



## COMPARATIVE EVALUATION OF MICROLEAKAGE OF BIODENTINE AND GERISTORE ROOT END FILLING MATERIALS IN DRY, SALIVA AND BLOOD CONTAMINATED ENVIRONMENTS – A FLUORESCENT MICROSCOPE STUDY.

### Dentistry

<b>Dr. Alan Winston David</b>	Department of Conservative Dentistry and Endodontics, Navodaya Dental College and Hospital, Raichur Karnataka India
<b>Dr. Sarvapelli Venkata Satish*</b>	Department of Conservative Dentistry and Endodontics, Navodaya Dental College and Hospital, Raichur Karnataka India *Corresponding Author
<b>Dr. Roshan Uthappa</b>	Department of Restorative Dental Sciences, College of Dentistry, Majamaah University, Saudi Arabia
<b>Dr. Ashwini M Patil</b>	Department of Conservative Dentistry and Endodontics, Navodaya Dental College and Hospital, Raichur Karnataka India
<b>Dr. Basavana Gowda</b>	Department of Conservative Dentistry and Endodontics, Navodaya Dental College and Hospital, Raichur Karnataka India

### ABSTRACT

**Aim:** The aim of this in vitro study was to compare and evaluate the microleakage of Biodentine and Geristore root end filling materials in dry, saliva and blood contaminated environment using fluorescent microscope. **Materials & methods:** After removing the anatomical crowns of ninety extracted human maxillary central incisors, their root canals were instrumented and obturated. The apical 3 mm of each root was resected, and a standardized root end cavity was prepared using a # 8 round bur. The roots were alienated into three equal subgroups for each material and the root end filling was performed in different environments namely dry, saliva contaminated, and blood contaminated. Samples were immersed in 0.2% Rhodamine B dye for 48 hrs. Roots were sectioned longitudinally and examined under a fluorescent microscope to measure the linear dye penetration. **Results:** Geristore showed higher microleakage compared to Biodentine in dry ( $0.47 \pm 0.516$ ), saliva ( $1 \pm 0.65$ ) and blood ( $1.27 \pm 0.59$ ) sub-groups. Statistically no significant difference was seen between the Biodentine and Geristore groups in dry sub group ( $p=0.52$ ), in saliva sub group ( $p=0.45$ ) and in blood sub group ( $p=0.054$ ). **Conclusion:** Microleakage was observed in both the tested groups. Biodentine exhibited the least apical leakage value, while Geristore exhibited the maximum apical leakage value. Statistical significant difference was seen between dry and blood subgroup in Geristore group, whereas there was no significant difference between any subgroups in Biodentine group.

### KEYWORDS

Biodentine, Geristore, Root end filling material, Rhodamine B dye.

### BACKGROUND:-

Success of endodontic treatment mainly relies on the complete elimination of microorganisms and the three-dimensional sealing of the root canal system. In spite of new endodontic techniques and development of more effective materials and instruments, the resolution of periapical lesion is not achieved in certain cases.<sup>1</sup>

Saving the naturals is our prime concern, so this procedure is an alternative to avoid extractions. It is an important conservative treatment and an extension of endodontic therapy whose purpose is to preserve the tooth.<sup>2</sup>

Sometimes treatment of the periapical lesions through conventional endodontic therapy is not enough and a surgical endodontic interference is a mandatory therapeutic choice. The main surgical intervention is the root tip resection and periapical curettage.<sup>3</sup>

During the peri-radicular surgery, an exposure of apical dentin surface bounded by cementum usually results from the root end resection. For good bone regeneration and apical seal, the orthograde gutta-percha filling only is not sufficient. Application of a root end filling material after the root end resection and ultrasonic root end preparation is recommended for enhancing a good apical seal.<sup>3</sup>

Sealing ability means the ability of a material to resist the microleakage through its entire thickness. The leakage of irritant materials from the infected root canals into the peri-radicular tissues is the main cause for most endodontic failures; therefore, an efficient apical seal is essential for enhancing endodontic success.<sup>3</sup>

Achieving a dry apical field is not always attainable during endodontic surgery. Clinically, it is predictable that the root end cavity preparations and filling materials will be contaminated by any moisture, including saliva and blood.<sup>1,4</sup>

