IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 17, Issue 2 Ver. 9 February. (2018), PP 77-83
www.iosrjournals.org

Bioceramics in Endodontics: Literature review of Biodentine and Mineral Trioxide Aggregate with case reports

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Abstract:*Major advances have been made in the field of bioceramics used for endodontic treatment. Bioceramics are biocompatible in nature and have excellent physico- chemical properties. They can function as cements, root repair materials, root canal sealers and filling materials, which have the advantages of antibacterial properties and better sealing ability. These materials have overcome certain limitations of earlier endodontic materials. This article reviews the properties of two most commonly used bioceramic materials: Biodentine and MTA and the application of the same.*

Keywords:*Bioceramics, Biodentine, MTA*

Date of Submission: 05-02-2018 Date of acceptance: 23-02-2018

I. Introduction

Bioceramic materials are biocompatible ceramic compounds obtained by various chemical processes, both in situ and in vivo. They exhibit excellent biocompatibility properties due to their similarity with biological hydroxyapatite. During the hydrationprocess,bioceramics produce different compounds, e.g. hydroxyapatites, which have the ability to induce a regenerative response in the human body. Mineral hydroxyapatite has an osteoconductive effect when placed in contact with the bone, leading to the bone formation at the interface. Bioceramics have an intrinsic osteoinductive capacity because of their ability to absorb osteoinductive substances if there is a bone healing process nearby.

They have the quality to be biocompatible and also to provide antibacterial properties. The antibacterial property occurs as result of precipitation in situ after the material's setting time, leading to bacterial sequestration. Bioceramics form porous powders containing nanocrystals which prevent bacterial adhesion.[1]

Bioceramic materials in endodontics can be considered as a boon which has changed the prognosis of many cases which were once considered as next to impossible.[2]Although the use of bioceramics has been improved through new technologies, however, their usage is limited. The level of sensitization is limited because of the lack of product availability and affordability all across the globe.[3]

Mineral Trioxide Aggregate (MTA) was introduced by MohmoudTorabinejad at Loma Linda University, California, USA in 1993.It was given approval for endodontic use by the U.S. Food andDrug Administration in 1998.[4]ProRootMTA (Dentsply Tulsa Dental Specialties, Johnson City, TN) was the first commercially available MTA product to be launched in the United States. MTA Angelus (Angelus, Londrina, Brazil / Clinician's Choice, New Milford, CT) was launched in Brazil in 2001 and received FDA approval in 2011.[5]Recently, newbioceramic materials have been introduced as alternatives to MTA.Biodentine designed as a "dentine replacement material was introduced by Septodent in 2009.[6]Bioaggregate (Innovative BioCeramix, Vancouver, BC, Canada) is a bioceramic material delivered as powder of nanoparticles composed of tricalcium silicate, dicalcium silicate, calcium phosphate monobasic, amorphous silicon dioxide and tantalum pentoxide (Zhang et al. 2009). Its constitution is similar to white MTA, differing mostly by being aluminium free and contains calcium phosphate monobasic and tantalum pentoxide. EndoSequence Root Repair Material (ERRM) (Brasseler USA, Savannah, GA, USA) is another bioceramic material that has been developed recently (Damas et al. 2011) composed of calcium silicates, zirconium oxide, tantalum oxide, calcium phosphate monobasic and filler agents. ERRM has been demonstrated to be biocompatible (Alanezi et al. 2010, Ma et al. 2011), able to seal root-end cavities (Nair et al. 2011 S), antibacterial (Lovato&Sedgley 2011).[7]Generex A (Dentsply Tulsa

Dental Specialties, Tulsa, OK, USA) is a calcium silicate based material similar to MTA but is mixed with a unique gel instead of water which improves the handling properties and shortens working time.[1]

The aim of this paper is to review the most widely usedbioceramic materials: Biodentine and MTA currently used in endodontics, their specific characteristics and clinical use.

