# Factors influencing the outcome of iatrogenic perforation repair in permanent teeth – a narrative review

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## ABSTRACT

The management of iatrogenic perforations in the permanent dentition is challenging. Early detection and timely repair of iatrogenic tooth perforations are crucial for achieving a favourable prognosis. This article brings together information on the factors that affect the success of perforation repair and categorizes them into three domains: perforation-related, patient-related, and clinician-related. By analysing the existing literature, the review offers a holistic perspective on how these factors impact on the prognosis of perforation repair, providing useful guidance for clinical decision-making and risk evaluation. In highlighting the current limitations within the evidence base, the review also suggests avenues for future research aimed at enhancing the predictability and success rates of iatrogenic perforation repair in contemporary endodontic treatment.



## KEYWORDS

Outcomes, iatrogenic perforation, perforation, prognosis, perforation repair

## INTRODUCTION

A perforation is an unintended communication between the root canal system and the external surface of the tooth (1). Such an event will compromise the structural integrity of the tooth and damage the surrounding periodontal tissues and bone (2). Perforations may arise either pathologically, due to caries or resorptive processes (Figure 1A, B), or as a result of iatrogenic causes, such as mishaps during endodontic procedures (Figure 1C, D) or post space preparation (Figure 1E) (3,4,5,6). Root perforations in adult patients undergoing root canal treatment or post space preparation have been documented between 0.6% and 17.6% of cases (5).

Iatrogenic perforations may occur during root canal procedures with common causes including discrepancies in crown-to-root angulation, calcification within the pulp chamber or canal orifices, anatomical irregularities, and excessive removal of dentine during access preparation (7,8) (Figures 2A-G). The primary aim of managing an iatrogenic perforation is to prevent loss of periodontal attachment by halting inflammation (Figures 3A-D). Where tissue breakdown has already occurred, the objective becomes the regeneration of the lost periodontal tissues (9,10). The prognosis of iatrogenic perforation repair is shaped by a range of factors. The time elapsed between the formation of a perforation and the initiation of appropriate treatment is of particular importance (11). Observations from several animal studies have revealed optimal healing only after immediate management performed under aseptic conditions (12,13). Smaller perforations are usually associated with minimal tissue damage and inflammation that results in more predictable healing (11). Site of perforation is yet another critical parameter in determining the favourable outcome of perforation repair as the therapeutic approach relies mainly on the position of the perforation and its relation to the crestal bone and attachment apparatus (11). Perforations located in the apical or middle third of the root were thought to offer a more favourable prognosis compared to those in the cervical third or pulpal floor (11). Non-surgical repair using biocompatible materials, particularly Mineral Trioxide Aggregate (MTA), have been linked with high success rates (14). Beyond local clinical considerations, systemic factors such as chronic illnesses, hormonal imbalances, and aging may also influence healing outcomes by altering the patient's immune response (15). Nonetheless, the correlation among these systemic

health variables and the prognosis of perforation repair is unclear and needs more research.

The systematic review and meta-analysis by Siew et al. (14) essentially assessed the treatment outcomes of repaired root perforations and aimed to identify various preoperative factors that influenced the outcome. The review by Estrela et al. (16) similarly focussed on therapeutic approaches, including aspects of diagnosis, prognosis and the various perforation repair materials employed. In another narrative review, several aspects of clinical techniques and outcomes following surgical and non-surgical repair were discussed (17). Accordingly, this narrative review focuses on the diverse etiological factors associated with iatrogenic perforations, categorizing them into perforation-related, patient-related, and clinician-related factors. By emphasizing these contributing factors rather than therapeutic approaches or clinical techniques, this review aims to provide a more comprehensive understanding of iatrogenic perforations and their outcomes. The objective is to identify the critical factors that influence the outcome of iatrogenic perforation repair, thereby offering clinicians important information to facilitate the development of well-informed management plans, while also addressing the discrepancies and limitations in outcome reporting within this field.

**LITERATURE SEARCH**

A comprehensive literature search was conducted using the PubMed and Scopus electronic databases to identify relevant studies on the various factors influencing the outcome of iatrogenic perforation repair. The search strategy involved the use of a combination of the following keywords: "iatrogenic perforation," "perforation repair," "treatment outcome," "prognostic factors," "success rate", “root canal treatment”, “perforation”, “root perforation,” “perforation management,” “furcal perforation management,” “endodontic complications,” “root perforation repair,” “apical perforation,” “coronal perforation,” “endodontic perforation,” “endodontics”. To capture a broad scope of relevant literature, filters were applied to include only peer-reviewed articles published in English, with no restriction on publication year. Additional refinement was achieved by screening titles and abstracts based on the following inclusion and exclusion criteria: clinical studies, reviews, non-human studies that assessed the outcomes following perforation repair were included whereas articles in languages other than

English were excluded. Titles and abstracts were independently screened by two reviewers. Any discrepancies between the two reviewers were resolved through discussion with a third author.

## PERFORATION-RELATED FACTORS

Perforation-related factors that impact the outcome of iatrogenic perforation repair are those directly associated with the perforation itself.

*Size of perforation*

The primary objective of repairing a perforation is to prevent bacterial contamination from the tooth passing into the periradicular tissues and to avoid periodontal irritation from the extrusion of repair materials. In the past, smaller perforations were deemed to have a better prognosis, as the likelihood of achieving a secure seal without overfilling into adjacent tissues is higher (11). They were also categorised using vague terms like "small" or "large," without standardized criteria. More recent research; however, has used quantitative techniques to measure the size of perforations, which has resulted in more consistent and reliable clinical assessments (18,19).

Himel et al. (20) evaluated the biological response to three different repair materials including tricalcium phosphate, calcium hydroxide, or Teflon discs in defects created on the pulpal floor of mandibular posterior teeth in dogs. The findings suggested that treatment outcomes were more favourable in larger teeth, where the perforations were smaller in proportion. MTA has improved outcomes in root perforation repair, and this effect extends not only to material choice but also influences the prognostic significance of perforation size and delay in repair, as highlighted by Gorni et al. (18). Mente et al. (21) demonstrated that the likelihood of healing decreased as the size of the perforation increased. The success rate of 67% was reported for teeth with larger perforations (>3 mm), in comparison to 88% for perforations that were medium size (2-3 mm), and 90% for teeth with very small perforations (<1 mm). From a long-term study that classified perforations into three sizes (<1 mm, 2-3 mm and >3 mm), the non-healing rates reported were 0%, 6% and 16% respectively. Consequently, the study demonstrated a negative association between perforation size and healing, indicating that larger perforations were linked to an increased likelihood of treatment failure (18). From a 14-year longitudinal

study, it was concluded that larger perforations (>3 mm) were associated with noticeably higher failure rates than smaller perforations (19). Furthermore, Askerbeyli Örs et al. (22) used three-dimensional finite element analysis to investigate the effects of various furcal perforation sizes on the stress distribution pattern in first mandibular molars. The structural integrity of teeth was directly influenced by the extent of the perforation, as evidenced by the increased stress concentration in the surrounding dentine and periodontal ligament of teeth with larger furcal perforations.