In the recent years, various materials such as Bioaggregate, Biodentine, Geristore, Cimento Endodontico Rapido Cement,

Endosequence Root Repair Material and Endocem have been introduced with the aim to fulfil the requirements of an ideal root end filling material.<sup>1,5</sup>

Ideally, the root end filling material should be impermeable to moisture, antibacterial, noncorrosive, nontoxic, non-resorbable, easy to manipulate, radiopaque, costeffective, easily adaptable and adhesive to dentin. It should promote the regeneration of the periodontal apparatus and should be biocompatible.<sup>5,6,7</sup> It should be able to create a 'biological seal' and 'physiological seal', thereby creating a 'double seal'.<sup>8</sup>

The root ends of the teeth could have variations in the root anatomy becoming the source of treatment failure. All these considerations make it mandatory to eliminate last apical three millimetres for maximum security.<sup>9,10</sup>

The plane of sectioning is equally important consideration in technique of root resection. 90° angulations has been proved to be most acceptable by earlier studies.<sup>9</sup>

For making a root end cavity we can use various instruments like conventional slow speed hand pieces, high speed air rotary hand piece, Sonics & ultra-sonics.<sup>9</sup>

The depth of penetration should be ideally 3mm, as more than that does not bestow any greater benefits, whereas lesser depth may jeopardize the long-term success of the apical seal.<sup>9,11</sup>

A variety of methods have been employed to assess the sealing ability of root end filling such as radioisotope penetration, degree of dye penetration, fluid filtration techniques, electrochemical methods, bacterial penetration, scanning electron microscopy and capillary flow porometry.

The dye penetration method used for measuring sealing ability is the most popular. Various dyes that can be used are India ink, basic fuchsin, silver nitrate, methylene blue and Rhodamine B.<sup>1,12</sup>

Hence in the present in vitro study we aimed to compare and evaluate the microleakage of Biodentine and Geristore root end filling materials in dry, saliva and blood contaminated environment using Rhodamine B dye penetration method and measured by fluorescent microscope.

**METHODS:-**

**Collection of samples:**

The ethical clearance was obtained from the ethical committee, Navodaya Dental College, Raichur. A total of ninety maxillary central incisors was extracted for periodontal reasons were taken from Department of Oral and Maxillofacial Surgery, Navodaya Dental College, Raichur. The roots were cleaned of attached tissues and calculus, washed, debrided with 5.25% NaOCl and then stored in normal saline until use.

**Preparation of samples:**

The crown was sectioned at the cemento-enamel junction using a diamond disc under constant water irrigation to a standardized length of 15 mm. The working length was determined and the canals were prepared using K-files and apical enlargement of each canal was carried out to a #35 K file, 0.5 mm short of working length and the rest of the canal was flared using step back technique to #50 K file. The canals were copiously irrigated with 5.25% NaOCl and normal saline at regular intervals.

After the preparation, root canals were thoroughly dried with paper points and obturation was done with lateral compaction technique using gutta percha and AH Plus sealer. The access cavity was subsequently etched, primed and filled with composite. The teeth were placed in a microbiological culture incubator at 37°C and 100% humidity for 5 days to simulate the oral environment.

Root end resections was performed by sectioning the apical 3 mm of the apex at a 90° angle to the long axis of the root using a straight fissure bur in a high speed handpiece under water spray. Root end cavity of 3 mm depth was prepared by using no #8 round bur with slow speed contra angle hand piece.

The prepared teeth were randomly divided into two equal experimental groups (group 1 & group 2) of 45 teeth each. Each group was further divided into three subgroups (A, B and C). The root end filling materials were mixed according to manufacturer's instructions and cavities in subgroup A, B and C were filled with dry, saliva and blood contaminated environment respectively.

Saliva was obtained from one of the colleagues and collected in a container. Blood was obtained using 27G needle from one of the colleagues, immediately before root end filling.

**Group 1 Biodentine Group:**

Biodentine was used as root end filling material. It was manipulated according to the manufacturer's instructions. Capsule was gently tapped and opened. Then it was placed on the capsule holder. 5 drops of liquid was poured into the capsule from the single dose container. Then the capsule was closed and placed in an Amalgamator and mixed for 30 seconds. Material was carried to the prepared cavity with an Amalgam carrier.

