Furcal area and root canal perforations treatment – case series report and literature review*

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ABSTRACT
Introduction: Perforation is a pathological connection between the root canal system and the external surface of the tooth that can occur unintentionally during pulp chamber preparation. The consequence of this complication is inflammation and destruction of the periodontal tissues. Therefore, it is essential to seal the perforation to avoid tooth loss. Among different bioactive materials, mineral trioxide aggregate (MTA) and Biodentine (BD) ensure a favorable prognosis in therapeutic dental procedures due to their healing properties.
Materials and methods: The present case series report describes successful treatments of different sizes, locations, and immediate and mediated perforations.
Results: Clinical and radiographic follow-up showed asymptomatic teeth without discomfort, swelling, fistula, or radiolucency in the furcal area.
Conclusion: Mineral trioxide aggregate and BD can be successfully used as a biocompatible material for the repair of furcal and root canal perforations.
Keywords: perforation; pulp chamber; MTA; Biodentine; root canal treatment.

INTRODUCTION

Currently, root canal therapy (RCT) is one of the most common dental procedures performed not only by specialists but also by general dentists [1]. However, as the number of endodontically treated teeth increases, the incidence of complications increases.

During the preparation of the access pulp cavity, some factors may predispose to iatrogenic complications related to root canal treatment or procedural errors [2]. One of these iatrogenic complications is pulp chamber and root perforation. These serious defects are associated with significantly poorer endodontic treatment outcomes, especially when the development of bacterial infection has occurred [3, 4, 5, 6].

Perforation has been defined by the American Association of Endodontists in the Glossary of Endodontic Terms [7] as a pathological connection between the root canal system and the outer surface of the tooth. According to the literature, the incidence of this complication ranges 0.6–17.6% [3, 4, 5, 8]. Epidemiological studies have shown that this iatrogenic injury occurs most often during prosthetic treatment – insertion of posts, rarely during endodontic procedures [4, 5, 9, 10, 11].

Perforation has been identified as one of the sources affecting RCT results [12]. In 1996, Fuss and Trope proposed a classification of root perforations according to factors that affect the prognosis of the tooth [4]. The prognosis of root perforation depends on its size, location, and time of injury [3, 4, 6, 9, 11].

The time between the appearance of the defect and the appropriate treatment with sealing was found to be an important factor in healing [3, 4, 13]. The most favorable healing conditions occurred when the injury was sealed immediately. The issue of perforation size has also been controversial. Small perforations are usually associated with less tissue loss and periodontal inflammation, and healing is more predictable in these cases.

However, the most important factor is the location of the injury, which may worsen the treatment prognosis. The connection between the perforation and the gingival sulcus, the oral cavity environment, is the most critical element. Fresh and small perforations away from the gingival sulcus and located coronal or apical to the crestal bone level usually have a good prognosis if adequate sealing and RCT are provided. Injury incidence in the furcation area of multirooted teeth is usually considered critical root perforation because the connection to the epithelial attachment and the gingival sulcus leads to inflammatory reactions and causes impairment of the periodontal tissues, resulting in tooth loss [3, 4, 5, 6].

Perforation can be pathological, as a result of caries, resorptive process [14] or iatrogenic. Iatrogenic injury most often occurs during or after RCT [5, 10, 11]. Some factors that make access to the cavity difficult are related to root canal treatment or procedural errors. The presence of pulp stones [15, 16], calcifications, obliterations, incorrect positioning of the tooth in an arch (tilting, rotation), prosthetic crown reconstruction, and preparation for a post are the most common factors.

The treatment of perforations was made possible by the introduction of mineral trioxide aggregate (MTA) into dentistry in 1993 [17]. Initially, this calcium silicate cement was used as a retrograde root canal filling. Before the widespread use of bioactive materials, various dental materials such as amalgam [18, 19], zinc oxide eugenol cement [19] or resin-modified glass ionomer cements [20] and resin materials [21] were used to repair root perforations.

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According to the literature [22, 23, 24], the clinical applications of bioactive endodontic cements (BEC) are apexification, regenerative endodontic procedures, perforation repair, retrograde and orthograde root canal filling, periodontal defects, and treatment of root fractures [25].

The purpose of this case series report was to describe the results of the treatment of fresh and old cases with different sizes and locations of furcal and root canal perforations using two bioactive materials, such as MTA and Biodentine (BD), in molars and single canines.

MATERIALS AND METHODS

Patients diagnosed with perforation were referred to the endodontic office. Written consent for RCT was obtained from all patients at the first appointment. The diagnosis of perforation was confirmed by clinical and radiological examination. The teeth were asymptomatic, and no periodontal defects were found on clinical examination after probing the gingival sulcus. Radiographs showed periapical radiolucency in all cases. Anesthesia was administered with 4% articaine hydrochloride with adrenaline 1 : 100,000 100,000 (Citocartin 100, Molteni Stoma, Italy). After placement of the rubber dam, the temporary filling was removed, and the pulp chamber was irrigated with saline, dried with cotton pellets, and examined under the operating microscope. Gates-Glidden drills (Dentsply Sirona, Switzerland) were used to prepare the canal orifices. After determining the working length with an apex locator, the canals were scored with manual stainless steel C+ files (Dentsply Sirona, Switzerland). In cases with old perforations in which granulation tissue was seen (Fig. 1A), it was removed with low-speed extended rose burrs, and a calcium hydroxide disinfectant dressing was applied for 1 week due to infection (Fig. 1B). At the first visit, in cases with fresh perforations, and during the second visit, in cases with old perforations after protection canal orifices with gutta-percha cones, MTA (Septodont, St. Maur-des-Fossés, France) or BD (DentsplyTulsa Dental, Tulsa, OK, USA) was prepared and applied in accordance with the manufacturer's instructions (Fig. 1C).

