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Review Article

The role of infection in root resorption mechanism and clinical implication

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Abstract

The aim of the Review is to explore the role of infection in the pathogenesis of root resorption and discuss its clinical implications and management strategies. Root resorption is a pathological condition involving the destruction of hard tissues such as dentin and cementum, often influenced by infection. The process is complex, requiring a multidisciplinary approach for effective management. A comprehensive review of the literature was conducted, focusing on infection-driven root resorption mechanisms, diagnostic techniques, and emerging treatment modalities. Infection-driven root resorption involves microbial invasion, an inflammatory response, osteoclastic activation, and tissue destruction. Early diagnosis and effective management strategies, including antimicrobial therapy, regenerative techniques, and advanced imaging, are critical for successful outcomes. Infection plays a central role in root resorption, emphasizing the importance of timely intervention. Emerging technologies and targeted therapies offer promising advances in diagnosis and treatment, necessitating ongoing research to enhance clinical outcomes.

Keywords: Root resorption, Infection-driven resorption, Internal resorption, External resorption, Inflammatory external resorption

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1. Introduction

Root resorption is a pathological condition characterized by the progressive destruction of hard dental tissues, including dentin and cementum, often as a result of various external and internal factors. While root resorption can occur physiologically, particularly in deciduous teeth as part of the natural exfoliation process, pathological root resorption can affect permanent teeth and lead to significant structural damage. The pathogenesis of root resorption is multifactorial, involving a complex interaction of mechanical, chemical, biological, and microbial factors. Understanding these underlying mechanisms is critical to diagnosing and managing this condition effectively.[1,2]

Pathological root resorption may arise due to several etiological factors, including trauma, orthodontic treatment, and infection. Among these, infection-induced root resorption is particularly challenging due to its silent progression and the difficulty in detecting it during the early stages. Infection-driven root resorption occurs when microorganisms invade the root canal system or periodontal tissues, causing inflammation, activating osteoclastic activity, and leading to the breakdown of tooth structure. Infections within the pulp, often as a result of pulpal necrosis or trauma, or infections stemming from periodontal disease can trigger this process.

Infection-driven root resorption can be broadly classified into internal resorption and external resorption, with distinct mechanisms and implications for treatment. Internal resorption begins within the pulp chamber or root canal and is commonly initiated by chronic pulpal inflammation, leading to dentin destruction. External resorption, on the other hand, occurs on the external surface of the tooth root

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and can be caused by inflammatory processes associated with microbial invasion, trauma, or periodontal disease. In particular, inflammatory external resorption is often linked to microbial infections, where microbial biofilms on the root surface or within the root canal contribute to the progressive degradation of the tooth structure.

The clinical challenge associated with infection-driven root resorption lies in its often asymptomatic progression. The early stages of resorption may not present noticeable symptoms, making it difficult to diagnose until substantial damage has occurred. By the time the condition is identified, significant tooth destruction may have already taken place, leading to compromised tooth stability, potential loss of the tooth, and complex treatment needs.

Given the severity and complexity of infection-driven root resorption, effective management requires a multidisciplinary approach. This typically involves endodontic treatments, antimicrobial interventions, and sometimes regenerative procedures to restore the tooth’s structural integrity. As the field of dentistry continues to evolve, emerging technologies, advanced imaging, and novel therapeutic strategies are being explored to enhance diagnosis, prevent further damage, and promote tissue regeneration. The potential to integrate regenerative approaches, such as stem cell therapy and biomaterials, offers exciting new possibilities for managing root resorption.

The goal of this review is to provide a comprehensive understanding of the etiology, mechanisms, and clinical implications of infection-driven root resorption. It will also examine current diagnostic techniques, treatment modalities, and the promising future perspectives for managing this complex and often debilitating condition. Through early diagnosis, appropriate intervention, and ongoing research, it is possible to improve the prognosis of affected teeth and enhance patient outcomes.

1.1. Etiology of root resorption[3,4]

Root resorption can be classified into two primary types: internal and external resorption, each with distinct causes and mechanisms.

1. Internal resorption
    a. This type typically originates from chronic inflammation of the pulp tissue, where infection or persistent irritation leads to dentin breakdown from within the pulp chamber or the root canal. The inflammation can be driven by bacterial infection or trauma, and the resorption process progresses until it results in a significant loss of tooth structure.
2. External resorption
    a. Inflammatory external resorption: Commonly triggered by microbial infections, trauma, or periodontal disease. The invading microorganisms and the formation of biofilms act as a catalyst for the resorption process.
    b. Replacement resorption: Typically seen after traumatic injury, where the affected root tissue is replaced by bone, resulting in the ankylosis of the tooth and a loss of its functional integrity.