**Group 2 Geristore Group:**

Geristore was used as a root end filling material. It was manipulated according to the manufacturer's instructions. Mix Geristore initiator A and shade B in equal parts. Apply to the area to be restored and it can be light-cured or selfcured. The samples were incubated for 24h at 37°C and 100% humidity. Then, all tooth surfaces were coated by two layer of nail varnish except for the area corresponding to resected root end surface.

**Dye penetration method:**

A 0.2% solution of Rhodamine B dye was prepared by dissolving 0.2g of dye in 100ml of distilled water. All the samples were suspended in dye solution for 48 hours. Thereafter, the samples were removed, rinsed for 15 minutes under running tap water and air dried.

Nail varnish was removed with scalpel and the roots were grooved on the lingual and buccal surfaces down to the gutta percha and were sectioned into two parts. Dye penetration was measured linearly to its furthest extent coronally within the root end cavity using a fluorescent microscope.

**Scoring for dye penetration for apical microleakage is as follows:<sup>36</sup>**

- 0- No dye penetration.
- 1- Dye penetration into apical one third of retrograde filling material.
- 2- Dye penetration into apical middle third of retrograde filling material.
- 3- Dye penetration into full length of retrograde filling material.
- 4- Dye penetration beyond retrograde filling material.

**Statistical analysis:**

Data was entered in the excel spread sheet. Descriptive statistics like mean, standard deviation and percentages was calculated. Inferential statistics like ANOVA with post hoc Bonferroni was used to compare the Biodentine and Geristore root end filling materials in dry, saliva and blood environment using SPSS (statistical Package for Social Sciences) version 20.(IBM SPASS statistics[IBM corp. released 2011].

**RESULTS:-**

**Table 1: Comparison of the mean scores of microleakage in Biodentine group using ANOVA**

Biodentine	N	Minimum	Maximum	Mean	Std. Deviation	F value	P value
Dry	15	0	1	0.40	0.507	1.82	0.17
Saliva	15	0	2	0.80	0.775		
Blood	15	0	2	0.80	0.676		

Table 1 shows the comparison of the mean scores of microleakage in Biodentine group. Microleakage scores were similar in blood subgroup (0.80 ±0.676) and saliva (0.80±0.775) followed by dry subgroup (0.40±0.507). ANOVA test showed no statistical significant difference among the subgroups (p=0.17).

**Table 2: Comparison of the mean scores of microleakage in Geristore group using ANOVA**

Geristore	N	Minimum	Maximum	Mean	Std. Deviation	F value	P value
Dry	15	0	1	0.47	0.516	7.12	0.002*
Saliva	15	0	2	1.00	0.655		
Blood	15	0	2	1.27	0.594		

\*significant

Table 2 shows the comparison of the mean scores of microleakage in Geristore group. Microleakage scores were higher in blood subgroup (1.27±0.594) followed by saliva subgroup(1.00±0.655) and dry subgroup(0.47±0.516). ANOVA test showed statistical significant difference among the subgroups (p=0.002).

**Table 3: Post-Hoc Bonferroni**

	Biodentine		Geristore	
	Mean diff	p value	Mean diff	p value
Dry v/s Saliva	-.400	.316	-.533	.053
Dry v/s Blood	-.400	.316	-.800	.002*
Saliva v/s Blood	0	1	-0.267	0.67

\*significant

Post-hoc Bonferroni test was applied to compare the subgroups within the group. Statistical significant difference was seen between dry and blood subgroup (p=0.002) in Geristore group, whereas there was no significant difference between any subgroups in Biodentine group.