Further preparation and obturation of the root canals were performed at the next appointment. In the cases described, all canals were prepared with ProTaper Next rotary files (Dentsply Sirona, Switzerland) using the crown-down technique. During treatment, 5.25% sodium hypochlorite was used as an irrigant in all cases. Gutta-percha points were placed and the canals were filled using the gutta-percha continuous wave condensation method with SuperEndo α2 and SuperEndo β (B&L Biotech, USA) and AH Plus sealer (Dentsply Sirona, Switzerland). The orifices of the canals and the pulp chamber were secured with a flowable composite. The cavity was sealed with a temporary filling. X-rays were taken immediately after RCT and at 1-year follow-up (Fig. 2).

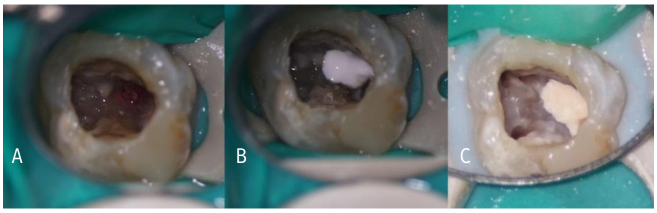

FIGURE 1. Photographs of maxillary left first molar with an old perforation in the furcation area. A clinical view of the perforation with: (A) granulation tissue, (B) calcium hydroxide dressing applied, and (C) Biodentine repair

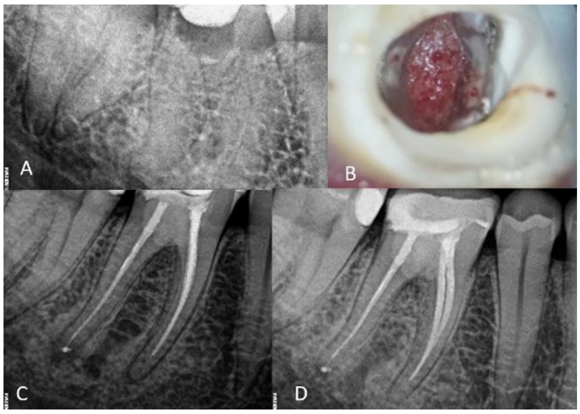

FIGURE 2. Mandibular right first molar with a large furcal perforation: (A) a preoperative radiograph shows a perforation in the pulp chamber, (B) a clinical view of the perforation, (C) a radiograph of the perforation repair with Biodentine and after root canal therapy, (D) a follow-up radiograph at 1 year. The outcome was classified as healed

RESULTS

The evaluation of patients and perforation and injury repair is shown in Table 1.

TABLE 1. Evaluation of patients and perforations

Case number	Age	Gender	Tooth	Position of perforation	Time of sealing	Size (mm)	BEC	Results
1	42	F	26	floor of pulp chamber	old	2	MTA	healed
2	38	M	26	floor of pulp chamber	old	2	BD	healing
3	27	F	46	floor of pulp chamber	fresh	4	BD	healed
4	48	F	36	floor of pulp chamber	fresh	4	MTA	healed
5	54	F	24	floor of pulp chamber	old	1	BD	healing
6	15	F	45	cervical third of root	fresh	2	MTA	healed
7	62	M	23	middle third of root	old	2	MTA	healing

BEC – bioactive endodontic cements; F – female; M – male; MTA – mineral trioxide aggregate; BD – Biodentine

During clinical and radiographic follow-up, the reported cases presented asymptomatic teeth with no pathological symptoms: discomfort, swelling, fistula, or radiolucency in the furcal area. After 1 year of observation, healing of the lesion in the periapical tissues was noted in 3 cases, and 4 cases were successfully treated.

DISCUSSION

According to the literature [4, 5, 9, 10, 11], iatrogenic injuries occur most frequently during post-placement (prosthetic treatment) and slightly less frequently during endodontic procedures. Similarly, in this report, all the cases presented were iatrogenic injuries related to the preparation of the pulp cavity access. In cases 3 and 4, very deep and excessive access preparation was observed. Prosthetic crown reconstruction was a causative factor in case 5, and incorrect positioning of the teeth in an arch (tilting, rotation) in cases 6 and 7 were possible causes of iatrogenic injury. Accidental perforation of the pulp chamber floor may have serious implications for the success of RCT. The subsequent laceration of the periodontal tissue leads to the development of bacterial infection, destruction of the periodontium, bone resorption, formation of granulomatous tissue, and ultimately the development of a periodontal defect [3, 4, 26].

An unrecognized and untreated perforation ultimately leads to tooth extraction. Perforations can occur in any part of the root canal system: pulp chamber, coronal, middle or apical part of the root canal. A classification system of perforation was presented in 1996 [4]. Based on the factors that influence the prognosis of the injury, such as time of repair, size, and location of the perforation, an ideal treatment strategy can be determined. Fuss and Trope emphasized that delayed repair, large perforations, and location in the cervical region of the tooth (connection to the gingival sulcus or crestal bone) reduce the chance of successful repair treatment [4]. In this study, fresh and old perforations of various sizes and locations were presented.

The presented sample size of 7 teeth was larger than in previously published studies (2–4 teeth) [27, 28] and smaller than in others (16–970 teeth) [29, 30, 31, 32, 33, 34, 35, 36]. Similarly, other studies [27, 29, 30, 31, 32, 33, 34, 35] have described the treatment of pulp chamber floor and root perforation cases using an orthograde approach to the injury in this investigation.