**Summary:** The size of perforations has always been considered a critical deterministic factor in obtaining favourable healing, with perforations that are larger usually associated with lower survival as well as reduced healing rates, emphasizing an inverse relation between perforation size and positive treatment outcomes. It is essential to quantify the exact dimensions of a perforation rather than relying on vague terms like "small" or "large." Clinicians should use standardized, quantitative approaches to measure perforation size, employing precise units and advanced imaging techniques such as high-resolution radiography, or CBCT to ensure accuracy and reproducibility. Future research should evaluate treatment outcomes in accordance with predetermined size ranges using contemporary repair materials.

*Time elapsed before repair of perforation*

In an experimental study, Lantz and Persson (12) created root perforations in dogs and treated them either immediately or after a delay. Their findings revealed that immediate repair of the perforations resulted in the most favourable healing outcomes, underscoring the importance of repair as soon as the perforation is identified and prior to bacterial contamination in order to prevent infection and protect the periradicular tissues. Similarly, Seltzer et al. (13) treated 22 cases of root perforations in monkeys with zinc oxide eugenol alone or with overlying amalgam from immediate management to 10 months. All cases had periodontal disease, but untreated and delayed cases had the more extensive tissue destruction. Beavers et al. (23) provided additional evidence to substantiate this finding.

Early intervention, that is repair performed as soon as possible, prevents microbial contamination, infection, and damage to tissues, yielding the most favourable outcomes. In cases of older, chronic, and potentially infected perforations, successful treatment is

contingent on thorough decontamination prior to repair, ensuring that the procedure is performed under aseptic conditions (7,9,24–27). Early intervention is therefore essential to prevent the establishment and limit the spread of infection (Figure 4).

**Summary:** Clinicians should prioritize the immediate detection and prompt repair of perforations. The timing of intervention following a perforation is a critical determinant of healing. Early intervention greatly improves the prognosis with more favourable healing patterns and less periodontal damage. Focus should be placed on adhering to an aseptic protocol with meticulous cleaning and decontamination of the perforation site in cases of delayed repair. Future studies should concentrate on creating uniform time frames and comparing different treatment modalities over time.

*Location*

The prognosis of iatrogenic perforation repair has been reported to be significantly influenced by the location of the defect in relation to the crestal bone level and the epithelial attachment, an area referred to as the "critical zone" (28). The prognosis is generally most unfavourable when the perforation occurs within this critical zone with perforations located coronal to this zone typically having a good prognosis, as they are more accessible and can be adequately restored with conventional materials, without involving the periodontal tissues (11). Similarly, perforations situated apical to the critical zone tend to have a more favourable prognosis, provided that the root canal is accessible and treatment is feasible. These perforations can generally be debrided and repaired effectively, with a lower risk of bacterial contamination (29,30). Clauder and Shin (7) described that when a perforation is located closer to or above the level of crestal bone, downgrowth of junctional epithelium and progressive development of periodontal pockets would greatly compromise the prognosis of teeth with infected perforations. Specifically, sub-crestal perforations carry a decreased risk of bacterial contamination owing to the reduced exposure to the oral environment and are therefore not as susceptible to junctional epithelial downgrowth and periodontal pocket formation.

Fuss and Trope (31) found that perforations near the crestal bone were particularly prone to epithelial tissue growth and the rapid development of periodontal pockets, which significantly reduces the likelihood of successful repair. Furcal perforations, in particular, are generally associated with a less favourable prognosis than apical or middle root

perforations, largely due to their increased susceptibility to contamination from the oral environment (13,14,32). In cases of furcal perforations, the main concerns are tissue damage and the potential communication with the gingival sulcus, with long-term studies reinforcing these observations (7,31,33). According to Gorni et al. (19), the middle third of the root had the highest percentage of non-healing perforations (12%), followed by the coronal third (3%), with the apical region having no failures (0%) (19). Gorni et al. (18) reported non-healing perforations in 13% of middle-third cases, 4% of coronal-third cases, and none in the apical third. The authors also concluded that although the size and site of the perforation used to be important determinants of prognosis, the introduction of MTA had fundamentally changed this perspective. It appears that the remarkable sealing properties and biocompatibility of MTA have diminished the significance of these prognostic factors in the contemporary clinical setting (21) (Figures 5, 6).

**Summary:** One of the most crucial factors impacting the prognosis of root perforations is its location in relation to the critical zone. However, most reports indicate that historical prognostic indicators, including location, are not as relevant as they were before MTA was introduced. Clinicians should accurately define and record the location of perforations while planning their treatment strategy. Future study should aim to perform a more systematic and comparative analysis of the influence of perforation location on clinical outcomes, focusing specifically on the critical zone and furcation areas, where the prognosis is generally poorer.

*Tooth type*

Higher success rates in treating perforations in maxillary teeth have been reported (14). A case series also demonstrated that 73% of maxillary teeth had their perforations effectively treated, but mandibular teeth made up a significant number of failed cases (62.5%) (34). According to Mente et al. (21), teeth with perforations in a single-rooted tooth had a healing success rate of 92%, which was significantly higher than the 75% rate for teeth with perforations in multiple roots. Gorni et al. (19) found that all anterior tooth perforations healed completely, with a small percentage of premolar (14%) and molar (8%) failing to heal. Healing outcomes may vary due to anatomical variations, better blood supply, more accessible and simple root canal anatomy, and lower contamination risk (19). This implies that tooth type affects perforation repair outcomes.

**Summary:** Tooth type and root configuration have a critical impact on the outcome of perforation repairs. These anatomical features underscore the significance of individualized treatment planning, customized to the unique attributes of each tooth, to enhance success rates and optimize outcomes for patients. Clinicians must consider tooth type in their evaluation and treatment strategy when treating teeth with perforations. Advanced imaging and magnification technologies provide accurate assessments of anatomical intricacies and guide precise, successful treatments. Future research should focus on examining the impact of different root configurations and tooth types on the outcomes of perforation repair.