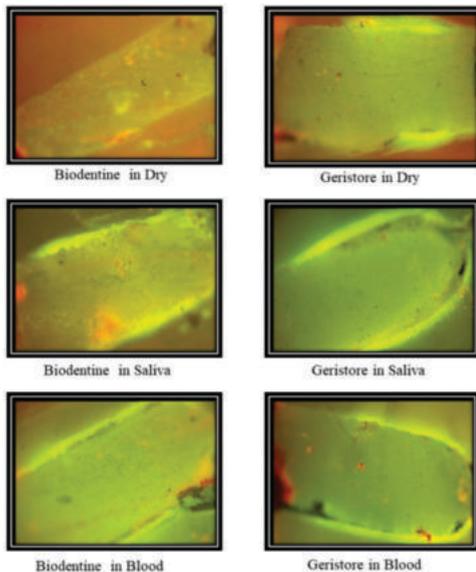
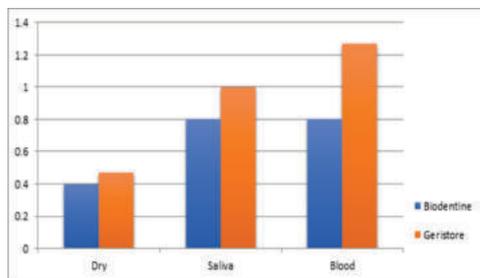
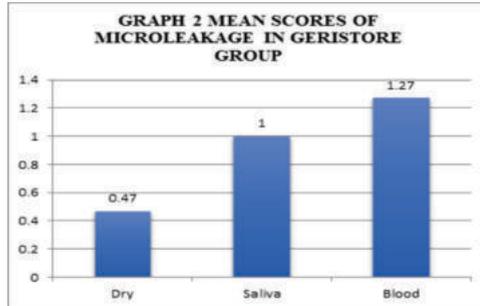
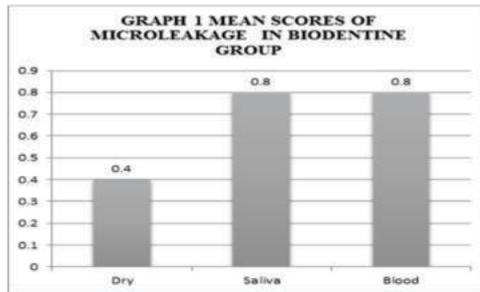
**Table 4: Comparison of Biodentine and Geristore with subgroups using independent sample t test**

		N	Min	Max	Mean	Std Deviation	Mean diff	Pvalue
Dry	Biodentine	15	0	1	0.4	0.507	0.067	0.52
	Geristore	15	0	1	0.47	0.516		
Saliva	Biodentine	15	0	2	0.8	0.775	0.162	0.45
	Geristore	15	0	2	1	0.655		
Blood	Biodentine	15	0	2	0.8	0.676	0.733	0.054
	Geristore	15	0	2	1.27	0.594		

Table 4 shows comparison of Biodentine and Geristore with subgroups using independent sample t test. Geristore showed higher microleakage (0.47 ±0.516) compared to Biodentine (0.4±0.507) in dry subgroup. Similarly Geristore showed higher microleakage in saliva (1±0.65) and blood(1.27±0.59) subgroups.

Statistically no significant difference was seen between the Biodentine

and Geristore groups in dry subgroup ( $p=0.52$ ), in saliva subgroup ( $p=0.45$ ) and in blood subgroup ( $p=0.054$ ).



**DISCUSSION:-**

Most of the tribulations in endodontics are resolved using conventional treatment approach. However, in certain conditions such as, large periapical lesions, separated instruments in the canals, apical variations, improper obturations, calcified canals and dilacerated roots etc., surgical intervention may be necessary.<sup>36</sup>

The goal of a periradicular surgery is to gain access to the affected area, evaluate the root circumference and root canal anatomy and place a biocompatible seal in the form of root end filling that stimulates the regeneration of periodontium.<sup>17</sup>

This involves the exposure of the involved root apex, resection of its

apical end, root end Class 1 cavity preparation and insertion of an appropriate root end filling material.<sup>29</sup>

The post-surgical healing of periradicular tissues depends upon the removal of all the irritants from the area surrounding the apex and stopping the entry of the newer irritants into the area. The root end filling material serves as a barrier for the possible irritants against re-entering into the periapical region. Gartner and Dorn suggested that an ideal root end filling material should provide a three dimensional seal to prevent leakage of microbial irritants into the periapical tissues.<sup>27</sup>

Mjör et al. showed that in root end resection at least 3 mm of the root end must be eliminated to reduce 98% of the apical ramifications and 93% of the lateral canals and that perpendicular resection minimizes the number of exposed dentinal tubules.<sup>35</sup>