II. Biodentine

Biodentine was commercially available in 2009 as a 'dentin replacement' material by Septodent (France). It is available in the form of a capsule containing the ideal ration of its powder and liquid.[2]

III. Properties of Biodentine

3.1Composition:

Biodentine is available in the form of a capsule containing the ideal ratio of its powder and liquid.[2]The powder contains tricalciumsilicate, dicalcium silicate, calcium carbonate and oxide filler,iron oxide shade, and zirconium oxide. Tricalcium silicate is indicated as the main core materialand dicalcium silicate are indicated as the second corematerial, respectively. Zirconium oxide serves as aradiopacifier.The liquid, on the other hand, contains calciumchloride which acts as an accelerator and a hydrosoluble polymer thatserves as a water reducing agent.[6]

3.2 Setting reaction of Biodentine:

After mixing, the calcium silicate particles of Biodentine react with water to form a high pH solution containing $Ca^{2+,}$ OH^- and silicate ions. The hydration of the tricalcium silicate leads to the formation of a hydrated calcium silicate gel on the cement particles and calcium hydroxide nucleates. With passage of time, calcium silicate hydrated gel polymerizes to form a solid network and the alkalinity of the surrounding medium increases due to the release of calcium hydroxide ions. Further the hydrated calcium silicate gel surrounds the unreacted tricalcium silicate particles and due to its relatively impermeable nature to water, it helps in slowing down the effects of further reactions.[2]

3.3 Setting Time:

The setting time of Biodentineaccording to manufacturers' instructions is 9-12 minutes.[6]The presence of setting accelerator in Biodentine results in fastersetting thereby improving its strength and handling characteristcs.[2]Grech et al. compared the setting times of Biodentine, zirconium replaced tricalcium silicate cement and BioAggregate and found out that Biodentine had the shortest setting time among tricalcium silicate cements(ProRoot MTA, MTA Angelus etc.).[8]

3.4 Density and porosity:

A study done by De Souza et al. compared Biodentine to other silicate based cements, IRoot BP Plus, Ceramicrete and ProRoot MTA using micro- CT characterization. No significant difference in porosity was found between IRoot BP Plus, Ceramicrete and Biodentine.[6]

3.5 Compressive Strength:

During the setting of Biodentine, compressive strength of Biodentineincreases upto 100 MPa in the first hour and 200 MPa at 24th hour. It continues to improve with time over several days reaching 300 MPa after one month which is comparable to the compressive strength of natural dentine i.e 297 MPa. Biodentine had highest compressive strengthin the study done by Grech et al. when compared to other tested materials due to the low water/cement ratio used.[2]

3.6 Flexural Strength:

Flexural strength of Biodentine recorded after two hours, has been found to be 34 MPa.[2]

3.7 Microhardness:

In the study done by Grech et al, Biodentine showed superior value of microhardness when compared to Bioaggregate and IRM. Goldberg et al., found the microhardness of Biodentine to be 51 Vickers Hardness Number (VHN) at 2 hour and 69 VHN after one month.[2]

3.8 Radiopacity:

ISO 6876:2001 has established that 3mm Al is the minimum radiopacity value for endodontic cements. Grech et al studied the radiopacity of tricalcium silicate cement, Bioaggregae and Biodentine and concluded that all the materials had radiopacity values greater than 3mm Al.[6]

3.9 Microleakage:

Biodentine is found to be associated with high pH (12) and releases calcium and silicon ions which stimulates mineralization. This creates a "mineral infiltration zone" along dentin-cement interface which imparts a better seal. [2]

3.10 Marginal Adaptation and Sealing Ability:

Micromechanical adhesion of Biodentineallowed excellent adaptability of Biodentine crystals to the underlying dentin.According to a study done bySoundappan S et al., MTA and IRM were significantly superior to Biodentine in terms of marginal adaptation when used as a root end filling material.[2]

3.11 Bond Strength:

Hashem DF et al., concluded that Biodentine has low strength during initial stages of setting, hence the application of final overlying resin composite restoration (laminated or layered) should be delayed for more than two weeks in order to achieve adequate bond strength of matured Biodentine to withstand contraction forces of composite.[2]

3.12 Biocompatibility and Cytotoxicity:

In a study done by Zhou et al., where Biodentinewas compared with white MTA (ProRoot) and glassionomer cement (FujiIX) using human fibroblasts, bothwhiteMTA and Biodentine were found to be less toxic compared toglass ionomer during the 1- and 7-day observation period. Another study done byP´erard et al.compared the gene expression ability and biocompatibility of Biodentine and MTAbased on the standpoint that three-dimensional(3D)multicellular spheroid cultures are currently consideredto be the in vitro model providing the most realistic simulationof the human tissue environment. They performeda biocompatibility investigation using these models.Biodentine and MTA were determined to modifythe proliferation of pulp cell lines.[6]

3.13 Bioactivity and Regenerative Potential:

Laurent P et al., assessed the ability of Biodentine, MTA, calcium hydroxide and Xeno III adhesive resin to induce reparative dentin synthesis and transforming growth factor beta 1 (TGF-b1) secretions. The study showed that both Biodentine and MTA involved in early odontoblastic differentiation and initiation of mineralisation and thus form reparative dentin synthesis compared to the other two materials.[2]

