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BOND STRENGTH AND ADAPTATION OF NANO IMPREGNATED BIODENTINE AS A REPAIR MATERIAL FOR FURCATION PERFORATIONS: AN IN VITRO STUDY

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ABSTRACT

Aim: Evaluate the Bond strength and the Adaptation of Nano Biodentine as a repair material for furcation perforation.

Materials and methods: Thirty Samples were randomly classified into three groups (n=10), 1 control group (MTA) and 2 experimental groups according to the materials used to fill the furcal perforations defects. Group 1 (Biodentine), group 2 (Nano-Biodentine) and group (MTA).

Results: There was a significant difference between different groups ($p<0.001$). The highest value was found in the Nano-biodentine group (11.12±0.77) followed by the Biodentine group (7.31±1.19) while the lowest value was found in MTA (6.24±0.66). Post hoc pairwise comparisons were all statistically significant ($p<0.001$).

Conclusion: Nano-biodentine showed to have the highest push-out bond strength, followed by the biodentine and then the MTA had the least push-out bond strength. While when looking at the adaptation of the materials, Nano-biodentine has the lowest adaptation followed by Biodentine and the lastly came the MTA with the highest adaptation.

KEYWORDS: Furcal perforation, Nano-Biodentine, Biodentine, MTA, adaptation.

INTRODUCTION

Dental perforations are a common procedural error that happens mainly during access cavity preparation or canal preparation. A perforation is the artificial communication between the root canal system connecting the pulp chamber with the periodontal ligament and the supporting structures that encircle the tooth affected. [1]

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Root perforations are the second most typical cause of endodontic treatment failure and are mainly divided into 2 main types, iatrogenic errors which is related to the operator or pathological causes that are mainly caused by either internal or external resorption of the roots. Operator related errors include post preparation and endodontic therapy with lack of knowledge either by the operator or by the use of the proper material for each case which usually results in a strip or apical perforations. On the other hand the pathological causes included trauma to the root resulting in a clastic activity of the cells around the root and thus resulting in a resorptive cascade which may end with a perforation in the root.[3]

The two most common types of perforation are furcal and strip perforations. Furcal perforation usually results during access cavity either by an unskilled operator unable to locate the proper canal location and thus causing destruction of the furcal dentin resulting in a perforation or improper assessment of the pre-operative X-ray of a calcified tooth with faded pulp chamber.[7]

While furcal and strip perforations are considered the most common perforations to occur, apical perforation may also happen. An apical perforation is considered the most challenging but it has the best prognosis compared to strip and furcal perfor-ations. [5,2]

In all these types of perforations, lots of materials were chosen to repair such defects. The most important properties of the material of choice is its sealing ability and bond strength on the long term, its adaptation on the wall of the perforation, biocompatibility, ease of handling, and its capability in promoting regenerative or reparative cells in the area. [2]

Many materials were used to repair perforations such as amalgam, zinc oxide eugenol, super ethoxy-benzoic acid (EBA), glass ionomer, calcium hydroxide, gutta-percha, intermediate restorative material (IRM), composite, and mineral trioxide aggregate (MTA). All showed some defects that could not provide the initial required properties that should be present in a perforation repair material, except MTA which showed acceptable results and is considered the gold standard as a repair material, as it stimulates osteoblasts for bone deposition, has acceptable adaptation and bond strength. [9]

To overcome the negative properties of MTA, which are the extended setting time and its challenging handling properties, new materials were introduced and tested to overcome these disadvantages. One of those materials is Biodentine, which shows high biocompatibility and great cells stimulation in addition to a fast setting time allowing the clinician to place the repair material and finish the root canal treatment in the same visit, without the need to wait for complete setting of the repair material which used to take up to 24 hours. [6]

Although Biodentine showed improved properties compared to MTA, it showed some disadvantages such as higher microleakage compared to MTA. [6]

The creation and construction of innovative biomaterials with unique biological, chemical, and physical features can benefit from nanotechnology. Therefore in an attempt to improve biodentine properties, Nano-Biodentine was introduced. Impregnation of Nano-particles improves the adaptation and the sealing ability of such material with the dentine walls. Thus the aim of this study is to evaluate the bond strength and adaptation of Nano-Biodentine as a repair material for furcation perforations.[7,13]