Root end resection can be done at different plans i.e., 30°, 45°, 90°. Among these the most accepted is 90° as it least affects the adaptability of root end materials, others have a disadvantage as they may lead to open dentinal tubules, more mechanical stresses, loss of dentine – cementum bone which may lead to compromised healing.<sup>11</sup>

The depth of penetration ideally should be 3 mm as more than that does not have any greater benefits whereas lesser depth may have negative effect on the long-term success of apical seal. Depth to an optimum of 3mm decreases the leakage. This is attributed to the occlusion of apical tubules by retro filling material. Hence the depth of retrograde cavities in this study was kept to an optimum of 3 mm.<sup>11</sup>

Solubility is a very important factor in assessing the suitability of potential substances to be used as restorative materials in dentistry. Lack of solubility has also been stated as an ideal characteristic for root end filling materials. It seems logical that lesser leakage would prevent migration of bacteria and toxins into the periradicular tissue.<sup>28</sup>

A number of materials have historically been used for retrograde filling and perforation repair such as Gutta-percha, amalgam, Cavit, IRM, Super-EBA, glass ionomer, composite resin, carboxylate cements, zinc phosphate and zinc oxide eugenol cements. Due to some disadvantages Gutta-percha, amalgam, GIC, composite resin were not used nowadays as Gutta-percha has a poor sealing ability as it has to be used with a sealer during obturation and amalgam has other disadvantages like marginal leakage, secondary corrosion, moisture sensitivity and safety issues due to mercury toxicity are not used as retrograde filling material. Considering the bond strength of polycarboxylate and Cavit, they are inferior to amalgam. Unfortunately, none of these materials have been able to satisfy all the requirements of root end filling materials.<sup>8</sup>

New experimental active Ca<sub>3</sub> SiO<sub>5</sub>-based restorative cement is introduced by name of Biodentine™ (Septodont, Saint-Maurdes-Fosses, France).<sup>25</sup> It uses novel active biosilicate technology to ensure superior mechanical properties.<sup>9</sup> It is available in the form of powder and liquid. Powder is composed of tricalcium, dicalcium silicate, calcium carbonate, zirconium dioxide. In liquid, calcium chloride is added in aqueous solution to increase its setting time. Both of them are mixed in triturator for 30s prior to insertion. It sets in about 12 min. The consistency of Biodentine is similar to that of phosphate cement. It is a calcium silicate-based material used for crown and root dentin repair treatment, repair of perforations or resorptions, apexification and root end fillings. With the addition of setting accelerators and softeners made its manipulation easy.<sup>25</sup>

Biodentine has lesser setting time as compared to MTA which improves its mechanical properties and it is a bioactive material. Han and Okiji compared Biodentine and MTA in terms of Ca and Si uptake by adjacent root canal dentine and concluded that tag-like structures are formed in Biodentine. They observed that dentinal element uptake was more prominent for Biodentine than MTA.<sup>8</sup>

Al-Sabek et al. (2005) reported that human gingival fibroblasts preferentially attached to Geristore with a morphology close to that of the controls, in comparison to the other rootend filling materials. Furthermore, Camp et al. (2003) evaluated the quantitative attachment of human periodontal ligament fibroblasts to different root end filling materials and showed that cellular attachment to Geristore was significantly higher than MTA, with an increase in cell count probably due to the proliferative effect of Geristore on the cells.<sup>16</sup>

Various techniques have been advocated for detection and evaluation of micro leakage around the root end filling material. Use of dyes as tracers is one of the oldest and most common method of detecting microleakage.<sup>25</sup>

The dye-immersion technique was introduced by Grossman in 1939 and is widely used because it is easy to perform, reproducible, safe, inexpensive, quantifiable and dyes are readily available. This technique is a passive method that depends on the phenomenon of capillarity, whereby the dye penetrates any space between the root end filling and the canal wall. According to Torabinejad et al. (1994) a filling material able to resist the penetration of small molecules such as dye, would have the potential to resist the penetration of larger bacteria and their by-products. It is important to use a tracer that mimics the clinical situation.<sup>7</sup>