*Level of contamination*

When a perforation is exposed to microorganisms, particularly from the oral cavity or periodontal tissues, the likelihood of successful healing is reduced (11). The introduction of bacteria into the perforated area can trigger an intense inflammatory response, disrupt tissue regeneration, and contribute to the formation or persistence of disease (35,36). Experimental research provides strong evidence for the association between bacterial presence and poor healing outcomes. In an animal study involving monkeys, cases where bacteria remained after root canal treatment had a significantly higher incidence of unresolved periapical lesions, approximately 79%, compared to only 28% in bacteria-free scenarios (37). This disparity highlights the harmful effect of persistent microbial contamination on the healing process, as it perpetuates inflammation and tissue breakdown. Numerous studies have shown that the presence of bacterial contamination at the time of repair leads to compromised healing, with less favourable clinical outcomes (7,38) (Figure 4).

**Summary:** Microbial contamination is an important factor affecting the healing and overall success of perforation repair. Bacterial infection severely impairs tissue repair, frequently leading to chronic periradicular inflammation, as demonstrated by both experimental research and clinical observations. Perforation repair carried out from an internal approach should be done aseptically with dental dam isolation and antimicrobial techniques to prevent contamination of the site and eradicate microorganisms and promote tissue repair. Future research should investigate methods to improve perforation-specific disinfection techniques.

*Periodontal health and radiographic changes at the perforation site*

The formation of pathological periodontal pockets can occur as a consequence of the apical migration of the periodontal attachment if a perforation is not repaired in a timely manner (33). Upon the formation of a pathological pocket, the perforated site remains chronically inflamed as a result of the continuous infiltration of bacteria through the defect. At this stage, the chances of achieving a successful repair are considerably reduced from a periodontal perspective (14,21,32,33). Specifically, when perforations are located in the coronal third of the root and are accompanied by periodontal pocket formation, treatment failure rates have been reported to reach as high as 100% (32). It has also been reported that perforated teeth with deep probing depths had a two-fold higher risk of healing failure and prolonged inflammation than those with a healthy periodontium (Figure 7) (18,39).

**Summary:** Periodontal health and radiographic evidence of disease at the perforation site are key factors in determining the success of perforation repair. Prompt diagnosis and intervention are crucial to preventing apical migration of the periodontal attachment and the formation of periodontal pockets as they significantly reduce the success of perforation repair, particularly when present at the coronal third of the root. Radiographic monitoring and clinical assessment should be used to detect early signs of pathosis at the perforation site. Future studies should investigate how the timing of intervention influences periodontal healing, especially in cases involving coronal third perforations.

## PATIENT-RELATED FACTORS

Patient-related factors are discrete attributes or characteristics which influence the treatment outcome and play a critical role in determining how a patient responds to specific procedures.

*Age*

Age plays a pivotal role in endodontics, as the decrease in vascularity associated with the process of aging has been reported to have a negative impact on healing (40). It has been reported that individuals aged over 50 years have a greater incidence of non-healing perforation repairs in comparison to the patients younger than 50 years supporting the

hypothesis that advancing age is linked to a decrease in successful perforation repair (19). Although younger patients typically demonstrate better healing, successful outcomes are not solely determined by age alone (19). Several other factors, such as site and size of the perforations, presence of microbial contamination, may have more significant impact on overall outcomes of treatment (32).

**Summary:** Age plays a role in the healing of perforation repairs, with younger patients tending to be associated with more favourable outcomes. Clinicians should recognize age as a factor influencing the healing potential of perforation repairs, with younger patients typically demonstrating more favourable outcomes. Future studies should investigate the biological mechanisms that cause age-related differences in healing following perforation repair.

*Gender*

The impact of gender in determining the outcomes of perforation repair remains unclear. A retrospective study of perforation repair revealed that females had a higher success rate than males (41). However, other studies have reported no such association (42–45). A systematic review also reported that no difference in success rates between male and females (14).

**Summary:** Gender is not currently considered a major determinant of prognosis following perforation repair. Clinicians should be aware that the gender of a patient is not considered a major contributing factor in determining the treatment outcome as the literature does not reveal a correlation. However, further research is needed to evaluate the effect of the gender of an individual on treatment and healing outcomes after perforation management.

*Systemic conditions*

Conditions such as diabetes mellitus, cardiovascular diseases, osteoporosis, HIV infection, and autoimmune disorders can impair tissue repair and reduce the success rate of treatments (46). For instance, diabetes mellitus, characterised by chronic hyperglycaemia, impairs collagen formation and disrupts matrix protein degradation, leading to delayed wound healing and an increased susceptibility to infections. Additionally, hypertension is linked to inflammation and vascular damage that can

generally impede the healing process (15,47). Chronic inflammation and immune dysregulation are pathognomonic features of autoimmune disorders lupus and rheumatoid arthritis that have a detrimental effect on the process of tissue repair. Further, medications that are involved in managing these conditions, such as corticosteroids and biological agents, may further impair immune function, raise the threat of infection and postpone healing (47). HIV infection further lowers the prognosis for endodontic treatments by impairing T-cell mediated immunity, which is critical for reducing inflammation.

**Summary:** Systemic health status has a significant impact on healing following perforation repair by impairing the immune response, bone turnover, and vascularisation. Clinicians must assess the systemic health of the patient prior to planning perforation repair procedures. Extended follow-up intervals, meticulous infection control, and potential use of additional therapies to enhance tissue repair should be considered and managed prior to the planning of treatment to promote optimal healing. Future studies should be directed towards examining the impact of various systemic health conditions on tissue vascularisation, bone remodelling, and immune response after perforation repair.

*Occlusal load*

Finite element analysis (FEA) has shown that mandibular molars with repaired perforations are subject to greater stress levels than intact teeth, with the highest stress concentrations occurring in buccal and furcal perforation sites (48). The increased stress levels within teeth are primarily due to the mismatch in the elastic modulus between dentine and repair materials such as calcium silicate-based cements, which do not replicate the biomechanical behaviour of tooth tissue (49). When occlusal forces are applied, they can intensify stress accumulation around the perforation site, heightening the risk of fracture especially in regions where the tooth structure has already been weakened by the perforation and its repair (48).