In this study, the outcome of root canal perforation repair with MTA and BD was evaluated. There are some discrepancies among scientists regarding the influence of preoperative factors on the treatment prognosis of perforated teeth. These factors include group of teeth (anterior, posterior), location (maxilla, mandible), injury prior to RCT, size of perforation, time elapsed between injury and intervention, and of course the type of agent used to close the perforation defect. Previous studies [29, 30, 33, 34, 36] reported that the tooth group was not a prognostic factor for perforation healing, which was consistent with this study. It was suggested that the location of the affected tooth influenced the treatment outcome. In a recent study [34], after 14 years of observation, all anterior teeth with perforations healed, whereas premolar and molar defects did not heal in all cases, although the difference was not statistically significant. Interestingly, it was also concluded that root perforations in the maxilla had a higher success rate [37].

Considering the size of the perforation, researchers [29, 30, 32, 34] concluded that over a long period of observation (4 years and more), the healing rate of larger perforations (size >3 mm) was lower than that of smaller sizes, but this was not statistically significant. The location of the perforation was identified by Pontius et al. [32] as a prognostic factor influencing healing, in contrast to other studies [36]. In the cited study [32], all failures were cases with perforations at or near the level of the bony crest, which may be related to the proximity of the epithelial attachment and the increased likelihood of bacterial contamination.

According to the literature [3, 4, 13], the time elapsing between the appearance of the perforation and the time of repair sealing has been found to be an important factor in healing. The best conditions for healing occur when the injury is sealed immediately. Marques et al. presented good results in a case report of immediate and delayed treatment of furcal perforations in primary molars [28]. In this study, the time of sealing the defect was different in the reported cases. In 4 cases, the defect was infected and ingrown granulation tissue was observed. In 3 cases, the perforation was fresh. Early sealing of the defect could prevent bacterial growth and inflammation of the periodontium, thereby improving the healing process of the periodontal tissues. This is particularly important in perforations of the furcal area due to its proximity to the oral environment.

In this study, in cases of fresh perforation, the defect was immediately sealed, in contrast to cases of old perforation where additional disinfection with calcium hydroxide dressing was required. This was in agreement with some previous studies [29, 30, 33, 34, 37] and in contrast to others [38]. Mente et al. applied a mixture of calcium hydroxide powder and chlorhexidine solution to the perforated area and root canals for several days in cases where bleeding from the defect would have contaminated the perforated area [29, 30]. However, in other studies [33, 34], calcium hydroxide was used only to control bleeding and MTA was applied immediately a few minutes after its application. Similar to this study, Alves de Melo et al. used calcium hydroxide to neutralize the inflammatory process before MTA insertion [37].

Recently, when BECs were introduced in endodontics, some discrepancies appeared among studies regarding the prognosis of perforated teeth [39, 40, 41]. Most authors concluded that the size of the perforation did not affect the success of the treatment [29, 30, 32, 36], which is consistent with this report, where defects of different sizes were effectively treated and in contrast to others [33, 34]. Bioactive endodontic cements, due to their advantages related to their physicochemical and biological properties similar to dentin and high compressive strength [23, 41, 42], demonstrate great sealing ability and biocompatibility [10, 43].

Krupp et al. investigated the success rate after using MTA to repair root perforations. The authors identified the lesion adjacent to the perforation site as a prognostic factor for healing. According to the cited study, a minimum period of time that seems to be sufficient to evaluate treatment outcome is 1 year [36], which is in agreement with this and other studies [44], but is in contrast to others that show 24 months of observation or more [27, 28, 29, 30, 33, 34, 45, 46, 47]. In a 14-year longitudinal study with up to 8 years of follow-up, a very low initial failure rate was observed, but after this period of follow-up, a significant increase in failure rates was found [34]. According to the literature, the healing rate after perforation repair ranges 69.8–93% [29, 30, 32, 34, 36, 40].

As in previously published case reports [45, 47], no radiolucency in the furcal area was observed in this study.

The use of a matrix barrier has long been controversial. There is still no consensus on the use of matrix barrier under BECs in perforation repair. According to the literature, a number of different barriers have been proposed, such as calcium sulfate [32, 48], collagen [32, 36, 49] or platelet-rich fibrin matrix [45, 50].

Several studies have investigated whether there are differences in healing outcomes between repair procedures with or without the barrier [48, 51, 52, 53]. Interestingly, Aladimi concluded that calcium sulfate under MTA gave the best results for repair of inadvertent furcation perforation [48]. Contrasting data were presented in an earlier study where MTA alone showed a better healing response than with calcium sulfate [52].

In this report, the treatment protocol of BEC application was similar to that reported previously [29, 30, 32, 37, 38, 44, 47, 54], where no matrix placement in the perforation defect was used prior to MTA and BD insertion. Other studies [48, 49, 51, 52] contradict this methodology by using repair materials with or without calcium sulfate.

Aladimi concluded that MTA with calcium sulfate or MTA alone showed more bone and cementum apposition and less bone resorption, epithelial proliferation, and inflammation compared to nanofilled resin-modified glass ionomer [48]. In other studies [45, 50], platelet-rich fibrin was used as an external matrix to prevent BD extrusion during the treatment of open apex, furcal perforation, and horizontal root fracture. The results of the cited study demonstrated remarkable healing and were followed for 2–3 years.

Interestingly, other papers [32, 53] reported that a resorbable matrix such as collagen or calcium sulfate was used only for large perforations. In addition, another study [9] reported that extrusion of the repaired material into the periodontal tissues may decrease the results of perforation treatment, which is in agreement with this research, where in the case of extrusion of MTA in tooth 23, after 1 year of observation, the healing process was in progress but still not completed.

In a previously published systematic review [55], it was concluded that MTA, since its introduction to the market in the 1990s, has the most biocompatible and predictable behavior, but BD also had favorable results, and there should be more clinical research comparing these materials to assess which one should be the "gold standard" for dental practitioners.

