International Journal of Medical Science and Clinical Research Studies

ISSN(print): 2767-8326, ISSN(online): 2767-8342

Volume 02 Issue 06 June 2022

Page No: 528-533

DOI: https://doi.org/10.47191/ijmscrs/v2-i6-16, Impact Factor: 5.365

Bioceramic Perforation Repair Materials

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ABSTRACT

In endodontic practice, procedural mishaps are encountered that might impact the prognosis of root canal treatment. One of these procedural mishaps is endodontic perforation. The success of perforation treatment is determined by whether the perforation can be repaired to avoid or eliminate bacterial infection at the perforated site. Materials used in perforation repair include Hemostatics, barrier materials and restoratives. The bioceramic restorative materials are broadly classified into three generations. This review paper summarizes the various bioceramic perforation repair materials and their effect on blood contamination.

KEYWORDS: Bioceramics, Biodentine, blood contamination, Bone cement, MTA, perforation repair.

ARTICLE DETAILS

Published On:
22 June 2022

Available on:
https://ijmscr.org/

1. INTRODUCTION

In endodontic practice, procedural mishaps are encountered that might impact the prognosis of root canal treatment. One of these procedural mishaps is endodontic perforation. According to the American Association of Endodontics (AAE) Glossary of Endodontic Terms (2020), perforation is a mechanical or pathological communication between the root canal system and the external tooth surface caused by caries, resorptions, or iatrogenic factors.[1] It has been identified as the second most significant cause of endodontic failure, accounting for 9.6% of all unsuccessful cases.[2]

Furcation perforation is one of the procedural mishaps which can cause an inflammatory response in the periodontium. Furcation perforation is defined as a perforation in the furcal area of the tooth.[1] Such perforations in the furcation area may occur due to several causes like progressive carious lesion, internal or external resorption, preparation errors of access cavities during post space preparation, and placement of posts and pins or when locating calcified canals. The most common cause of furcation perforation is iatrogenic because of the misaligned use of rotary burs amid endodontic access preparation and search for root canal orifices.[3]

The success of perforation treatment is determined by whether the perforation can be repaired to avoid or eliminate bacterial infection at the perforated site. The destruction of the periodontal tissues may occur due to furcation perforation, ultimately leading to tooth loss.[4] The prognosis of the afflicted tooth depends upon various factors:

- The severity of damage to the periodontal tissues
- The size and location of the perforation
- The bacterial contamination
- The cytotoxicity and sealing ability of the repair materials.[5,6]

Furcation perforations can be treated either surgically or non-surgically. The main risk for surgical procedures to repair

such defects is pocket formation.[7] The rationale for the non-surgical treatment of the perforation is to prevent periradicular inflammation. This can be accomplished by immediate sealing of the perforation with a non-irritating material that will establish an adequate seal to prevent microbial penetration. Even if a non-toxic and biocompatible material is used to repair a furcal perforation, the extensive injury may cause irreversible damage to the periodontal attachment apparatus at the furcation area. In the case of late and improper repair, the prognosis will be poor.[8] Therefore, appropriate and early treatment of the involved teeth is necessary to retain such teeth.

In large perforations, the complete repair of the perforation with a sealing material is complex as it allows irritants to penetrate the furcation area continuously.[9] Perforations close to the gingival sulcus produce persistent inflammation and a down-growth of sulcular epithelium into the defect.[3] Coronally located perforations, including furcal perforations, are more severe than those in the middle and apical third of a canal.

2. MATERIALS USED IN PERFORATION REPAIR

1. Hemostatics
2. Barrier material
3. Restoratives

2.1. Hemostatics

Perforation defects exhibit massive bleeding. A dry field enhances vision while creating an environment for the predictable placement of a restorative agent.

Examples of common hemostatic agents used are:

1. Collagen
2. Gelatin foam
3. Bone wax
4. Ferric sulphate [10]
5. Aluminium chloride
6. Sodium Hypochlorite (1%-3%)
7. Lasers: Diode lasers have been used recently to achieve a hemostatic effect.[11]

2.2. Barrier materials

The two main challenges on attempting the perforation repair are hemostasis and the controlled placement of the material in the perforation area. Barrier material which is placed in the perforation area will provide dry field or a back stop to condense the restorative materials against it.

When a barrier membrane is placed over the body defects and closely adapted to the surrounding bone surface, an environment that prevents invasion of competing non-osteogenic cells from the overlying soft tissues can be created. This environment provides the bony defect time to heal.

Lemon RR in 1992 introduced the "internal matrix concept" for the treatment of perforations. He recommended the use of a matrix of hydroxyapatite for sealing the perforation.[12] The matrix was suggested for use under repair materials to prevent their extrusion into the periodontal ligament. Because the material cannot be removed after placement, it must be sterile or capable of being sterilized, biocompatible, non-toxic, and should not produce any inflammatory response. Collaplug, calcium sulfate, gelatin sponges, and plaster of Paris are highlighted as carrier materials in dentistry.