**Summary:** The impact of occlusal load on the outcome of perforation repair highlights the need to evaluate biomechanical factors during treatment planning. Clinicians should thoroughly assess the occlusal load in patients receiving perforation repair. Selecting suitable repair materials and designing appropriate restorations are crucial steps in

promoting the longevity and effectiveness of the repair and the survival of teeth. Future studies should explore the role of occlusal load on the outcome of perforation repair, especially the impact of various forces acting occlusally and bite patterns on healing outcomes. Furthermore, studies should also examine how effectively occlusal modifications affect the stress at perforation sites, so as to promote the longevity and effectiveness of treatment.

## Clinician-related factors

Clinician-related factors refer to elements that depend directly on the knowledge, skill, decision-making, and actions of healthcare professionals performing a specific treatment.

*Selecting the appropriate repair material*

According to Alshehri et al. (50) the ideal perforation repair material should be biocompatible, promote bone regeneration, possess antibacterial abilities, and offer exceptional sealing abilities. In the past, frequently employed materials for perforation repair included amalgam, zinc oxide eugenol, gutta percha, calcium hydroxide, glass ionomer cement, intermediate restorative material, composite resin and super ethoxy benzoic acid cements. However, current practice favours the use of bioactive materials that have demonstrated higher success rates, ranging from 73.3% to 92%, particularly when using larger sample sizes and extended follow-up periods. They have also provided a reliable long-term seal (18,21,32,41). A systematic review by Siew et al. (14) reported that nonsurgical repair of perforation with ProRoot MTA (Dentsply Maillefer, Ballaigues, Switzerland; grey and tooth-coloured versions), produced higher success rates in comparison with other materials, with an overall success rate of approximately 81% (14). Results from a laboratory study evaluating the performance of ERRM (Brasseler, Savannah, GA, USA), MTA (ProRoot MTA, Dentsply Tulsa, Tulsa, OK, USA), and GIC (Fuji II, GC Corporation, Tokyo, Japan) revealed that both ERRM and MTA had a similar sealing ability at the perforation site and performed better than GIC (51). Gorni et al. (19), reported that substantial reversal of healing occurs in the long term, even with MTA. The favourable sealing results observed with MTA and ERRM may be attributed to their composition and hydrophilic nature. This emphasizes the importance of calcium silicate-based cements as an effective and valuable alternative in tooth preservation. Moreover, Gorni et al. (18) concluded that the possibility of inflammatory progression following

perforation repair management with ProRoot MTA (Dentsply Maillefer; grey and tooth-coloured versions) was minimal, indicating its potential for long-term healing.

Considering the superior sealing ability, biocompatibility, and improved healing abilities of calcium silicate-based cements, it has become the material of choice for perforation repair in cases where the defects are situated apical to the crestal bone. However, calcium silicate-based cements have limitations such as their potential to discolour teeth and become dislodged mainly in the region coronal to the crestal bone, when there is direct communication between perforation site and oral cavity. In such circumstances, alternative materials such as bonded composites or resin-modified glass ionomers, may yield more stable, aesthetic, and reliable results (Figure 8). A laboratory study (52) concluded that Bioaggregate (Diadent Group International) offered better biocompatibility and perforation repair in comparison to Portland cement and MTA Angelus (Angelus, Londrina, Brazil) when used as perforation repair and root-end filling materials. Hashem and Amin (53) revealed that MTA Angelus (Angelus) was influenced comparatively more by acidic pH in comparison to Bioaggregate (Innovative Bioceramix) when used as perforation repair material. Sinkar et al. (54) evaluated the sealing ability and microleakage between Biodentine (Septodont), RetroMTA (BioMTA, Seoul, Korea) and ProRoot MTA (Dentsply Maillefer), and concluded that Biodentine offered the better sealing ability and least microleakage. Guneser et al. (55) evaluated various perforation materials and reported that Biodentine (Septodont) performed considerably better in comparison with other repair materials including ProRoot MTA (Dentsply Maillefer) when subjected to various endodontic irrigants.

Though newer bioactive endodontic cements show promise, long-term follow-up studies and larger-scale clinical trials are needed to verify their efficacy and establish stronger guidelines for their use. Ultimately, the selection of an appropriate material for perforation repair is based on factors such as the specific type, location, and characteristics of the perforation, which is a crucial determinant of the prognosis.

**Summary:** The selection of a material has an impact on the success of repair and should be primarily based on particular clinical circumstances, such as the type and location of the perforation. While ProRoot MTA (Dentsply Maillefer) remains the gold standard for perforation repair due to its proven high success rates, alternative bioactive materials

have demonstrated promising results in particular cases. Clinicians must carefully consider the choice of perforation repair material, as it directly impacts the long-term prognosis. Material selection should be guided by key clinical factors such as moisture control, location and size of the perforation and accessibility. Future research should focus on long-term clinical trials to assess the performance and longevity of newer bioactive materials in perforation repair.

*Adopting the appropriate clinical approach*

In the past, surgery was the preferred approach for managing perforations, primarily due to limited access and visibility, as well as the absence of tools to magnify and illuminate the site. However, the standard of care has changed as a result of these technological breakthroughs, favouring non-surgical procedures when possible. Non-surgical perforation repair using biocompatible materials in combination with use of microscopes has demonstrated success rates ranging from 72.5% to 90%, underlining the importance of prioritising this approach where appropriate (14,18,21,32,41,56). Surgical treatment is generally reserved for cases that either do not respond to non-surgical methods or require periodontal intervention (7,38,57). One of the key challenges during perforation repair is preventing salivary ingress and bacterial contamination, as these can compromise the sealing ability of the repair materials and increase the likelihood of post-treatment disease. Effective disinfection of a perforation site is crucial during repair procedures to minimize the risk of infection and support proper healing. Giovarruscio et al. (58) recommended using 1% sodium hypochlorite (NaOCl) in cases of perforation, as it offers the benefit of minimizing the caustic effects on periradicular tissues while still providing essential antibacterial activity. Although NaOCl is an effective irrigant with strong antimicrobial properties, its inadvertent use at perforation sites can lead to several complications due to its cytotoxic nature.