Microbial invasion, particularly after trauma or pulpal necrosis, stimulates osteoclast activation and accelerates resorption, leading to the progressive destruction of the root structure.

1.2. Mechanism of infection-driven root resorption[5,6,7]

The relationship between infection and root resorption involves several distinct steps:

1. Microbial invasion
    a. Pathogenic microorganisms such as Porphyromonas gingivalis, Fusobacterium nucleatum, and Prevotella intermedia are commonly involved. These bacteria typically invade the root canal system through cracks, fractures, or necrotic pulp tissue, establishing an infection that can persist for an extended period.
2. Inflammatory response
    a. The host's immune system responds to the microbial invasion by releasing pro-inflammatory cytokines, including IL-1, IL-6, and TNF-α. These cytokines recruit osteoclast precursors to the affected site and play a crucial role in osteoclast activation.
3. Osteoclastic activation
    a. The inflammatory environment enhances the expression of RANKL (receptor activator of nuclear factor kappa-β ligand), a key mediator that promotes osteoclast differentiation and activity. Osteoclasts then resorb dentin and cementum, progressively weakening the tooth structure.
4. Tissue destruction
    a. The combined actions of osteoclasts and microbial enzymes, such as collagenases and proteases, accelerate the breakdown of tooth tissues, ultimately leading to severe structural damage and resorption.

1.3. Clinical implications[8,9,10,11]

Infection-driven root resorption presents a number of clinical challenges:

1. Delayed diagnosis
    a. Early stages of infection-driven resorption are often asymptomatic, making it difficult to detect until significant damage has occurred. This delayed detection complicates treatment and can result in tooth loss.
2. Compromised tooth stability

   a. As resorption progresses, the tooth becomes structurally compromised, increasing the risk of fractures and loss of functionality.
3. Endodontic challenges
   a. The presence of microbial biofilms within the complex root canal system makes it difficult to eradicate the infection completely, often leading to treatment failure.
4. Prosthodontic and Orthodontic Limitations:
   a. Severe resorption can reduce the prognosis for prosthetic and orthodontic interventions, requiring alternative strategies to manage affected teeth.
5. Aesthetic concerns
   a. Resorption of visible teeth can have significant aesthetic implications for patients, impacting both their confidence and oral health.

1.4. Diagnosis

Accurate and early diagnosis is critical for successful management. Diagnostic approaches include:

1. Radiographic Imaging:[12,13]
   a. Periapical Radiographs are often used to detect resorptive lesions in the early stages.
   b. Cone-Beam Computed Tomography (CBCT) offers a more detailed, three-dimensional view of the root structure, helping to assess the extent and location of resorption.
2. Clinical Examination:[14,15]
   a. Visual inspection may reveal signs such as tooth discoloration, fistula formation, or crown destruction. Palpation and percussion tests help detect tenderness or tooth mobility, which could indicate the presence of resorption.
3. Microbial Analysis:[16,17]
   a. Culturing and identifying specific microbial species from the root canal can guide antimicrobial therapy. Genetic and molecular testing may also help identify resistant strains or pathogenic microorganisms involved in the infection.

1.5. Management strategies:[18,19,20]

Effective management of infection-driven root resorption involves a combination of infection control, regenerative techniques, and restorative approaches to prevent further destruction and enhance tissue healing.

1. Infection Control
   a. Mechanical Debridement: Thorough removal of necrotic tissue and biofilms using rotary and hand instruments.
   b. Antimicrobial irrigation
      i. Sodium hypochlorite (NaOCl) for tissue dissolution and bacterial eradication.
      ii. Chlorhexidine (CHX) for long-lasting antibacterial effects.
      iii. EDTA for smear layer removal and enhanced penetration of antimicrobial agents.
   c. Ultrasonic Activation: Enhances penetration of irrigants into complex canal anatomy.
2. Intracanal medicament placement
   a. Calcium hydroxide ($Ca(OH)_2$)
      i. Creates an alkaline pH to inhibit osteoclastic activity.
      ii. Promotes hard tissue formation and antimicrobial action.
   b. Triple antibiotic paste (TAP)
      i. A mix of metronidazole, ciprofloxacin, and minocycline to combat resistant infections.
      ii. Used in cases with persistent bacterial contamination.
   c. Newer Alternatives:
      i. Nano-antibiotics for enhanced biofilm penetration.
      ii. Photodynamic therapy (PDT) for selective bacterial eradication.
3. Definitive restoration
   a. Root canal obturation
      i. Mineral Trioxide Aggregate (MTA): Biocompatible material with sealing and regenerative properties.
      ii. Bioceramic Sealers: Provide antimicrobial action and superior sealing ability.
      iii. Coronal Sealing: Composite resins or ceramic restorations to prevent reinfection and restore function.
4. Regenerative approaches
   a. Pulp revascularization
      i. Inducing bleeding from the periapical region to promote stem cell migration.
      ii. Encourages dentin and pulp-like tissue regeneration.
   b. Growth factor therapy
      i. Platelet-rich fibrin (PRF) and platelet-derived growth factors to accelerate healing.
   c. Stem Cell Therapy (Experimental)
      i. Use of mesenchymal stem cells (MSCs) to regenerate dentin and periodontal tissues.
   d. Biomimetic scaffolds
      i. Hydrogels, collagen matrices, and bioactive scaffolds for tissue engineering.
5. Long-Term Monitoring
   a. Regular Follow-ups: Clinical and radiographic assessments every 3–6 months.
   b. Indicators of success
      i. Thickening of dentinal walls.
      ii. Continued root development.
      iii. Absence of periapical pathology.