IV. Mineral Trioxide Aggregate

Mineral Trioxide Aaggregate, a remarkable biocompatible material used for various clinical applications was pioneered by Dr. Mahmoud Torabinejad and coworkers in Loma Linda University.[2]It is a fine hydrophilicpowder available in single use sachets of 1 gram.Commercially available MTA are ProRootMTA (Dentsply), White ProRoot MTA (Dentsply),MTA- Angelus (SolucoesOdontologicas), MTA- AngelusBlanco (SolucoesOdontologicas), MTA Bio (SolucoesOdontologicas).[9]

V. Properties of Mineral Trioxide Aggregate

5.1 Chemical composition of MTA:

MTA is basically a mixture of three powder ingredients: portland cement (75%), bismuth oxide (20%) and gypsum (5%). It consists of calcium oxide (50-75 wt %) and silicon oxide (15-20 wt %), which together constitute 70-95% of the cement. Blending of these raw materials producestricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite.[10]There are two commercial types of MTA: grey and white and the difference lies due to the presence of iron in the white MTA which further forms the tetracalciumalumino-ferrite phase.[2]

5.2 Setting reaction:

The hydration reaction during setting occurs between tricalcium silicate and dicalcium silicate to form a calcium hydroxide and calcium silicate hydrate gel, producing an alkaline pH. A further reaction between tricalcium aluminate and calcium phosphate forms a high-sulphate calcium sulphoaluminate. The calcium ions leach through the dentinal tubules, and the concentration increases with time as the material cures.[2]

5.3 Setting time:

According to Torabinejadet al. setting time is 2 hours and 45mins for grey MTA. Islam et al.claimed it to be 2 hours and 55mins for grey MTA and 2 hours and 20 minutes for white MTA.[4]

5.4 Mechanism of action:

When placed in direct contact with human tissue it forms CH that releases calcium ions for cell attachment and proliferation, creates an antibacterial environment by its alkaline pH, modulates cytokine production, encourages the differentiation and migration of hard tissue– producing cells and forms HA (or carbonated apatite) on the MTA surface and provides a biologic seal.[11]

5.5 Density and porosity:

The study performed by Torabinejad M et al., did not reveal any significant solubility of MTA. On the other hand, Fridland M and Rosado R have reported the significant increase in solubility and porosity of ProRootMTA with the increase in water to powder ratio.[2]

5.6 Compressive Strength:

According to Torabinejad M et al., the compressive strength of MTA at 24 hours is 40.0 MPa and at 21 days is 67.3 MPa. Compressive strength of Gray MTA was found to be greater than that of white MTA.[4]

5.7 Flexural Strength:

A study done by Walker MP et al., showed that the flexural strength of MTA was 14.27 MPa when specimens were exposed to two-sided moisture after 24th hour of setting time.[2]

5.8 Microhardness:

The microhardness of 2-mm and 5-mm thicknesses of GMTA andWMTA was investigated by Matt G D et al. when the materials were used as an apical barrier. It was found that 5-mm thickness is significantly harder than a 2-mm thickness regardless of the formulation of MTA or placement technique used.Less humidity, low pH values, the presence of a chelating agent, and more condensation pressure might adverselyaffect MTA microhardness.[12]

5.9 Radiopacity:

Torabinejad et al. reported the mean radiopacity for MTA at 7.17mmof anequivalent thickness of aluminum.[12]

5.10 Microleakage:

Torabinejad M revised a comprehensive literature to investigate studies regarding the leakage of MTA and concluded that MTA has good sealing ability and it seals well.[2]

5.11 Marginal adaptation and sealing ability:

Shipper et al.(2004) and Torabinejadet al. (1995)explained that MTA hasexcellent sealing ability which may occur because MTA expandsduring setting reaction. Sealing ability of MTA is enhanced n presence of moist environment due to the setting expansion so it is suggested that a moistened cotton pellet beplaced in contact with MTA before placement of the permanentrestoration. According to Valois et al.(2004) about 4-mmthickness of MTA is sufficient to ensure a good sealing.[4]

5.12 Bond strength:

Tunc ES et al., stated that the application of total-etch 1-bond adhesive system with a composite and compomer over MTA results significantly higher bond strength than with a 1-step self-etch adhesive system.[2]