To ensure favourable healing, it is crucial to implement effective isolation techniques. These provide a controlled environment that enhances the success of the procedure (59–61). Arens and Torabinejad (24) described cleaning of infected perforations and the wound with copious irrigation of 2.5% sodium hypochlorite before placement of the repair material. Sodium hypochlorite is an effective antimicrobial agent but should be used cautiously because of the risk of complications should the solution come into contact

with bone. The use of an internal matrix has been found to support the healing of furcation perforations, particularly when compared to traditional materials such as amalgam, which lack a structural scaffold (62). However, with the introduction of calcium silicate-based cements, some studies suggest that the need for an internal matrix is reduced (63). Research has shown that the extrusion of calcium silicate-based cements into the alveolar bone does not impede the healing process (63–65). Instead, calcium silicate-based cements seem to facilitate biological repair by promoting cementum formation and aiding the regeneration of the periodontal apparatus. One factor not mentioned in reports is the optimum thickness of the repair material. The stability and resilience of the material is of prime importance, and it is surprising that no research has been published on this potential factor.

**Summary:** Technological advancements in visualization have made non-surgical repair the preferred approach for perforation management when conditions are favourable. Clinicians must use bioactive materials and advanced imaging methods to repair root perforations. Effective isolation and decontamination with careful use of sodium hypochlorite is recommended. Sodium hypochlorite should be used carefully for disinfection to minimize risks. The use of an internal matrix should be based on specific clinical situations. Surgical treatments are now reserved for cases that do not respond to conservative methods or have additional complications. The optimum thickness of the repair material has not been investigated. Future studies should compare perforation repair outcomes by non-surgical and surgical approaches, particularly in terms of size, location, time frame, and periodontal involvement.

*Clinician's expertise, magnification and illumination*

Effective management of iatrogenic perforations relies on the use of appropriate devices that enhance visibility and ensure accurate treatment, ultimately improving clinical results. Cone beam computed tomography (CBCT) is increasingly used to detect and assess root perforations (66). It increases the possibility of diagnosing root perforations by offering three-dimensional imaging that tends to overcome the drawbacks of conventional periapical radiographs (16,67). An *ex vivo* study (68) comparing digital periapical radiographs and CBCT to detect strip and root perforations revealed that despite higher risk of misdiagnosis found among both the modalities of imaging, CBCT

displayed higher sensitivity in comparison to periapical radiographs. This greater sensitivity associated with CBCT permits precise detection, decreasing the possibilities of false negatives. Thus, CBCT not only aids in diagnosing perforations but also decreases the risks associated with management and assists in perforation repair (69).

Root canal treatments performed by specialists are more likely to result in predictably consistent and successful outcomes (18,21,70,71). The operating microscope, in particular, is recognised as a critical tool in the successful repair of perforations, as it greatly improves both visibility and precision during the procedure. The favourable outcomes associated with calcium silicate based cements are often attributed to the increased accuracy of its placement, alongside the material's beneficial biological properties (14,55). To ensure a precise evaluation of the perforation site, it is imperative to have optimum visualization using an operating microscope (7).

**Summary:** The clinician's expertise is a significant factor in the success of perforation repair, and the utilization of sophisticated equipment significantly improves precision and visibility. Clinicians should undertake training and be proficient in the use of advanced visualization and instrumentation tools in order to enhance precision, visibility, and control, especially in complex or minimally accessible areas. Future research should investigate how technologies such as magnification enhance the outcome of perforation repair when combined with bioactive materials with a focus on precision and visibility.

## CONCLUSIONS

The outcome of iatrogenic perforation repair is affected by various perforation-related, patient-related and clinician-related factors that determine healing and long-term tooth survival. Effective planning and treatment are possible only if there is a clear understanding of these key parameters. Table 1 summarizes the major considerations that determine the success of perforation repair, emphasizing the key clinical and procedural factors.

A variety of interconnected factors influence the outcome of perforation repair, each influencing treatment outcomes. Among various determinants of perforation repair outcomes, the presence of periodontal pockets in association with inflammation and bone loss, anatomical position of the perforation, perforation size, timing of treatment, and type

of repair material play a crucial role. Furthermore, the expertise of clinicians, the subsequent treatment strategy, and use of predictable case management protocols are other critical factors. Interdependency of these factors offers a growing necessity to formulate an updated system of classification of root perforations. Such a system would be an important tool to assist clinicians in making evidence-based decisions about diagnosis, treatment planning and management. An in-depth awareness of the factors influencing the prognosis is essential for providing reliable, effective and successful outcomes in treating iatrogenic perforations. The incorporation of these factors into clinical guidelines and classification systems will ultimately lead to improved patient care and well-being as well as long-term treatment success.

**Table 1:** Key factors that have the potential to influence the outcome of iatrogenic perforation repair

| Key Factors | Impact on the outcome | Clinical and procedural aspects |
|---|---|---|
| Size of Perforation | Smaller perforations are linked to better healing and survival rates | Inverse/Negative correlation between perforation size and treatment success. Smaller perforation possesses less tissue disruption and better sealing |
| Location of Perforation | Apical > Coronal/Furcal in terms of prognosis | Perforations within critical zone always offer poor prognosis. Coronal/Apical to critical zone are often accessible and so sealed effectively |
| Time of Repair | Early intervention leads to better healing | Delayed treatment increases risk of infection and tissue destruction. Bacterial ingress from saliva or root canal system worsens the prognosis |
| Contamination Level | Lower contamination offers better outcome | Residual bacterial infection hampers the tissue repair often resulting in persistent periapical inflammation |
| Repair Material | Bioactive materials have demonstrated better success rates | Mineral Trioxide Aggregate (MTA) remains gold standard due to its proven biocompatibility, sealing ability, and high success rates |
| Systemic Health | Systemic health greatly influences parameters like immune response, bone turnover, vascularisation, tissue regeneration and have positive correlation between health and healing | Diabetes, immunosuppression, or other systemic conditions may impair healing |

| | | |
|---|---|---|
| Age of Patient | Younger patients generally show better healing | Younger individuals possess greater regenerative capacity, better blood supply, enhanced stem cell activity and stronger immune function |
| Technique Quality | Precise, well-isolated perforation repair improves prognosis | Use of magnification, illumination and proper sealing materials are crucial |
| Periodontal Involvement | Compromised periodontium offers only a poorer prognosis | Periodontal pockets or bone loss near perforation site reduce success rate |
| Occlusal Load | Stress accumulation around the perforation site, increases the risk of fracture | Comprehensive biomechanical assessment is crucial to promote long term functional stability. |