MATERIALS AND METHODS

Thirty extracted maxillary molars were collected. To rule out any samples with previous root fractures, fissures, or caries, root surfaces; samples were examined under a dental operating microscope at a magnification of 10X. The collected samples were concealed, randomized and allocated using (www.random.org) website. The samples were then stored in an anonymous manner and de-identified. Teeth were inserted in an epoxy resin material followed by decoronation of the teeth, then 2 mm discs from just below the cemento-enamel junction were obtained by sectioning.[1]

The pulp chamber floor of all 30 samples was then perforated in the centre using a number 4 round carbide bur with a high-speed handpiece. To standerdize the perforation width, the same bur was used for all samples. While the depth of each perforation was already standardized by the disc thickness of 2mm. No further entrance of the bur or any instrument was allowed inside the perforation area to prevent any change in the dimensions of the perforation ensuring the unification of all samples with the same size. A final irrigation was applied for 1 min by using 2ml 17% EDTA for the removal of smear layer, then the perforation was rinsed with 5mL distilled water, and dried with paper point on the walls of the perforations.[2] The discs were embedded in putty elastomeric material to simulate the periodontal apparatus and aid in condensation of the perforation filling material.[3]

Thirty samples were randomly classified into three groups (n=10), 1 control group and 2 experimental groups according to the materials used to fill the furcal perforations defects. Each of the three groups will have a further subdivision into two subgroups (n=5) according to the test that is going to be done either push-out or adaptability tests. The groups are as follow: Group 1: Biodentine as a perforation filling material, Group 2: Nano Biodentine as a perforation filling material, Group 3: MTA as a perforation filling material (control group).

In group 1, perforation cavities were repaired with Biodentine (BD) material which was administrated as capsules to be mixed in the amalgamator. These capsules contained tricalcium silicate, calcium carbonate, zirconium oxide, and water- based calcium chloride liquid, hydrosoluble polymer and water.[4] Biodentine was placed into the perforations using the MTA carrier and condensed using a hand plugger with the appropriate fitting size. Biodentine was packed until resistance was felt by the putty elastomeric material to simulate the periodontal apparatus. The manufacturer's recommendations was followed stating that biodentine setting time is 45 minutes.[5,7]

For the second group Nano-Biodentine was used, which was obtained by grinding Biodentine using a zirconium ball in a milling machine in a repetitive manner for 24 h (Raymer Engineering, Mumbai, India).[6] After transforming to nano-particles, the Nano-Biodentine powder was returned to the capsule where it was activated and used as the conventional one. Nano-Biodentine revealed spheroidal crystallites agglomerations with an average size of 21 nm and 33 nm approximately. The Nano-Biodentine was placed in the perforation sites as Group I.

For the third group MTA was used to seal the perforations of the 10 samples. MTA was placed in the perforation sites as Group I.

For the push-out bond strength test: The cross-sectioning of teeth was done using an IsoMet 4000 microsaw mounted with a diamond disc of 0.6 mm thickness at a feeding rate of 10 mm/min while operating at a speed of 2500 rpm. The prepared two mm thick tooth slices for assessment of push out bond strength were used for the test. In order to guarantee that the filling materials don't contain any dentin cracks or voids, stereomicroscope (Nikon MA100 Japan) was used to photograph and inspect the apical and coronal portions of each sample.

A 0.9 mm diameter stainless steel plunger was then loaded over the filling material placed inside the perforation areas. The plunger was mounted on the upper part of a universal testing machine (Instron universal testing machine model 3345 England data recorded using computer software Bluehill 3 version 3.3). To prevent any constriction interference, The samples were placed in an apical to coronal direction over a support jig. A 500N load cell was used in the tests, which were run at a cross head speed of 0.5 min-1. The highest value recorded was taken as the push-out bond strength. The area under load was calculated by: Area = circumference of restoration × thickness. The push-out value in MPa was calculated from force (N) divided by area in mm^2.

As for the adaptation test, the samples were sent to the laboratory where the epoxy resin Discs were mounted on metallic stubs. Samples were then placed in hummer 8.0 gold-sputtering machines and later evaluated under a SEM (Joel, Boston, USA) under ×500, x1000 and ×2000 magnification. Using SEM all gaps at the dentin-material interface were accessed and analyzed by a blinded technician. Measurements and records were made of the transverse and longitudinal gaps in eight different regions. The calculations for each samples used the maximum gap area present.