5.13 Biocompatibility and Cytotoxicity:

A study done by Kettering and Torabinejadshowed that MTA it is not mutagenicand is much less cytotoxic compared to SuperEBA and IRM.No DNA damage was seen with genotoxicity tests of cells after treatment of peripherallymphocytes with MTA.On direct contact they produce minimal or noinflammatory reaction in soft tissues and arecapable of inducing tissue regeneration. MTA produced cementum growth which wasvery unique compared to other root-end filling materials in animal studies.Arens and Torabinejaddescribed osseous repairof furcation perforations treated with MTA. It showed good interaction with bone-forming cells;cells remained viable and released collagen even after72 hours with good adherence. Studies by Koh et al revealed that MTAoffers a biologically active substrate for bone cells andstimulates interleukin production. MTA is also said tostimulate cytokine production in human osteoblasts.[9]

5.13 Bioactivity and Regenerative Potential:

The ability of calcium hydroxide, MTA,Biodentine, and Xeno III adhesive resin to induce reparative dentin synthesis and transforming growth factor beta 1 (TGF-β1) secretionswas evaluated by Laurent P et al. They showed that early odontoblastic differentiation and initiation of mineralisationwas seen with both MTA and Biodentineand thus form reparative dentin synthesis compared to than other two materials. TGF-β1 secretion was significantly increased with Biodentine, MTAand calcium hydroxide than with Xeno III. Bonson S et al., detected differentiation of fibroblasts and bone formation when MTA was placed on cell cultures of gingival and periodontal ligament fibroblasts. HenceMTA is considered as a bioactive material with osteoinductive properties.[2]

VI. Case Reports

6.1 Case 1:

A 42-year-old female patient reported with a chief complaint of discolored upper front tooth and intermittent pus discharge from the gums in relation to the tooth since 4 years. History revealed trauma to the same region 5 years back. Clinically slightly discolored 11 with sinus tract opening wasseen. Intra oralradiographic examination revealed well-defined radiolucency involving 11 and 12 region and endodontic treatment was initiated. 3 months post obturation there was evidence of sinus opening and hence surgery was planned. 3 mm thickness of Biodentine was place as retrograde restorative material. Follow up was done at time intervals of 1, 3, 6, and 12 months to evaluate healing.