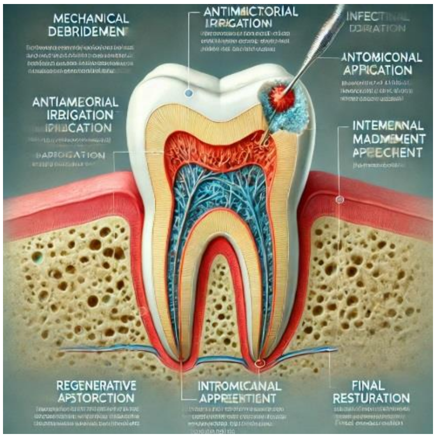

Figure 1:

2. Discussion[21,22]

Root resorption, particularly infection-driven root resorption, remains a significant clinical challenge due to its complex pathogenesis and often silent progression. The involvement of microbial biofilms, host inflammatory responses, and osteoclastic activation makes this condition difficult to manage with traditional approaches alone. However, advances in technology, materials, and therapeutic strategies offer hope for improved treatment outcomes. This section discusses the multifaceted nature of root resorption and the potential future advancements that could revolutionize its diagnosis, management, and prevention.

2.1. Infection and root resorption

The role of infection in root resorption is well-documented, with microbial biofilms playing a central role in the initiation and progression of the resorptive process. These biofilms are often composed of a wide variety of bacteria, including anaerobic microorganisms such as Porphyromonas gingivalis, Fusobacterium nucleatum, and Prevotella intermedia. These pathogens are capable of thriving in the anaerobic environments of necrotic pulp and periodontal pockets. The biofilms they form within the root canal system are particularly difficult to eliminate, leading to persistent inflammation, osteoclastic activation, and subsequent root resorption.

This interaction between microbial biofilms and the host immune response creates a vicious cycle where inflammation exacerbates tissue breakdown, and microbial toxins further stimulate the resorption process. This underscores the importance of not only eradicating the infection but also preventing recurrence and promoting healing. The challenge lies in addressing both the microbial component and the tissue damage caused by inflammation and osteoclastic activity.

2.2. Traditional and emerging therapies

Historically, infection-driven root resorption has been treated with mechanical debridement, antimicrobial irrigation, and the placement of intracanal medicaments such as calcium hydroxide. While these techniques remain effective, they often do not fully address the complexity of infection, particularly when biofilms are involved. As a result, emerging technologies and treatment modalities are being explored to improve efficacy and outcomes.

1. Photodynamic therapy (PDT)
    a. Photodynamic therapy is an emerging treatment modality that uses light-activated photosensitizers to target bacterial cells. When exposed to a specific wavelength of light, these photosensitizers generate reactive oxygen species (ROS) that can selectively destroy microbial cells. PDT offers a promising alternative for treating infections that are resistant to conventional methods, particularly in cases where biofilms are present. It has shown potential in reducing bacterial load in root canals, enhancing the effectiveness of traditional root canal therapy.
2. Nano-antibiotics
    a. The use of nano-antibiotics is another promising development. These materials are engineered to penetrate biofilms more effectively than traditional antibiotics due to their small size and enhanced surface area. Nano-antibiotics can be loaded with antibiotics or antimicrobial peptides, improving their ability to reach and destroy bacterial colonies within the root canal. This targeted approach is particularly useful in treating resistant bacterial strains and reducing the risk of reinfection.
3. Regenerative approaches
    a. Regenerative therapies are revolutionizing the management of root resorption, especially in cases where the root structure has been significantly damaged. These approaches aim to restore the tooth's natural tissues through the stimulation of stem cell activity, growth factors, and biomimetic scaffolds.
        i. Pulp revascularization, for instance, involves the induction of bleeding from the periapical region to encourage the migration of stem cells and the regeneration of dentin and pulp-like tissue.
        ii. Growth factor therapy using platelet-rich fibrin (PRF) or platelet-derived growth factors has been shown to accelerate tissue healing and regeneration in both dentin and periodontal tissues.
        iii. Stem cell therapy holds tremendous potential for regenerating both hard and soft tissues in the tooth structure. The use of mesenchymal stem cells (MSCs) could lead to the restoration of dentin, cementum, and even the periodontal ligament in cases of advanced resorption. This represents a significant leap forward in endodontic and periodontic treatments.