2.3. Restorative materials

2.3.1. The ideal requirements of perforation repair materials are:[13]

1. It should provide adequate seal.
2. It should be biocompatible.
3. It should have ability to produce osteogenesis and cemento-genesis.
4. It should be bacteriostatic, and radiopaque.
5. It should also be beneficial to use a resorbable matrix in which a sealing material can be condensed.
6. It should be relatively inexpensive.
7. It should be non-toxic, non-cariogenic and easy to place.

Various traditional materials used for perforation repair include Indium foil, amalgam, Plaster of Paris (POP), Zinc oxide eugenol (ZOE), Super Ethoxy Benzoic acid (EBA), Intermediate restorative material (IRM), Gutta-percha, Cavit, Glass ionomer cement (GIC), Metal-modified GIC, resin modified GIC, Composites, Calcium hydroxide [Ca (OH)2] and Portland cement. However, the divergent outcomes have demonstrated that no material has fulfilled all the ideal requirements of a perforation repair material so far.

In search for the ideal material, numerous sealing materials and techniques have been tested over the years with varying success. Biological solutions to biological problems, it's the era of Bioceramic materials.

2.3.2. Generations of Bioceramic perforation repair materials

2.3.2.1. 1st Generation Biomaterials: Bio-inert

Bio-inert, they did not generate any/little response to the tissues where they are used. They were limited to simulating the mechanical characteristics of the surrounding tissues.

2.3.2.2. 2nd Generation Biomaterials: Bioactive

They are either osteoinductive or osteoconductive or both. They sought to provoke a specific controlled action in biological environment.

2.3.2.3. 3rd Generation: Biodegradable

It focused on the process of tissue regeneration including cell adhesion, proliferation, differentiation through the activation of specific genes.

2.3.3. Bioceramic materials used for perforation repair

2.3.3.1. Mineral trioxide aggregate (MTA):

Mahmoud Taorabinejad introduced Mineral Trioxide Aggregate at Loma Linda University, California, the USA, in 1993. It is formulated from commercial Portland cement. MTA is a calcium-silicate based material composed of tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, calcium sulfate, and bismuth oxide.

MTA has been extensively used in perforation repairs, apexification, regenerative procedures, apexogenesis, pulpotomies, and pulp capping.[14] MTA is considered as a gold standard repair material for perforations. Various studies, with long-term follow-up, have successfully demonstrated the ability of MTA to repair strip, lateral, and furcation perforations.[15] MTA has many favourable properties, including a good sealing characteristic, biocompatibility,[16,17] bacteriostatic or bactericidal,[18] radiopacity and ability to set in the presence of blood or moisture.[19] MTA stimulates cementoblasts to produce a matrix for cementum formation. The drawbacks of MTA are its long setting time, difficulty in handling, and discolouration potential.[14] To overcome these shortcomings, new calcium-silicate-based bioactive restorative cements has been developed.

2.3.3.2. Biodentine:

Biodentine (Septodont, Saint Maur des Fosse's, France) is relatively a new calcium silicate-based material introduced as a bioactive dentine substitute specifically designed as a "dentine replacement" material by Gilles and Oliver in 2010.[20] It is mainly composed of highly pure tricalcium silicate, which regulates the setting reaction, calcium carbonate (filler), zirconium dioxide (radiopacifier), calcium chloride (setting accelerator), water reducing agent (superplasticizer), and water.[21] Biodentine can be used for pulp capping, pulpotomy, apexification, root perforation, internal and external resorption, and as a root-end filling material.

Its interactions with soft and hard tissues lead to better marginal sealing, preventing microleakage. Biodentine application does not require any pre-conditioning of the dentin surface, unlike other dentin substitutes. As Biodentine penetrates the dentinal tubules forming tag-like structures, micromechanical retention provides restoration sealing. It can be bonded with various adhesives before composite resin for the final restoration. [22]

Its properties are good sealing ability, colour stability, high compressive and flexural strengths, biocompatibility[23], bioactivity, biomineralization properties[24], and ease of manipulation. The setting time of the material is as short as 9–12 minutes. The shorter setting time was attributed to the addition of calcium chloride to the mixing liquid.[22] The presence of a setting accelerator in Biodentine results in a faster setting, thereby improving its handling properties and strength.[24] A specific advantage of Biodentine over MTA is its capacity to continue improving the compressive strength with time over a month.[23]

2.3.3.3. Endosequence:

EndoSequence is a bioceramic material. It is composed of calcium silicates, zirconium oxide, tantalum oxide, calcium phosphate monobasic and filler agents. It has a working time of more than 30 minutes and a setting reaction initiated by moisture with a final set achieved in approximately 4 hours. It is produced with nanosphere particles that allow the material to enter into the dentinal tubules and interact with the moisture present in the dentin. This creates a mechanical bond on setting and renders the material with exceptional dimensional stability, along with this the material has superior biocompatibility characteristics due to its high pH. [25,26]

Endosequence root repair material simulates tissue fluid, phosphate buffered saline and results in precipitation of apatite crystals that become larger with increasing immersion times concluding it to be bioactive.[27] In a study by Jeevani et al., Endosequence showed better sealing ability when compared to MTA and Biodentine as furcation repair materials.[28]