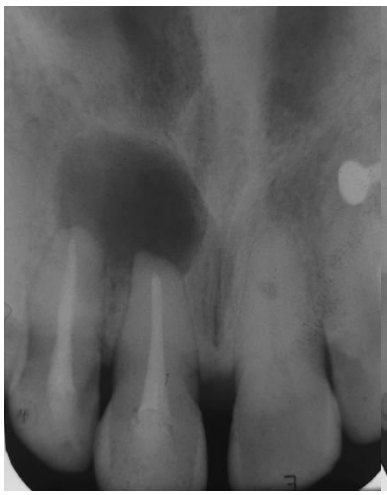

Fig 1: Post-obturation IOPAR

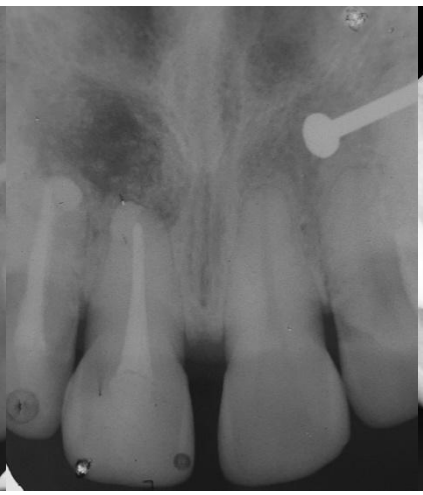

Fig 2: 1 week follow-upIOPAR

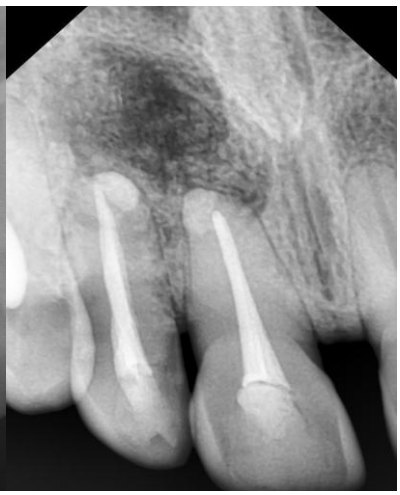

Fig 3: 1 month follow-upIOPAR

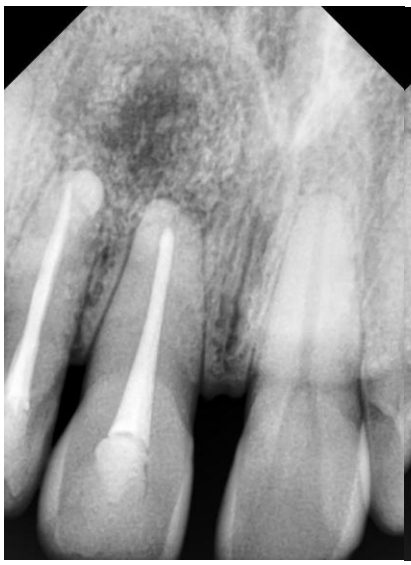

Fig 4**:** 3 months follow-up IOPAR

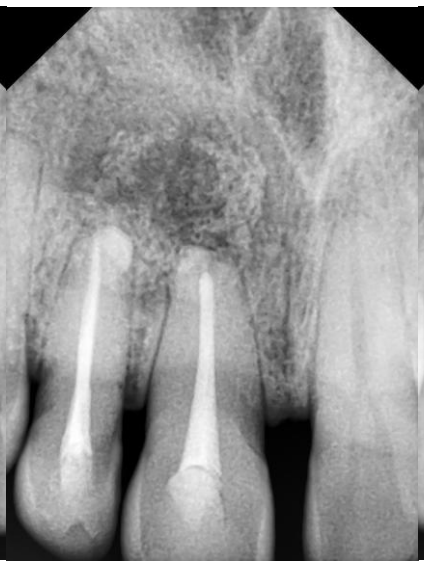

Fig 5: 6 months follow-up IOPAR

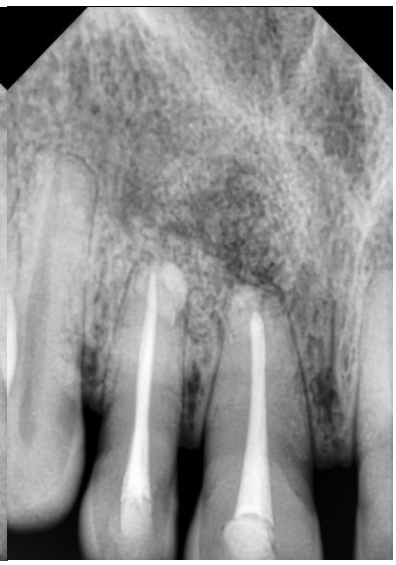

Fig 6:12 months follow-up IOPAR

6.2 Case 2:

A 20 year-old male patient reported with a chief complaint of intermittent pus discharge from the gums in relation to the upper front tooth region since 1 year. Clinically a soft, fluctuant, and non-tender swelling with purulent discharge was noticed in the same region. History revealed root canal treatment done for 11; 2 years back. Intra- oral radiographic examination revealed diffused radiolucency involving 11 and 12. Hence retreatment of 11 and endodontic treatment for 12 was planned. Following endodontic treatment, surgery was planned in which MTA was used as the retrograde filling material.Follow up was done at time intervals of 1, 3, 6, and 12 months to evaluate healing.