iv. Biomimetic scaffolds, such as hydrogels and collagen matrices, serve as frameworks that support tissue regeneration. These materials are designed to mimic the natural extracellular matrix, enhancing the growth of new tissue and supporting the regeneration of damaged structures.

4. Biomaterial Innovations:
    a. Bioactive cements and sealants are continuously being developed to improve the sealing of root canals and prevent microbial ingress. For example, bioceramic sealers are not only antimicrobial but also encourage tissue regeneration by creating a conducive environment for healing. In addition, the development of bioactive hydrogels for controlled drug delivery is opening new possibilities for localized treatment of infections and resorption.
5. Advanced Imaging Technologies:
    a. Accurate diagnosis is critical in managing root resorption. New imaging technologies, particularly Cone Beam Computed Tomography (CBCT), provide detailed three-dimensional imaging that can help clinicians assess the extent of resorption and plan treatment more effectively. In the future, artificial intelligence (AI) integrated into imaging analysis could further enhance diagnostic accuracy and treatment prediction, enabling personalized treatment plans based on the precise characteristics of each case.

2.3. Future perspectives[23,24,25]

The future of managing infection-driven root resorption lies in the continued development of both diagnostic and therapeutic innovations. With a deeper understanding of the molecular and microbial aspects of the disease, more effective and personalized treatments can be developed.

2.3.1. Targeted antimicrobial therapies

In the future, targeted antimicrobial strategies will become increasingly important. The development of nano-antibiotics, peptide-based antimicrobials, and molecularly targeted therapies will allow for more precise eradication of bacterial biofilms. These treatments will be particularly beneficial in cases of antibiotic resistance, where traditional therapies may fail.

Additionally, photodynamic therapy may become more integrated into routine endodontic practice, allowing for non-invasive bacterial eradication in difficult-to-treat areas.

2.3.2. Molecular and genetic research

Genetic research into the molecular pathways that drive root resorption is essential to uncover new biomarkers and therapeutic targets. Understanding genetic predispositions to resorption will enable clinicians to identify patients at higher risk and tailor treatment plans accordingly. In addition, proteomic and genomic analyses of infected tissues will allow for better prognostication and the development of new therapeutic agents aimed at controlling resorption.

2.3.3. Artificial intelligence and advanced imaging

The integration of artificial intelligence (AI) in diagnostic imaging could drastically improve the detection of root resorption in its early stages. AI algorithms can analyze radiographic and CBCT scans more quickly and accurately than human clinicians, allowing for earlier intervention. AI could also help predict treatment outcomes and guide decision-making, offering highly personalized care.

2.3.4. Biomaterial development

Future biomaterial innovations will likely focus on improving the regenerative potential of root canal sealers, scaffolds, and growth factors. Bioactive and regenerative materials will continue to evolve, enabling better integration with host tissues and promoting the restoration of lost dentin and other tooth structures. Hydrogels, nanoparticles, and mesoporous materials for drug delivery systems may further enhance localized treatment delivery, ensuring that antimicrobial agents and growth factors are released precisely where they are needed.

3. Conclusion

Infection-driven root resorption is a multifactorial condition that involves a complex interplay between microbial infection, the host immune response, and osteoclastic activity. The clinical implications of this condition are significant, affecting tooth stability, endodontic treatment success, and patient quality of life. Early diagnosis and timely intervention are essential for preventing the progression of resorption and minimizing the need for tooth extraction.

While traditional therapies such as mechanical debridement and antimicrobial irrigation remain vital components of treatment, emerging technologies and therapies are poised to transform the management of infection-driven root resorption. The development of **t**argeted antimicrobial therapies, regenerative treatments, and biomaterial innovations holds the promise of improving outcomes for patients with this challenging condition. Furthermore, advanced imaging technologies and artificial intelligence will enable earlier detection and more personalized treatment plans, further enhancing the effectiveness of interventions.

The future of root resorption treatment lies in the integration of cutting-edge technologies, personalized care, and a multidisciplinary approach to managing this complex condition. Continued research, collaboration, and innovation will be crucial in refining existing treatment protocols and developing novel therapeutic strategies to combat infection-driven root resorption.

4. Source of Funding

None.

5. Conflict of Interest

None.

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