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**FIGURE LEGENDS**

Figure1. Clinical and radiographic presentations of perforations due to various iatrogenic and pathological causes. A. Buccal view of tooth 12 showing granulation tissue in an extensive perforation caused by cervical resorption, B. 3D-reconstruction of tooth 12 revealing the extent of the resorptive defect, C. Preoperative periapical radiograph of tooth 46, D. Periapical radiograph of tooth 46 with an endodontic file in a perforation that occurred in the floor of the pulp chamber during access cavity preparation. There is no bone destruction in the furcal region as the perforation just occurred, E. Periapical radiograph of teeth 36 and 37 showing posts emerging through extensive perforations that occurred during post space preparation, which led to extensive bone destruction (Image courtesy: Dr. Thomas Clauder)

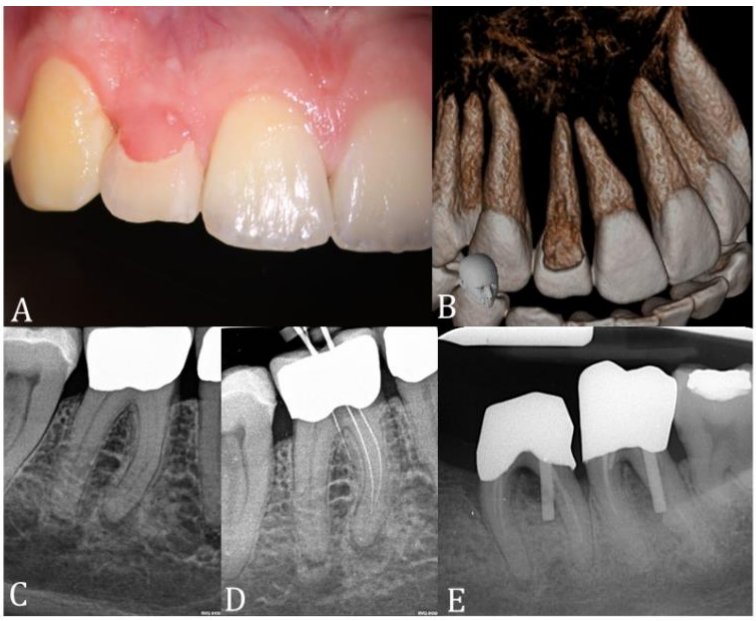


Figure 1

Figure 2. Radiographic and clinical images of various iatrogenic perforations. A. Periapical radiograph of tooth 14 with a perforation, B. Periapical radiograph of tooth 24 showing a perforation with extruded root filling material. A, B perforation occurred due misinterpretation of the crown-root angulation, C, D. Periapical radiograph and occlusal view of a pulp chamber perforation due to excessive removal of dentine associated with calcification of the pulp chamber, E, F, G. Periapical radiographs and occlusal view of a pulp chamber perforation due to excessive removal of dentine associated with calcification of the pulp chamber (Images courtesy: Dr. Thomas Clauder).

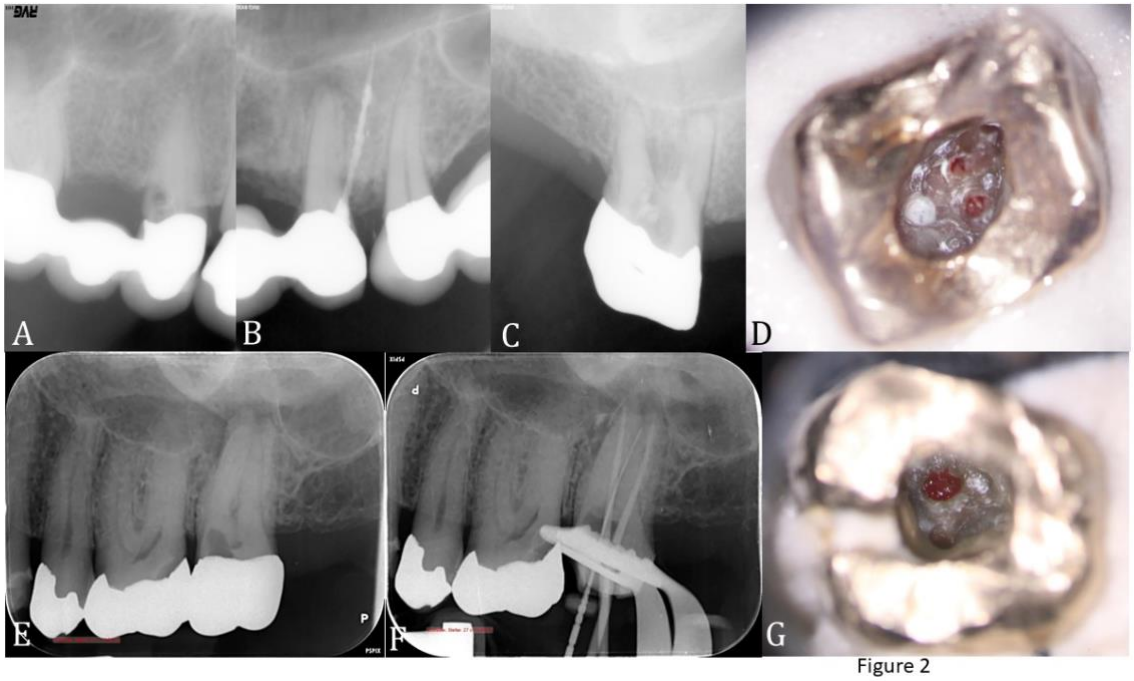

Figure 2

Figure 3. Radiographic and clinical management of a pulp chamber floor perforation in tooth 36. A. Periapical radiograph of tooth 36 showing extensive tooth tissue loss that occurred during access cavity preparation and resulted in a perforation to the pulp chamber floor. No bone destruction in the furcal region is evident, B. Perforation site on tooth 36 and thinned-out pulpal floor, C. Closure of the perforation site and adhesive reconstruction of the pulpal floor with a resin bonded glass ionomer material (Geristore, Denmat), D. One-year post-operative periapical radiograph of tooth 36 showing the root filling and perforation repair with no signs of periradicular pathosis (Images courtesy: Dr. Thomas Clauder).