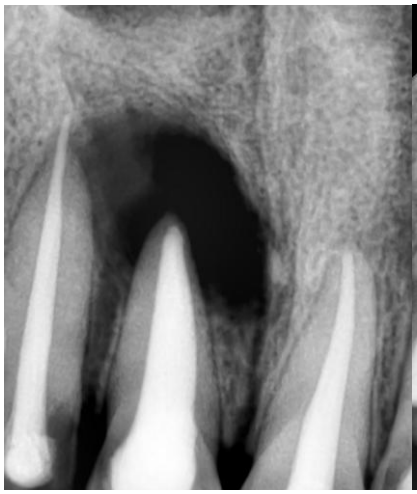

Fig 1: Post-obturation IOPAR

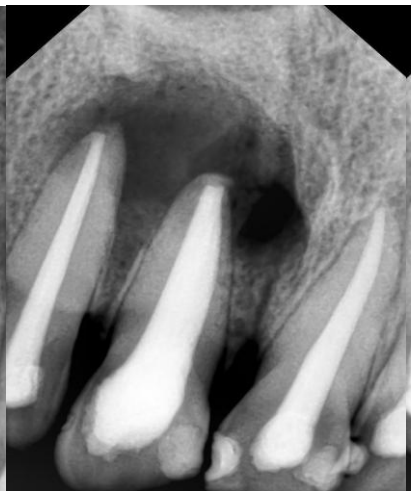

Fig 2: One month follow-up IOPAR

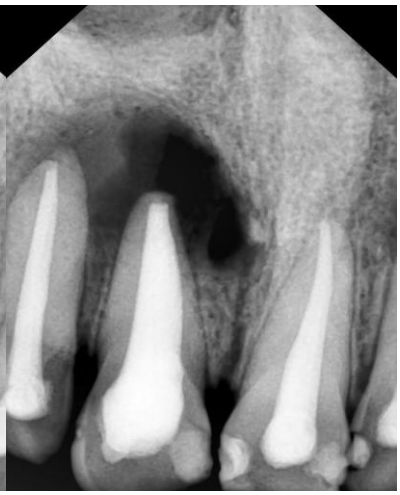

Fig 3: 3 months follow-up IOPAR

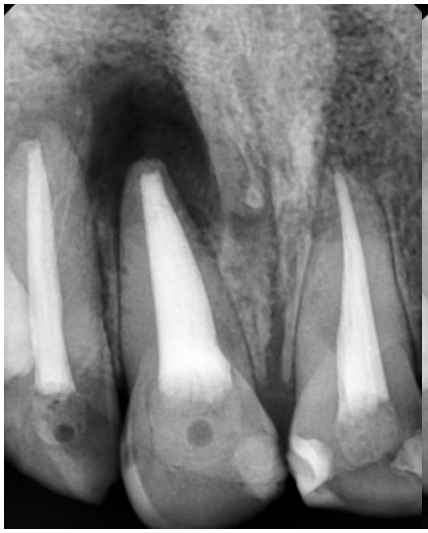

Fig 4: 6 months follow-up IOPAR

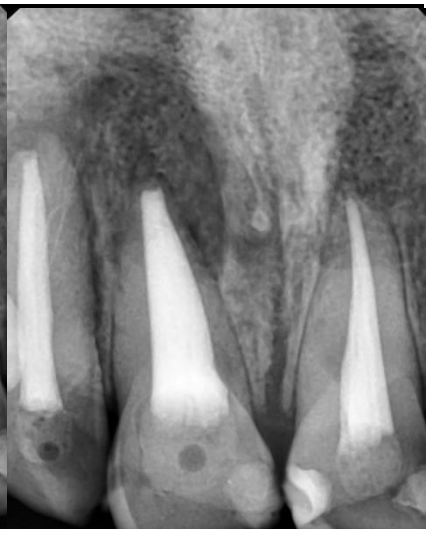

Fig 5: 12 months follow-up IOPAR

VII. Discussion

MTA can be used in surgical applications, direct pulp capping, perforation repairs in roots or furcations, apexification and root end fillings. Despite the high clinical efficacy of this cement, there are certain limitations. The important ones being very long setting time and difficult manipulation.

Biodentine, new bioactive calcium silicate-based cement was launched in the market as a 'dentin substitute'. This new biologically active material aids its penetration through opened dentinal tubules to crystallize interlocking with dentin. Biodentine has been formulated using MTA based cement technology and hence; claims improvements of some of the properties such as physical qualities, decreased setting time and handling, including its other wide range of applications like endodontic repair and pulp capping in restorative dentistry. [2]

In the first case, Biodentine was used as a root-end filling material and MTA used in the second case.

A study done by Kokate and Pawar compared the microleakage of GIC, MTA, and Biodentine when used as a retrograde filling material and concluded that Biodentine exhibited the least microleakage when compared to other materials used. Research suggests that the high pH and released calcium ions are required for a material to stimulate mineralization in the process of hard tissue healing. Sulthan carried out a similar study to evaluate the pH and calcium ion release of MTA and Biodentine when used as root end fillings. It was concluded that Biodentine had an alkaline pH and ability to release calcium ions similar to that of MTA.[13]

In the follow-ups of both the cases, excellent clinical and radiographic periapical healing was seen as there was reduction in the size of the lesion by the end of 12 months. Hence Biodentine and MTA is considered as a promising a root-end filling materials.

VIII. Conclusion

The advent of bioceramic technology has changed the outcome of both surgical and non-surgical endodontic treatment. These materials provide a number of advantages and have a promising future in dentistry. However limitations still exist when compared to the ideal material. With further research and modifications, bioceramics have the potential to become the preferred materials for the various endodontic procedures.

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MaryaGul "Bioceramics in Endodontics: Literature review of Biodentine and Mineral Trioxide Aggregate with case reports". "IOSR Journal of Dental and Medical Sciences (IOSR-JDMS), Volume 17, Issue 2 (2018), PP 77-83.