Rhodamine B an organic dye compounded by a red-violet powder is classified as a Xanthenic dye. It presents greater diffusion on human dentin than methylene blue. According to Franci, the molecules of rhodamine B are nanometric and are optimal to simulate enzymes and toxins of leakage resulting from bacterial metabolism.<sup>29</sup> It is water soluble fluorescent dye which is easily detectable, even in a low concentration, moves freely along the interface, low toxicity and are stable in an aqueous environment, stable in varying pH, non-destructive to the substrate or material in contact.<sup>25</sup> Rhodamine B presented more penetrability in apical dentin and such finding could be related to the greater facility of visualization when compared to methylene blue. Corroborative results were found by Hamaoka, Moura (1996) and Souza (2004). When comparing several tracer solutions in the apical region, they observed that rhodamine demonstrated higher leakage.<sup>12</sup>

A controversial topic in the literature is the moment at which the specimens should be immersed in the dye solution. In the present study, immediate immersion was selected based on the fact that in the clinical situation the root end material will be in contact with secretions like blood soon after their insertion in the cavities.<sup>12</sup>

In the present study both the tested material showed micro leakage whereas Biodentine showed the least micro leakage compared to Geristore root end filling material. The result of this study are also concurrent with the study done by Kokate et al, who compared the microleakage using MTA, GIC & Biodentine using dye penetration method under stereomicroscope. The results of their study showed that there was significantly less leakage in Biodentine when compared to MTA & GIC. A study conducted by Ankita Khandelwal et al, compared the sealing ability of MTA and Biodentine as root end filling material using Rhodamine B dye. In this study also Biodentine showed significantly less microleakage than MTA which is in agreement with the present study.<sup>11</sup>

In case of contaminated environment like dry, saliva and blood, Biodentine material showed least microleakage in dry(0.4±0.507) whereas there was comparatively highest microleakage was noticed in saliva(0.8±0.775) and blood(0.8±0.676), Geristore material showed highest micro leakage in dry (0.47±0.516), saliva (1±0.655) and blood (1.27±0.594).[Table 4]. But no statistical significance difference among Biodentine subgroups (P=0.17) [Table 1] whereas statistical significant difference was noticed in Geristore subgroups (P=0.002) [Table 2].

In the present study, least microleakage was seen in Biodentine which can be owed to its property of having excellent marginal adaptation and sealing ability. Biodentine shows absorption of dihydrogen monoxide during hydration of the powder leading to expansion during setting which may be the reason for excellent sealing ability.

## CONCLUSION:-

Microleakage was observed in both the tested groups. Biodentine exhibited the least apical leakage value, while Geristore exhibited the maximum apical leakage value. Statistical significant difference was seen between dry and blood subgroup in the Geristore group, whereas there was no significant difference between any subgroups in the Biodentine group.

## REFERENCES :-

- Pandey R, Dixit N, Dixit KK, Roy S, Gaba C, Goyal C. Comparative evaluation of microleakage of mineral trioxide aggregate and Geristore root-end filling materials in different environments: An in vitro study. *J Conserv Dent.* 2018;21(3):328-32.