With over 30 years of use in endodontics, MTA is the most studied hydraulic calcium silicate cement to date. As a result, MTA is now considered the "gold standard" for perforation repair. With the introduction of biocompatible materials to seal the perforation, the prevention of bacterial leakage has become more predictable and successful [3, 9, 10, 11, 23, 26, 41, 43, 56], which was consistent with this report.

Biodentine was introduced to the dental market in 2009. It is a 2-component material. The powder consists of tricalcium silicate, dicalcium silicate, calcium carbonate, and zirconium dioxide as contrast. The liquid component consists of calcium chloride (setting accelerator) water reducing agent in aqueous solution with a polycarboxylate additive. According to the manufacturer's instructions, the setting time after placing the BD on the defect site is 12 min, and RCT should be performed at the next visit according to current recommendations.

According to Buła et al., after mixing the material, the first setting phase lasts 15 min and the second phase, which the cited authors call "maturation", lasts 120 min. The authors stated that it is advisable to divide the endodontic treatment with BD into 2 separate visits [57]. Similarly, in this report, the sealing of the pulp chamber perforation was performed in two visits. On the first visit, cases 2, 3, and 5 were sealed with BD and on the next visit, the RCT was completed.

Interestingly, *in vitro* and *in vivo* studies published in 2023 [58], the authors concluded that the nanoparticle size distribution of BD is crucial for the osteogenic potential at an earlier stage of setting compared to MTA.

Case reports of the treatment of furcation perforation with MTA in primary molars [28, 59] and permanent teeth [29, 30, 31, 32, 36, 37, 56, 60] have been reported in the literature. Previously published studies have evaluated the immunoinflammatory response and bone formation in the sealing of furcation perforations in rat [61, 62] and canine molars [54, 63] after repair with BD and MTA.

The results of da Fonseca et al. indicate the role of BD and MTA in exerting an immuno-inflammatory response that favors the regression of the inflammatory response and the formation of periodontium structural components such as collagen fibers and bone matrix [61]. In previous studies [30, 31, 32, 36, 37], based on the results of clinical research, scientists concluded that MTA provides effective sealing of root perforations and can improve the prognosis of perforated teeth.

In another *in vivo* study [63], histopathological analysis of tissue responses after sealing furcation perforations in canine teeth with BD and MTA was evaluated. The results showed no significant difference in the formation of mineralized tissue and partial reinsertion of collagen fibers between BD and MTA, but according to the scientists, only MTA induced the expression of proteins associated with the formation of cementum-like mineralized tissue.

Similar to earlier results [64], MTA and BD after sealing furcation perforations in canine teeth showed a higher frequency of complete sealing, newly formed mineralized tissue had greater thickness and area after MTA placement than after using BD [63, 64]. In addition, BD had positive histopathological results and can be considered an adequate repair material for furcation perforation [64].

Tissue responses after furcation perforation in rat teeth after immediate sealing with these BECs have been evaluated by others. Researchers reported that BD and MTA promoted appropriate periradicular tissue responses, with a milder inflammatory response, less bone resorption than the positive control, and cementum repair after sealing furcation perforation [62]. Interestingly, according to the systematic review of the literature, repair of furcation perforation with BD has a better outcome compared to MTA [39].

One of the animal studies compared the histological responses, radiographic and micro-computed tomographic results after repair of furcation perforation with BD and MTA in canine teeth [65]. Cited scientists obtained equivalent radiographic response with similar hard tissue resorption and repair for tasted BECs, but the group with BD showed significantly less inflammation, lower volume of extruded material after sealing, and higher cement repair than in the MTA group. Previously mentioned authors [65] concluded that after furcal perforation repair in canine teeth, BD showed biocompatibility, and allowed the formation of mineralized tissue with similar morphology and integrity, but cement formation was greater than in MTA group.

In a study comparing MTA and BD used in the treatment of pulp chamber floor perforation in extracted mandibular molars, the push-out bond strength of BECs increased with increasing setting time [49]. The push-out bond strength of MTA and BD in non-blood contaminated specimens was similar. Blood contamination of perforations repaired with BD did not affect the push-out bond strength. Different results were observed in perforations repaired with MTA in blood-contaminated specimens, with blood contamination affecting MTA specimens with a setting time of 7 days. This was confirmed in a systematic review and meta-analysis of *in vitro* studies published in 2022 [66].

The push-out bond strength of calcium silicate-based cements has also been tested after the application of a calcium hydroxide dressing [67, 68, 69]. Nagas et al. claimed that BD had a higher bond strength to root canal dentin than MTA. The results of the cited study [67] indicated that the placement of calcium hydroxide as an intracanal medication increased the resistance to dislodgement of both calcium silicate cements. Contrasting data have been presented [68, 69]. Alsubait et al. concluded that $Ca(OH)_2$ promoted lower bond strength of MTA to root dentin [68], which was in contrast to another study [69] where scientists found no influence on the dislodgement resistance of MTA to root dentin. In this case report, calcium hydroxide was used as an intracanal medication (in all cases) and as a perforation dressing (old perforation cases), and it did not diminish the treatment results.

The evaluation of the sealing capacity of MTA and BD for the repair of furcation perforations has been evaluated by others [49, 70]. An *in vitro* study by Das et al. evaluated the sealing ability of 3 BECs and showed that BD manifested a better sealing capacity than EndoSequence and MTA Angelus. The cited authors concluded that BD can be considered as an agent for the repair of furcal perforation [70].

