjustment, ultimately resulting in stable bone healing and continued tooth function over a 24-month observation period. Compared to conventional intervention methods, the stepwise integrated strategy reduced postoperative complications, improved survival rate, and significantly enhanced patient satisfaction [7].

4.4. Clinical significance and prospective value

The establishment of a systematic management model represents a paradigm shift in the clinical handling of VRF.

It redefines treatment from being procedure-centered to outcome-oriented, emphasizing long-term functional preservation rather than short-term repair. By structuring clinical steps within a repeatable framework, this model provides both a theoretical foundation and a practical guideline for clinicians. Moreover, its adaptability to emerging biomaterials, digital imaging, and regenerative technologies ensures its continued relevance in modern endodontic practice. Future research should aim to validate this model through multicenter clinical trials and quantitative outcome measurement, further refining its application scope and standardization potential.

5. Discussion

The findings and clinical experiences summarized in this study underscore that vertical root fracture (VRF) is not merely a mechanical injury but a multifactorial pathology influenced by occlusal stress distribution, endodontic integrity, restorative design, and periodontal support. The sequential and systematic management model proposed herein redefines the therapeutic pathway by integrating early diagnosis, evidence-based intervention, and structured maintenance. Such an approach facilitates a transition from traditionally reactive management to proactive, predictive care. By emphasizing diagnostic accuracy and multidisciplinary coordination, clinicians can significantly reduce misdiagnosis rates and improve treatment predictability.

From a theoretical perspective, this framework extends the understanding of VRF beyond a static lesion model to a dynamic, biologically responsive system. Healing outcomes depend not only on the fracture morphology but also on microenvironmental factors such as inflammation control, bone remodeling capacity, and vascular supply. The integration of regenerative and biomimetic principles in treatment further expands the potential for functional rehabilitation while minimizing invasive procedures.

Clinical implementation of the systematic management protocol has demonstrated substantial advantages in ensuring biological healing and maintaining occlusal stability. The emphasis on treatment sequencing, ranging from initial assessment to restorative rehabilitation, enables personalized strategies tailored to the extent and progression of each fracture. These strategies improve tooth survival rates, reduce postoperative complications, and enhance patient satisfaction through careful follow-up and functional evaluation.

Moreover, standardized documentation and digital imaging analytics embedded in the management system provide valuable data for longitudinal evaluation and interdisciplinary communication. Such structured data collection aids in refining diagnostic criteria, predicting prognosis, and facilitating evidence accumulation for future guideline development [8].

Despite the promising advantages, several challenges remain. Precise early detection of microfractures continues to depend on high-resolution imaging and clinician expertise. Variations in operator skill, case complexity, and patient compliance may influence long-term outcomes. Furthermore, large-scale multicenter studies are needed to validate the reproducibility of the sequential management model and its applicability across diverse clinical settings. Future research should also explore the integration of artificial intelligence–assisted diagnostic algorithms and biomaterial-based regenerative approaches, which could further enhance the sensitivity, precision, and biological compatibility of fracture management.

6. Conclusion

In conclusion, the proposed sequential and systematic management model offers a comprehensive and structured

framework for addressing vertical root fractures in molars. By unifying diagnostic, therapeutic, and restorative elements into a cohesive sequence, it standardizes clinical decision-making and improves outcome predictability. This model not only elevates the scientific understanding of VRF but also provides a practical and sustainable pathway for clinical application. As technology and biomaterials evolve, the integration of digital, regenerative, and data-driven strategies will continue to refine this model, contributing to more precise, conservative, and patient-centered management of complex endodontic fractures.

Disclosure statement

The authors declare no conflict of interest.

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