2.3.3.4. Bioaggregate:

Bioaggregate is a bioceramic material composed of tricalcium silicate, dicalcium silicate, calcium phosphate monobasic, amorphous silicon di oxide and tantalum pentoxide.[29] It induces mineralized tissue formation and precipitation of apatite crystals that become larger with increasing immersion time suggesting it to be bioactive.[27] It has comparable biocompatibility and sealing ability to MTA.[29] In a study by Hashem et al., concluded that MTA is more influenced by acidic pH than Bioaggregate when used as perforation repair material. [30]

2.3.3.5. New endodontic cement:

"New endodontic cement (NEC)" a bioactive material consisting of different calcium compounds was later termed as Calcium Enriched Mixture (CEM). It is composed of calcium oxide, calcium phosphate, calcium carbonate, calcium silicate, calcium sulfate, calcium hydroxide, and calcium chloride. [31] It has a setting time of less than 1 hour and sets in aqueous medium. [32]

It is composed of different calcium compounds; it produces greater amount of calcium and phosphate ions which most likely forms hydroxyapatite in higher concentrations and this would make CEM cement preferable as a furcal perforation repair material in close proximity to the exposed periodontium. [31] Asgary et al., observed cementogenesis and periodontal regeneration when CEM was used as perforation repair material. [33]

2.3.3.6. Tricalcium phosphate:

Tricalcium phosphate consist of biodegradable ceramic (Synthograft) and had shown a very promising application in periodontal therapy because they are compatible with periodontal tissues. When used as perforation repair material tricalcium phosphate showed evidence of healing by the presence of layers of epithelium, collagen, and bone, with few inflammatory cells at the perforation site [34] but the degree of inflammation it caused was greater than Amalgam, hydroxyapatite and less than calcium hydroxide. [34,35]

2.3.3.7. Hydroxyapatite:

It can be used both as an internal matrix and as a direct perforation repair material. When used as furcation perforation repair material has shown to reconstruct furcation bone loss due to iatrogenic root perforation. When used as an

internal matrix to prevent the extrusion of materials such as amalgam or glass ionomer acts as a stable matrix supporting the repair material that is going to be placed subsequently. [36]

2.3.3.8. Bio-C- repair:

Introduced by Angelus. It is composed of calcium silicates, calcium aluminate, calcium oxide, zirconium oxide, iron oxide, silicon dioxide and dispersing agent. Its setting time is less than 120 minutes.[37] Its use a perforation repair material has been investigated recently and effective results were observed after one year follow-up. It showed greater viability, adhesion and cell migration rates.[38]

2.3.3.9. Other repair materials:

Bone cement (Surgical Simplex P, Stryker, Australia) is a new repair material that has been recently investigated in dentistry as a root-end filling material and for stabilizing dental implants. It has been used in oral and orthopaedic surgery for 40 years. The first bone cement use in Orthopaedics is widely credited to the famous English surgeon, Dr. John Charnley, who, in 1958, used it for total hip arthroplasty. It is commonly used in orthopaedic surgery, mainly for fixation of the prosthesis, stabilizing the compressive vertebral fracture, or filling bone defects.[39] It is a PMMA based material packaged as a powder (polymethylmetacrylate polymer, methyl methacrylate-styrene-copolymer, and barium sulfate) and a liquid (methyl methyl methacrylate monomer) that are mixed at the time of application.[40]

Bone cement has many properties that make it well suited as a repair material for various endodontic treatments. Its properties are good strength and load-bearing capacity, good handling and working properties, faster setting time of around 15 minutes, and good marginal adaptation.[41]The bone cement is said to exhibit low cytotoxicity compared to MTA, and the powder was non-toxic in nature.[42] Its excellent biocompatibility allows for tissue reattachment. In addition, bone cement tolerates a moist environment very well.

2.3.4. Effect of Blood contamination:

These perforation repair materials are inadvertently in contact with the blood, saliva, fluids, and microorganisms at the perforation site.[3,5] Although calcium silicate cements like MTA and Biodentine are hydrophilic[14], blood contamination can happen when these cements are used in perforation repair. It can reduce the bond strength of the cement to dentin over time, leading to cement degradation and failure. In contrast, some authors showed that blood contamination did not affect the bond strength of Biodentine; and that blood contamination increased the bond strength of MTA.[43]

The contamination of Bone cement with blood can negatively affect the properties of the set cement. Bone cement is a brittle material with a high susceptibility to internal stresses caused by cavity formation in the material structure. This is in accordance with the study done by Karpinski R et al., who showed that the addition of more than 6% of blood (by weight) and more than 4% of saline to the bone cement caused the specimens to exhibit lower strength than the minimum critical value of 70 MPa. To prevent the cement material strength from deteriorating below the minimum threshold, great care must be taken to restrict the interaction of the bone cement with physiological fluids that naturally occur in the operational area, particularly while the material cures.[44]

Acknowledgements: Nil
Conflicts of Interest: Nil

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