Considering the influence of different endodontic irrigants on the push-out bond strength of BD and MTA, Guneser et al. concluded that BD showed significantly higher push-out bond strength than MTA after exposure to different endodontic irrigants [71]. This was in contrast to a later published study [68] in which the push-out bond strength of MTA increased significantly after exposure to 2.5% NaOCl in the early setting phase, while that of BD decreased significantly.

Several studies have investigated the discoloration of dental tissues after the placement of different calcium silicate-based cements in the pulp chamber [22, 72, 73]. Interestingly, BD showed less tooth discoloration than MTA. In this study, neither material had any effect on the color change of the treated tooth. This may be related to the placement of MTA in the defect of the pulp chamber floor, which is clinically below the gingival margin and was not seen in these cases.

It should be emphasized that dealing with pulp chamber perforation is a great challenge for the dentist. It is also worth noting that the correct practice of clinicians is to refer such difficult cases to a specialist. The use of new technologies and equipment, knowledge of the anatomy of the root canal system, and patience of the endodontist are the keys to success in the treatment of perforated teeth. Proper preparation of the root canal system helps to avoid further iatrogenic complications and to preserve the patient's natural teeth.

CONCLUSION

The bioactive materials used in this report promote favorable conditions for regeneration and have been successfully used for pulp chamber floor and root canal perforation repair. Biodentine and MTA can be considered biocompatible materials for the repair of root canal perforations regardless of the size of the injury and the time of intervention.

REFERENCES

1. Pietrzycka K, Radwanski M, Hardan L, Bourgi R, Mancino D, Haikel Y, et al. The Assessment of Quality of the Root Canal Filling and the Number of Visits Needed for Completing Primary Root Canal Treatment by Operators with Different Experience. Bioengineering (Basel) 2022;9(9):468. doi: 10.3390/bioengineering9090468.
2. Estrela C, Pécora JD, Estrela CRA, Guedes OA, Silva BSF, Soares CJ, et al. Common Operative Procedural Errors and Clinical Factors Associated with Root Canal Treatment. Braz Dent J 2017;28(2):179-90. doi: 10.1590/0103-6440201702451.
3. Tsesis I, Fuss Z. Diagnosis and Treatment of Accidental Root Perforations. Endod Top 2006;13:95-107. doi: 10.1111/j.1601-1546.2006.00213.x.
4. Fuss Z, Trope M. Root Perforations: Classification and Treatment Choices Based on Prognostic Factors. Endod Dent Traumatol 1996;12(6):255-64. doi: 10.1111/j.1600-9657.1996.tb00524.x.
5. Sarao SK, Berlin-Broner Y, Levin L. Occurrence and Risk Factors of Dental Root Perforations: A Systematic Review. Int Dent J 2021;71(2):96-105. doi: 10.1111/idj.12602.
6. Askerbeyli Örs S, Aksel H, Küçükkaya Eren S, Serper A. Effect of Perforation Size and Furcal Lesion on Stress Distribution in Mandibular Molars: A Finite Element Analysis. Int Endod J 2019;52(3):377-84. doi: 10.1111/iej.13013.