- Nepal M, Shubham S, Tripathi R, Khadka J, Kunwar D, Gautam V, Gautam N. Spectrophotometric analysis evaluating apical microleakage in retrograde filling using GIC, MTA and Biodentine: an in-vitro study. *BMC Oral Health.* 2020;20(1):37.
- Nabel M, Tawfik HM, Abu-Seida AM, Elgendy AA. Sealing ability of Biodentine versus ProRoot mineral trioxide aggregate as root-end filling materials. *Saudi Dent J.* 2019;31:16-22.
- Subramanyam D, Vasantharajan M. Effect of oral tissue fluids on compressive strength of MTA and Biodentine: An in vitro study. *J Clin Diagn Res.* 2017;11(4):94-6.
- Solanki NP, Venkappa KK, Shah NC. Biocompatibility and sealing ability of mineral trioxide aggregate and Biodentine as root-end filling material: A systematic review. *J Conserv Dent.* 2018;21(1):10-5.
- Chhapparwal S, Ballal NV, Menezes ND, Kamath SU. Effect of chelating agents on sealing ability of Biodentine and mineral trioxide aggregate. *Saudi Endod J.* 2017;7(1):16-22.
- Seedat HC, Van der Vyver PJ. An in-vitro comparison of microleakage between three calcium silicate cements and amalgam. *S Afr Dent J.* 2016;71(3):100-5.
- Srivastava S, Paliwal A, Srivastava I, Sachan S, Shah V. Mineral trioxide aggregate versus Biodentine as retrograde filling material- a clinical review. *J Evolution Med Dent Sci.* 2017;6(44):3483-3486.
- Mandava P, Bolla N, Thumu J, Vemuri S, Chukka S. Microleakage evaluation around retrograde filling materials prepared using conventional and ultrasonic techniques. *J Clin Diagn Res.* 2015;9(2):43-6.
- Aydemir S, Cimilli H, Gemi PM, Bozkurt A, Orucoglu H, Chandler N, Kartal N. Comparison of the sealing ability of Biodentine, iRoot BP plus and mineral trioxide aggregate. *Cumhuriyet Dent J.* 2016;19(2):166-171.
- Srivastava H, Srivastava AA, Prasad AB, Raisingani D. Sealing Ability of Glass Ionomer Cement, Biodentine, Mineral Trioxide Aggregate & Bone Cement When Used As Retrograde Filling Materials In Endodontic Surgery. *Int J Curr Med Pharm Res.* 2016;2(6):379-82.
- Vogt BF, Xavier CB, Demarco FF, Padilha MS. Dentin penetrability evaluation of three different dyes in root-end cavities filled with mineral trioxide aggregate (MTA). *Braz Oral Res.* 2006 Apr;20(2):132-6.
- Greer BD, West LA, Liewehr FR, Pashley DH. Sealing ability of Dyract, Geristore, IRM, and super-EBA as root-end filling materials. *J Endod.* 2001;27(7):441-3.
- Roy CO, Jeansonne BG, Gerrets TF. Effect of an acid environment on leakage of root-end filling materials. *J Endod.* 2001;27(1):7-8.
- Pichardo MR, George SW, Bergeron BE, Jeansonne BG, Rutledge R. Apical leakage of root-end placed SuperEBA, MTA, and Geristore restorations in human teeth previously stored in 10% formalin. *J Endod.* 2006;32(10):956-9.
- Al-Hiyasat AS, Al-Sa'Ed OR, Darmani H. Quality of cellular attachment to various root-end filling materials. *J Appl Oral Sci.* 2012;20(1):82-8.
- Kokate SR, Pawar AM. An in vitro comparative stereomicroscopic evaluation of marginal seal between MTA, glass ionomer cement and Biodentine as root end filling materials using 1% methylene blue as tracer. *Endodontology.* 2012;24(2):36-42.
- Chakmakchi MN, Yahya MM, AL-Ashouh WM. Sealing Ability of Biodentine as a Retrograde Filling Materials (A Comparative in vitro study). *Al-Rafidain Dent J.* 2013;14(3):357-361.
- Ravichandra PV, Harikumar Vemisetty DK, Jayaprada Reddy S, Ramkiran D, Jaya Nagendra Krishna M. Comparative evaluation of marginal adaptation of Biodentine™ and other commonly used root end filling materials- an in vitro study. *J Clin Diagn Res.* 2014;8(3):243-5.
- Soundappan S, Sundaramurthy JL, Raghu S, Natanasabapathy V. Biodentine versus mineral trioxide aggregate versus intermediate restorative material for retrograde root end filling: an in vitro study. *J Dent (Tehran).* 2014;11(2):143-9.
- Radeva E, Uzunov T, Kosturkov D. Microleakage associated with retrograde filling after root end resection (in vitro study). *JIMAB.* 2014;20(3):578-583.