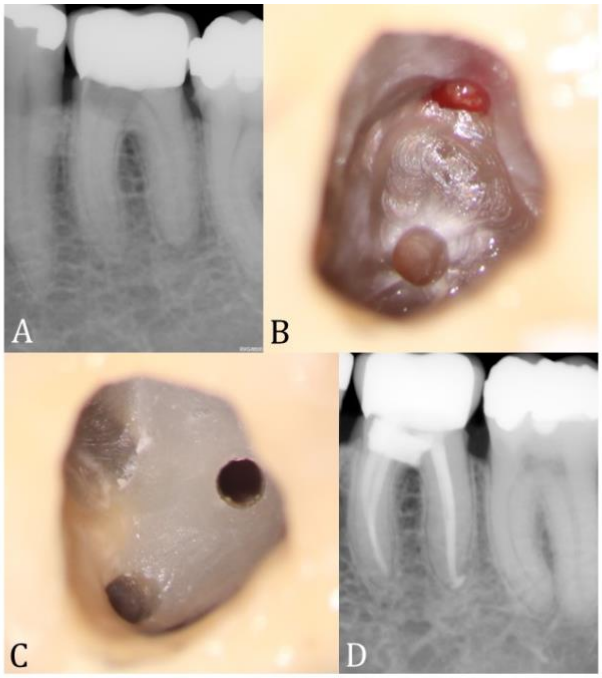


Figure 3

Figure 4. Repair of an infected furcal perforation in tooth 16. A. Periapical radiograph shows no evidence of a perforation due to superimposition of restorative materials, B. Clinical image of tooth 16 with a massively infected long-term perforation between the buccal roots in the furcation, C. Situation after appropriate cleaning of the furcation and instrumentation of the previously undetected distobuccal canal, D. Use of a gutta-percha point as a space maintainer to prevent repair material blocking the canal, E. After perforation repair with ProRoot MTA and removal of the space maintainer, F. Filling of the canals after setting of the repair material, G. Immediate postoperative periapical radiograph, H. One-year postoperative radiograph shows no signs of pathosis (Images courtesy: Dr. Thomas Clauder).

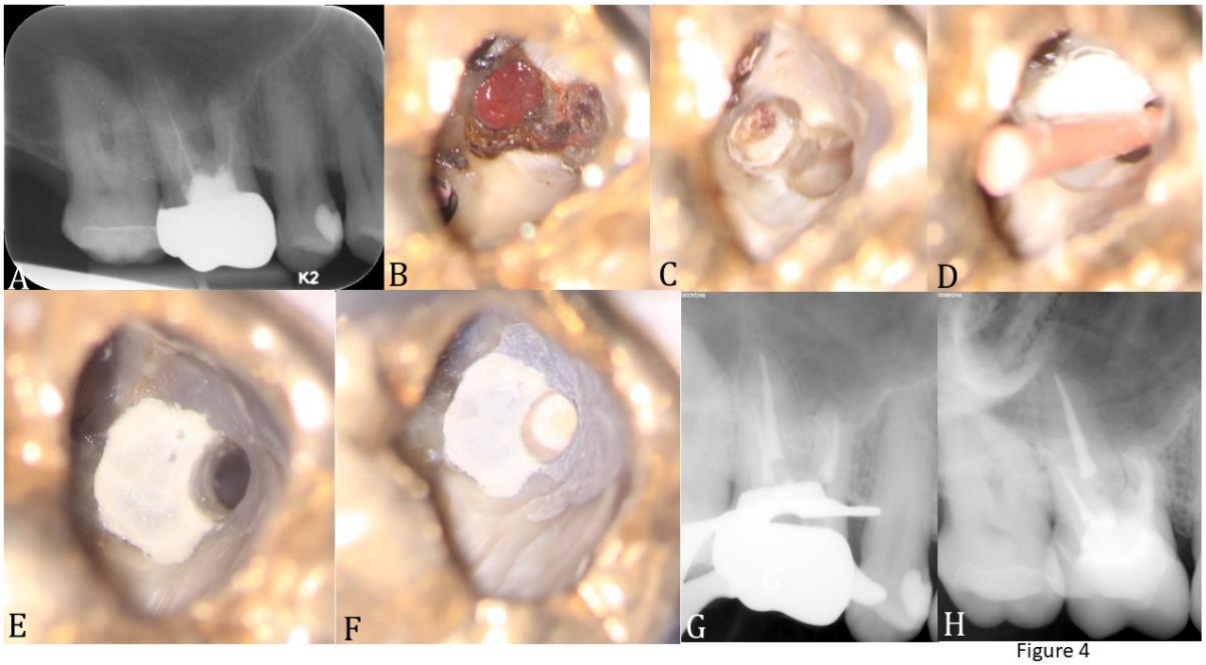

Figure 4

Figure 5. Repair of a perforation in the middle third of the mesial root of tooth 47. A. Strip perforation on the mesial root of tooth 47 not clearly visible on the preoperative periapical radiograph, B, C. Strip perforation clearly visible on CBCT images. D. Strip perforation caused by extensive removal of dentine during root canal preparation visible using a microscope, E. Strip perforation repair - with ProRoot MTA filling the entire coronal section of the canal, F. Postoperative periapical radiograph showing the perforation repair prior to tooth restoration (Images courtesy: Dr. Thomas Clauder).

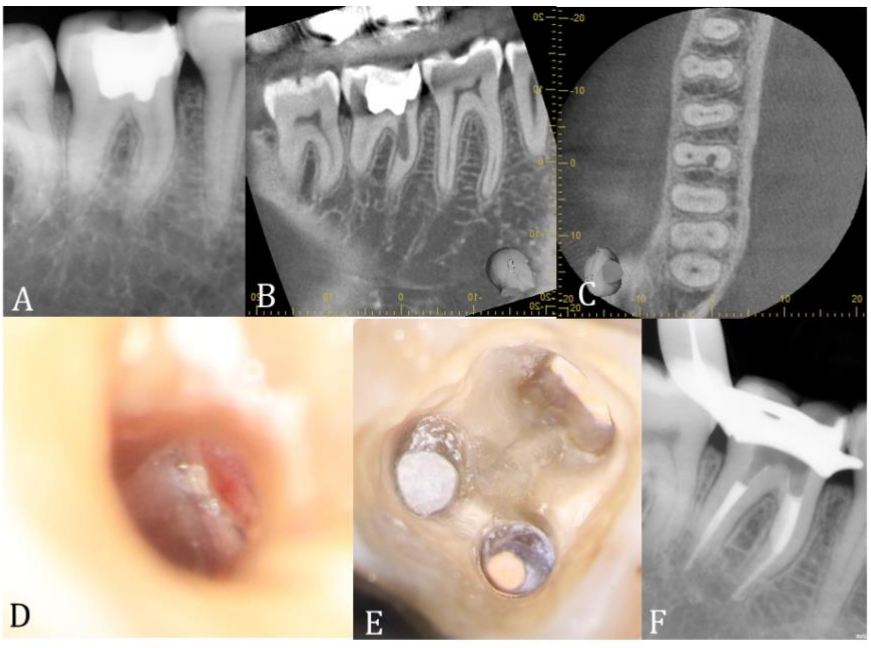

Figure 5

Figure 6. Repair of a perforation in the apical third of the mesial root of tooth 16. A. Preoperative periapical radiograph showing an insufficient root filling, massive apical transportation of the mesiobuccal canal and possible perforation in the apical third; note the gutta-percha point in the buccal fistula, B. Perforation in the apical third of the mesiobuccal root visible under high magnification, C. Perforation repair and root filling of MB1 with MTA, with warm vertical compaction of gutta-percha in MB 2, D. Postoperative radiograph with no signs of pathosis (Images courtesy: Dr. Thomas Clauder).