7. Glossary of Endodontic Terms. 10th ed. Chicago: American Association of Endodontists; 2020.
8. Olcay K, Ataoglu H, Belli S. Evaluation of Related Factors in the Failure of Endodontically Treated Teeth: A Cross-Sectional Study. J Endod 2018:44(1):38-45. doi: 10.1016/j.joen.2017.08.029.
9. Clauder T. Present Status and Future Directions – Managing Perforations. Int Endod J 2022;55 Suppl 4:872-91. doi: 10.1111/iej.13748.
10. Estrela C, Decurcio D de A, Rossi-Fedele G, Silva JA, Guedes OA, Borges ÁH. Root perforations: a review of diagnosis, prognosis and materials. Braz Oral Res 2018;32(Suppl 1):e73. doi: 10.1590/1807-3107bor-2018.vol32.0073.
11. Saed SM, Ashley MP, Darcey J. Root Perforations: Aetiology, Management Strategies and Outcomes. The Hole Truth. Br Dent J 2016;220(4):171-80. doi: 10.1038/sj.bdj.2016.132.
12. Löst C. Quality Guidelines for Endodontic Treatment: Consensus Report of the European Society of Endodontology. Int Endod J 2006;39(12):921-30.
13. Beavers RA, Bergenholtz G, Cox CF. Periodontal Wound Healing Following Intentional Root Perforations in Permaent Teeth of Macaca Mulatta. Int Endod J 1986;19(1):36-44. doi: 10.1111/j.1365-2591.1986.tb00888.x.
14. Pietrzycka K, Pawlicka H. Treatment of internal inflammatory root resorption – based on own observations. J Stoma 2015;68(3):367-79. doi: 10.5604/00114553.1165619.
15. Pietrzycka K, Pawlicka H. Clinical Aspects of Pulp Stones: A Case Report Series. Dent Med Probl 2020;57(2):213-20. doi: 10.17219/dmp/117944.
16. Palatyńska-Ulatowska A, Pietrzycka K, Koprowicz A. Denticles of the pulp chamber – diagnostics and management. Case studies. Pomeranian J Life Sci 2019;65(2):29-36. doi: 10.21164/pomjlifesci.580.
17. Torabinejad M, Watson TF, Pitt Ford TR. Sealing Ability of a Mineral Trioxide Aggregate When Used as a Root End Filling Material. J Endod 1993;19(12):591-5. doi: 10.1016/S0099-2399(06)80271-2.
18. Nakata TT, Bae KS, Baumgartner JC. Perforation Repair Comparing Mineral Trioxide Aggregate and Amalgam Using an Anaerobic Bacterial Leakage Model. J Endod 1998;24(3):184-6. doi: 10.1016/S0099-2399(98)80180-5.
19. Lee SJ, Monsef M, Torabinejad M. Sealing Ability of a Mineral Trioxide Aggregate for Repair of Lateral Root Perforations. J Endod 1993;19(11):541-4. doi: 10.1016/S0099-2399(06)81282-3.
20. Daoudi M, Saunders W. *In Vitro* Evaluation of Furcal Perforation Repair Using Mineral Trioxide Aggregate or Resin Modified Glass Ionomer Cement with and without the Use of the Operating Microscope. J Endod 2002;28(7):512-5. doi: 10.1097/00004770-200207000-00006.
21. Hardy I, Liewehr F, Joyce A, Agee K, Pashley D. Sealing Ability of One-Up Bond and MTA With and Without a Secondary Seal as Furcation Perforation Repair Materials. J Endod 2004;30(9):658-61. doi: 10.1097/01.DON.0000121619.33952.9A.
22. Torabinejad M, Parirokh M, Dummer PMH. Mineral Trioxide Aggregate and Other Bioactive Endodontic Cements: An Updated Overview – Part II: Other Clinical Applications and Complications. Int Endod J 2018;51(3):284-317. doi: 10.1111/iej.12843.
23. Dong X, Xu X. Bioceramics in Endodontics: Updates and Future Perspectives. Bioengineering 2023;10(3):354. doi: 10.3390/bioengineering10030354.
24. Tsai YL, Liao WC, Wang CY, Chang MC, Chang SH, Chang SF, et al. Horizontal Root Fractures in Posterior Teeth without Dental Trauma: Tooth/Root Distribution and Clinical Characteristics. Int Endod J 2017;50(9):830-5. doi: 10.1111/iej.12704.
25. Wang P, Wang S, Ni L. The Combination of a Mineral Trioxide Aggregate and an Adhesive Restorative Approach to Treat a Crown-Root Fracture Coupled with Lateral Root Perforation in a Mandibular Second Molar: A Case Report. Oper Dent 2009;34(4):497-502. doi: 10.2341/08-080-S.
26. Tsesis I, Rosenberg E, Faivishevsky V, Kfir A, Katz M, Rosen E. Prevalence and Associated Periodontal Status of Teeth with Root Perforation: A Retrospective Study of 2,002 Patients' Medical Records. J Endod 2010;36(5):797-800. doi: 10.1016/j.joen.2010.02.012.
27. Ree M, Schwartz R. Management of Perforations: Four Cases from Two Private Practices with Medium- to Long-Term Recalls. J Endod 2012;38(10):1422-7. doi: 10.1016/j.joen.2012.06.029.
28. Marques NCT, Lourenço Neto N, Oliveira TM. Immediate and Mediate Furcal Perforation Treatment in Primary Molars: 24-Month Follow-Up. Eur Arch Paediatr Dent 2016;17(6):489-94. doi: 10.1007/s40368-016-0249-5.
29. Mente J, Hage N, Pfefferle T, Koch MJ, Geletneky B, Dreyhaupt J, et al. Treatment Outcome of Mineral Trioxide Aggregate: Repair of Root Perforations. J Endod 2010;36(2):208-13. doi: 10.1016/j.joen.2009.10.012.