- Hindlekar A, Raghavendra SS. Comparative evaluation of sealing ability of three root-end filling materials- an in vitro study. *Int J Dent Clin.* 2014;6(4):4-7.
- Jang YE, Lee BN, Koh JT, Park YJ, Joo NE, Chang HS, Hwang IN, Oh WM, Hwang YC. Cytotoxicity and physical properties of tricalcium silicate-based endodontic materials. *Restor Dent Endod.* 2014;39(2):89-94.
- Singh H, Kaur M, Markan S, Kapoor P. Biodentine: A promising dentin substitute. *J Interdiscipl Med Dent Sci.* 2014;2(5):1-5.
- Khandelwal A, Karthik J, Nadig RR, Jain A. Sealing ability of mineral trioxide aggregate and Biodentine as root end filling material, using two different retro preparation techniques- an in vitro study. *Int J Contemp Dent Med Rev.* 2015;1:6.
- Pradhan PK, Das S, Patri G, Patil AB, Sahoo KC, Pattanaik S. Evaluation of Sealing Ability of Five Different Root End Filling Material: An In Vitro Study. *J Int Oral Health.* 2015;7(11):11-15.
- Gupta PK, Garg G, Kalita C, Saikia A, Srinivasa TS, Satish G. Evaluation of sealing ability of Biodentine as retrograde filling material by using two different manipulation methods: an in vitro study. *J Int Oral Health.* 2015;7(7):111-114.
- Pathak S. Comparative evaluation of sealing ability of root end filling materials: an in vitro study. *Int J Dent Med Res.* 2015;1(5):48-52.
- Saraswathi DD, Tejavath SK, Babu MR, Swetha B, Gandhi B, Shaanthi. A comparative evaluation of sealing ability of three recent root-end filling materials: an in vitro study. *J Adv Oral Res.* 2015;6(2):33-39.
- Naik MM, de Ataide ID, Fernandes M, Lambor R. Assessment of apical seal obtained after irrigation of root end cavity with MTAD followed by subsequent retrofilling with MTA and Biodentine: An in vitro study. *J Conserv Dent.* 2015;18(2):132-5.
- Bolhari B, Yazdi KA, Sharifi F, Pirmoazen S. Comparative scanning electron microscopic study of the marginal adaptation of four root-end filling materials in presence and absence of blood. *J Dent (Tehran).* 2015;12(3):226-34.
- Malhotra S, Hegde MN. Analysis of marginal seal of ProRoot MTA, MTA angelus Biodentine, and glass ionomer cement as root-end filling materials: an in vitro study. *J Oral Res Rev.* 2015;7(2):44-9.
- Bhavana V, Chaitanya KP, Gandhi P, Patil J, Dola B, Reddy RB. Evaluation of antibacterial and antifungal activity of new calcium-based cement (Biodentine) compared to MTA and glass ionomer cement. *J Conserv Dent.* 2015;18(1):44-6.
- Desai N, Rajeev S, Sahana S, Jayalakshmi KB, Hemalatha B, Sivaji K, Vijay KR, Vamshi KV, Savitri D, Gyanendra PS. In vitro comparative evaluation of apical microleakage with three different root-end filling materials. *Int J Appl Dent Sci.* 2016;2(3):29-32.
- Mathew LA, Kini S, Acharya SR, Kamath S, Menezes ND, Rao S. A comparative evaluation of the microleakage of blood-contaminated mineral trioxide aggregate and Biodentine as root-end filling materials: An in vitro study. *J Interdiscipl Dent.* 2016;6(1):19-24.
- Jain A, Ponnappa KC, Yadav P, Rao Y, Relhan N, Gupta P, Choubey A, Bhardwaj S. Comparison of the root end sealing ability of four different retrograde filling materials in teeth with root apices resected at different angles- An in vitro study. *J Clin Diagn Res.* 2016;10(1):14-17.
- Demiryurek EO, Ozyurek T, Gulhan T, Keskin C. Evaluation of antibacterial and antifungal activity of calcium silicate based retrograde filling materials. *Int J Appl Dent Sci.* 2016;2(2):85-88.

38. Helvacıoglu-Yigit D, Kocasarac HD, Bechara B, Noujeim M. Evaluation and reduction of artifacts generated by 4 different root-end filling materials by using multiple cone-beam computed tomography imaging settings. *J Endod.* 2016;42(2):1-8.
39. Agrafioti A, Tzimpoulas N, Chatzitheodoridis E, Kontakiotis EG. Comparative evaluation of sealing ability and microstructure of MTA and Biodentine after exposure to different environments. *Clin Oral Invest.* 2016;20:1535-40.
40. Shetty S, Hiremath G, Yeli M. A comparative evaluation of sealing ability of four root end filling materials using fluid filtration method: An in vitro study. *J Conserv Dent.* 2017;20(5):307-10.