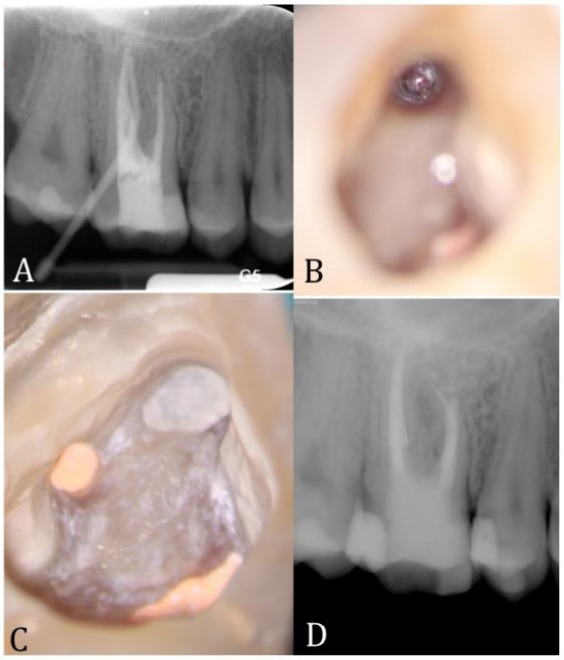


Figure 6

Figure 7. Repair of mesial perforation in tooth 46 at the crestal bone level. A. Periapical radiograph showing post-treatment endodontic disease apically as well as in the furcation. The perforation on the mesial aspect of the mesial root led to the formation of a periodontal pocket, B. Massive infection of the perforation site, C. One-year postoperative periapical radiograph shows healing of the apical and furcation lesions. The periodontal pocket caused by the perforation is stable but without resolving the probing depth (Images courtesy: Dr. Thomas Clauder).

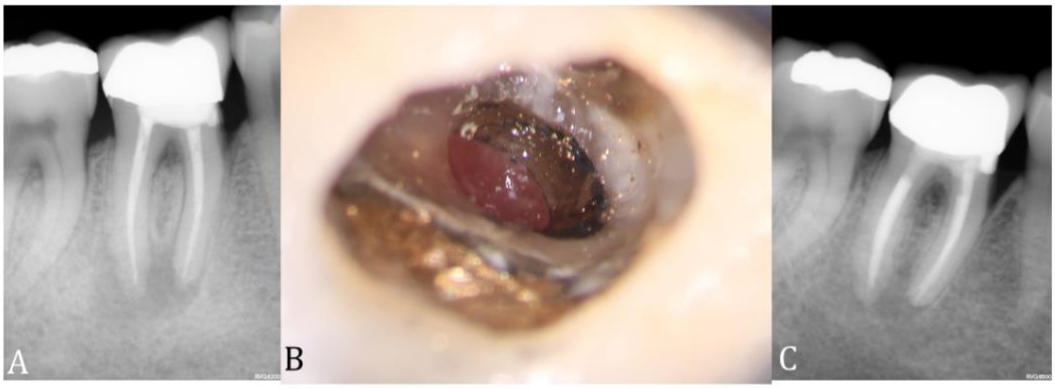


Figure 7

Figure 8. Repair of a supracrestal, buccal perforation due to misangulation during accessing 11. A. Preoperative periapical radiograph not clearly showing a perforation, B. CBCT images reveal the extent of the perforation, C. Buccal perforation visible with the operating microscope through the access cavity, D. Perforation visible with the operating microscope from the buccal side, E. After restoring the perforation due to its supracrestal localization with composite, F. radiological postop after root canal obturation (Images courtesy: Dr. Thomas Clauder).

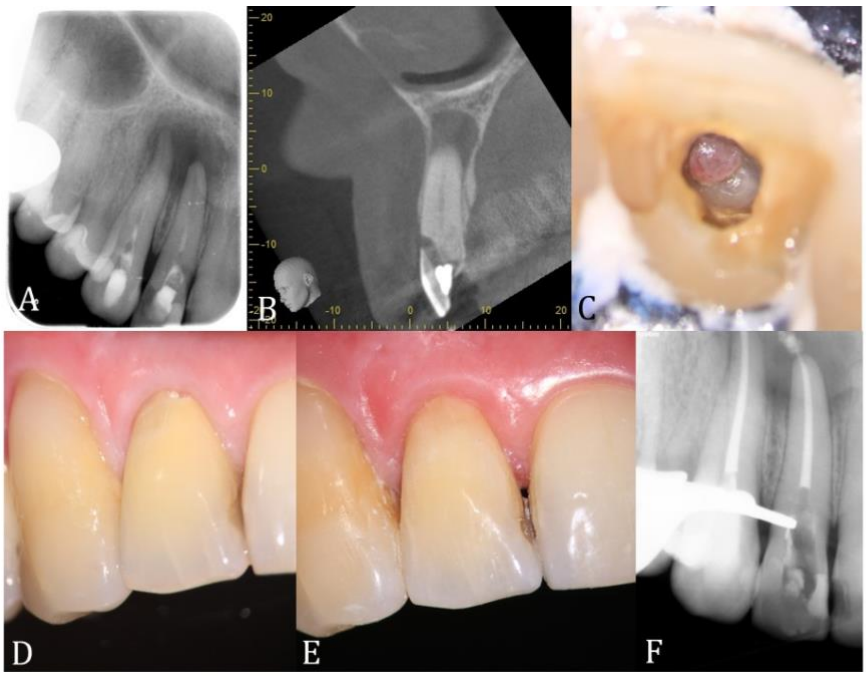


FIGURE 8