30. Mente J, Leo M, Panagidis D, Saure D, Pfefferle T. Treatment Outcome of Mineral Trioxide Aggregate: Repair of Root Perforations – Long-Term Results. J Endod 2014;40(6):790-6. doi: 10.1016/j.joen.2014.02.003.
31. Main C, Mirzayan N, Shabahang S, Torabinejad M. Repair of Root Perforations Using Mineral Trioxide Aggregate: A Long-Term Study. J Endod 2004;30(2):80-3. doi: 10.1097/00004770-200402000-00004.
32. Pontius V, Pontius O, Braun A, Frankenberger R, Roggendorf MJ. Retrospective Evaluation of Perforation Repairs in 6 Private Practices. J Endod 2013;39(11):1346-58. doi: 10.1016/j.joen.2013.08.006.
33. Gorni FG, Andreano A, Ambrogi F, Brambilla E, Gagliani M. Patient and Clinical Characteristics Associated with Primary Healing of Iatrogenic Perforations after Root Canal Treatment: Results of a Long-Term Italian Study. J Endod 2016;42(2):211-5. doi: 10.1016/j.joen.2015.11.006.
34. Gorni FG, Ionescu AC, Ambrogi F, Brambilla E, Gagliani MM. Prognostic Factors and Primary Healing on Root Perforation Repaired with MTA: A 14-Year Longitudinal Study. J Endod 2022;48(9):1092-9. doi: 10.1016/j.joen.2022.06.005.
35. Vehkalahti MM, Swanljung O. Accidental Perforations during Root Canal Treatment: An 8-Year Nationwide Perspective on Healthcare Malpractice Claims. Clin Oral Investig 2020;24(10):3683-90. doi: 10.1007/s00784-020-03246-z.
36. Krupp C, Bargholz C, Brüsehaber M, Hülsmann M. Treatment Outcome after Repair of Root Perforations with Mineral Trioxide Aggregate: A Retrospective Evaluation of 90 Teeth. J Endod 2013;39(11):1364-8. doi: 10.1016/j.joen.2013.06.030.
37. Alves de Melo PH, Machado AG, Barbosa Machado AL, Carvalho FN, de Melo JB, Jochims Schneider LF. Evaluation of Root Perforation Treatments with Mineral Trioxide Aggregate: A Retrospective Case Series Study. Iran Endod J 2019;14(2):144-51. doi: 10.22037/iej.v14i2.22769.
38. Pace R, Giuliani V, Pagavino G. Mineral Trioxide Aggregate as Repair Material for Furcal Perforation: Case Series. J Endod 2008;34(9):1130-3. doi: 10.1016/j.joen.2008.05.019.
39. Al-Nazhan S, El Mansy I, Al-Nazhan N, Al-Rowais N, Al-Awad G. Outcomes of Furcal Perforation Management Using Mineral Trioxide Aggregate and Biodentine: A Systematic Review. J Appl Oral Sci 2022;30:e20220330. doi: 10.1590/1678-7757-2022-0330.
40. Siew K, Lee AHC, Cheung GSP. Treatment Outcome of Repaired Root Perforation: A Systematic Review and Meta-Analysis. J Endod 2015;41(11):1795-804. doi: 10.1016/j.joen.2015.07.007.
41. Barczak K, Palczewska-Komsa M, Sikora M, Buczkowska-Radlińska J. Biodentine™ – Use in Dentistry. Literature Review. Pomeranian J Life Sci 2020;66(2):39-45. doi: 10.21164/pomjlifesci.666.
42. Mungekar-Markandey S, Mistry L, Jawdekar A. Clinical Success of Iatrogenic Perforation Repair Using Mineral Trioxide Aggregate and Other Materials in Primary Molars: A Systematic Review and Meta-Analysis. Int J Clin Pediatr Dent 2022;15(5):610-6. doi: 10.5005/jp-journals-10005-2038.
43. Estrela C, Cintra LTA, Duarte MAH, Rossi-Fedele G, Gavini G, Damião Sousa-Neto M. Mechanism of Action of Bioactive Endodontic Materials. Braz Dent J 2023;34(1):1-11. doi: 10.1590/0103-6440202305278.
44. Abdelmotelb MA, Gomaa YF, Khattab NMA, Elheeny AAH. Premixed Bioceramics versus Mineral Trioxide Aggregate in Furcal Perforation Repair of Primary Molars: *In Vitro* and *in Vivo* Study. Clin Oral Investig 2021;25(8):4915-25. doi: 10.1007/s00784-021-03800-3.
45. Pruthi P, Goel S, Yadav P, Nawal R, Talwar S. Novel Application of a Calcium Silicate-based Cement and Platelet-Rich Fibrin in Complex Endodontic Cases: A Case Series. Gen Dent 2022;68(3):46-9.
46. Park HE, Song HY, Han K, Cho KH, Kim YH. Number of Remaining Teeth and Health-Related Quality of Life: The Korean National Health and Nutrition Examination Survey 2010–2012. Health Qual Life Outcomes 2019;17(1):5. doi: 10.1186/s12955-019-1078-0.
47. Park S, Byun S, Kim J, Yang B, Oh S. Treatment of Molar Incisor Malformation and the Short Term Follow-up: Case Reports. Eur J Paediatr Dent 2020;21(3):238-42. doi: 10.23804/ejpd.2020.21.03.15.
48. Aladimi A. Histologic Evaluation of Artificial Floors under MTA and Nano-Filled Resin-Modified Glass Ionomer Used to Repair Furcation Perforation in Dogs. Eur Endod J 2020;5(2):138-44. doi: 10.14744/eej.2020.44127.
49. Aggarwal V, Singla M, Miglani S, Kohli S. Comparative Evaluation of Push-out Bond Strength of ProRoot MTA, Biodentine, and MTA Plus in Furcation

Perforation Repair. J Conserv Dent 2013;16(5):462. doi: 10.4103/0972-0707.117504.
50. Tawfik HE, Abu-Seida AM, Hashem AA, El-Khawlani MM. Treatment of Experimental Furcation Perforations with Mineral Trioxide Aggregate, Platelet Rich Plasma or Platelet Rich Fibrin in Dogs' Teeth. Exp Toxicol Pathol 2016;68(6):321-7. doi: 10.1016/j.etp.2016.03.004.
51. Bakhtiar H, Mirzaei H, Bagheri MR, Fani N, Mashhadiabbas F, Baghaban Eslaminejad M, et al. Histologic Tissue Response to Furcation Perforation Repair Using Mineral Trioxide Aggregate or Dental Pulp Stem Cells Loaded onto Treated Dentin Matrix or Tricalcium Phosphate. Clin Oral Investig 2017;21(5):1579-88. doi: 10.1007/s00784-016-1967-0.
52. Al-Daafas A, Al-Nazhan S. Histological Evaluation of Contaminated Furcal Perforation in Dogs' Teeth Repaired by MTA with or without Internal Matrix. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103(3):e92-9. doi: 10.1016/j.tripleo.2006.09.007.
53. Al-Nahlawi T, Ala Rachi M, Abu Hasna A. Endodontic Perforation Closure by Five Mineral Oxides Silicate-Based Cement with/without Collagen Sponge Matrix. Int J Dent 2021;2021:4683689. doi: 10.1155/2021/4683689.
54. Youssef Youssef Abdelati N, Hassan Elkalla I, Mohamed Awad S, Mahmoud Shalan H. Histopathological Evaluation of Periodontium after Repairing Furcation Perforation with MTA and Biodentine. Pediatr Dent J 2018;28(1):33-9. doi: 10.1016/j.pdj.2017.09.002.
55. Pinheiro LS, Kopper PMP, Quintana RM, Scarparo RK, Grecca FS. Does MTA Provide a More Favourable Histological Response than Other Materials in the Repair of Furcal Perforations? A Systematic Review. Int Endod J 2021;54(12):2195-218. doi: 10.1111/iej.13617.
56. Ibarrola JL, Biggs SG, Beeson TJ. Repair of a Large Furcation Perforation: A Four-Year Follow-Up. J Endod 2008;34(5):617-9. doi: 10.1016/j.joen.2008.01.017.
57. Buła K, Palatyńska-Ulatowska A, Klimek L. Biodentine Management and Setting Time with Vicat and Vickers Evaluation; a Survey-Based Study on Clinicians' Experience. Arch Mater Sci Eng 2020;103(2):75-85. doi: 10.5604/01.3001.0014.3358.
58. Ezawa N, Akashi Y, Nakajima K, Kokubun K, Furusawa M, Matsuzaka K. The Effects of Tricalcium-Silicate-Nanoparticle-Containing Cement: *In Vitro* and *In Vivo* Studies. Materials (Basel) 2023;16(12):4451. doi: 10.3390/ma16124451.
59. Oliveira TM, Sakai VT, Silva TC, Santos CF, Machado MAAM, Abdo RCC. Repair of Furcal Perforation Treated with Mineral Trioxide Aggregate in a Primary Molar Tooth: 20-Month Follow-Up. J Dent Child (Chic) 2008;75(2):188-91.
60. Drukteinis S, Peciuliene V, Shemesh H, Tusas P, Bendinskaite R. Porosity Distribution in Apically Perforated Curved Root Canals Filled with Two Different Calcium Silicate Based Materials and Techniques: A Micro-Computed Tomography Study. Materials (Basel) 2019;12(11):1729. doi: 10.3390/ma12111729.
61. da Fonseca TS, Silva GF, Guerreiro-Tanomaru JM, Delfino MM, Sasso-Cerri E, Tanomaru-Filho M, et al. Biodentine and MTA Modulate Immunoinflammatory Response Favoring Bone Formation in Sealing of Furcation Perforations in Rat Molars. Clin Oral Investig 2019;23(3):1237-52. doi: 10.1007/s00784-018-2550-7.
62. de Sousa Reis M, Scarparo RK, Steier L, de Figueiredo JAP. Periradicular Inflammatory Response, Bone Resorption, and Cementum Repair after Sealing of Furcation Perforation with Mineral Trioxide Aggregate (MTA Angelus™) or Biodentine™. Clin Oral Investig 2019;23(11):4019-27. doi: 10.1007/s00784-019-02833-z.
63. Silva RAB, Borges ATN, Hernandéz-Gatón P, de Queiroz AM, Arzate H, Romualdo PC, et al. Histopathological, Histoenzymological, Immunohistochemical and Immunofluorescence Analysis of Tissue Response to Sealing Materials after Furcation Perforation. Int Endod J 2019;52(10):1489-500. doi: 10.1111/iej.13145.
64. Silva LAB, Pieroni KAMG, Nelson-Filho P, Silva RAB, Hernandéz-Gatón P, Lucisano MP, et al. Furcation Perforation: Periradicular Tissue Response to Biodentine as a Repair Material by Histopathologic and Indirect Immunofluorescence Analyses. J Endod 2017;43(7):1137-42. doi: 10.1016/j.joen.2017.02.001.
65. Cardoso M, Dos Anjos Pires M, Correlo V, Reis R, Paulo M, Viegas C. Biodentine for Furcation Perforation Repair: An Animal Study with Histological, Radiographic and Micro-Computed Tomographic Assessment. Iran Endod J 2018;13(3):323-30. doi: 10.22037/iej.v13i3.19890.
66. Alipour M, Faraji Gavgani L, Ghasemi N. Push-out Bond Strength of the Calcium Silicate-based Endodontic Cements in the Presence of Blood: A Systematic Review and Meta-analysis of *in Vitro* Studies. Clin Exp Dent Res 2022;8(2):571-82. doi: 10.1002/cre2.546.
67. Nagas E, Cehreli ZC, Uyanik MO, Vallittu PK, Lassila LVJ. Effect of Several Intracanal Medicaments on the Push-out Bond Strength of ProRoot MTA and Biodentine. Int Endod J 2016;49(2):184-8. doi: 10.1111/iej.12433.
68. Alsubait S, Alsaad N, Alahmari S, Alfaraj F, Alfawaz H, Alqedairi A. The Effect of Intracanal Medicaments Used in Endodontics on the Dislocation Resistance of Two Calcium Silicate-Based Filling Materials. BMC Oral Health 2020;20(1):57. doi: 10.1186/s12903-020-1044-6.
69. Afkhami F, Razavi S, Ghabraei S. The Effect of Different Intracanal Medicaments on the Dislodgement Resistance of Mineral Trioxide Aggregate. BMC Oral Health 2022(1);22:207. doi: 10.1186/s12903-022-02213-2.
70. Das M, Al Malwi AA, Mohapatra A, Kader MMA, Ali ABM, Shetty SC, et al. *In Vitro* Assessment of Sealing Ability of Various Materials Used for Repair of Furcal Perforation: A SEM Study. J Contemp Dent Pract 2022;23(11):1136-9. doi: 10.5005/jp-journals-10024-3425.
71. Guneser MB, Akbulut MB, Eldeniz AU. Effect of Various Endodontic Irrigants on the Push-out Bond Strength of Biodentine and Conventional Root Perforation Repair Materials. J Endod 2013;39(3):380-4. doi: 10.1016/j.joen.2012.11.033.
72. Możyńska J, Metlerski M, Lipski M, Nowicka A. Tooth Discoloration Induced by Different Calcium Silicate-Based Cements: A Systematic Review of *In Vitro* Studies. J Endod 2017;43(10):1593-601. doi: 10.1016/j.joen.2017.04.002.
73. Shokouhinejad N, Nekoofar MH, Pirmoazen S, Shamshiri AR, Dummer PMH. Evaluation and Comparison of Occurrence of Tooth Discoloration after the Application of Various Calcium Silicate-Based Cements: An *Ex Vivo* Study. J Endod 2016;42(1):140-4. doi: 10.1016/j.joen.2015.08.034.