RESULTS

In the form of mean and standard deviation (SD) values, numerical data were given. They were examined for normalcy using the Shapiro-Wilk test and the data distribution. For intergroup comparisons, one-way ANOVA followed by a Tukey's post hoc test was performed because the data had a parametric distribution. The significance level was set at $p \le 0.05$. Statistical analysis was performed with statistical analysis software version 4.1.2 for Windows[*].

For Pushout bond strength, a significant difference between different groups ($p<0.001$) was seen. The highest value was present in Nano-Biodentine (11.12±0.77), followed by Biodentine (7.31±1.19) while the lowest value was found in MTA (6.24±0.66). Post hoc pairwise comparisons were all statistically significant ($p<0.001$). **(Table 1)**

TABLE (1) Mean, Standard deviation (SD) values of shear bond strength (MPa) for different groups.

Pushout bond strength (MPa)			**p-value**
Nano-biodentine	**Biodentine**	**MTA**	
11.12±0.77^{A}	7.31±1.19^{B}	6.24±0.66^{C}	**<0.001***

Significant (p ≤ 0.05).

The failure of the samples was either cohesive failure where cement was covering the perforation wall, or adhesive failure where samples were dislodged from the perforation site leaving no cement remnant on the perforation wall, or combined failure where some area of the perforation wall had cement on them while other areas in the same perforation site showed no cement on its walls.

When examined under 1000X magnification, the adaptation test showed to have a significant difference between the groups (p 0.001). Nanobiodentine was determined to have the lowest value (2.34±0.50), followed by Biodentine (3.13±0.37), while the highest value was found in MTA (3.92±0.51). Post hoc pairwise comparisons showed different groups to have significantly different values from each other ($p<0.001$). **(Table 2) (Figure 1-3)**

TABLE (2) Mean, Standard deviation (SD) values of adaptation at 1000x magnification (μm) for different groups.

Adaptation at 1000x magnification (μm)			**p-value**
Nano-biodentine	**Biodentine**	**MTA**	
2.34±0.50^{A}	3.13±0.37^{B}	3.92±0.51^{C}	**<0.001***

Significant (p ≤ 0.05).

* R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

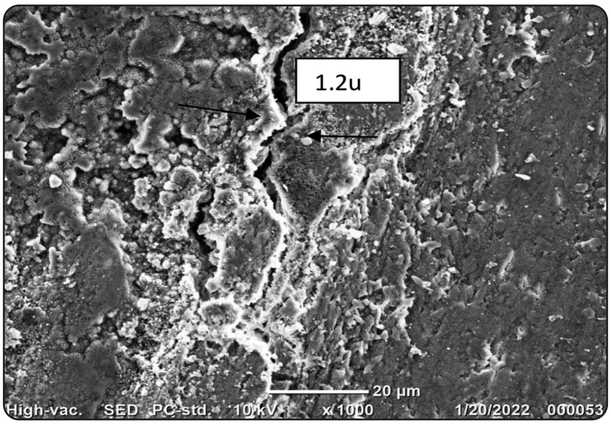

Fig. (1) SEM image of Nano-Biodentine samples under 1000X magnification.

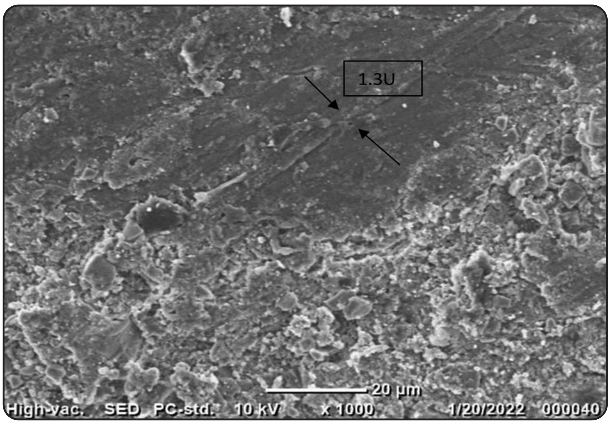

Fig. (2): SEM image of MTA samples under 1000X magnification.

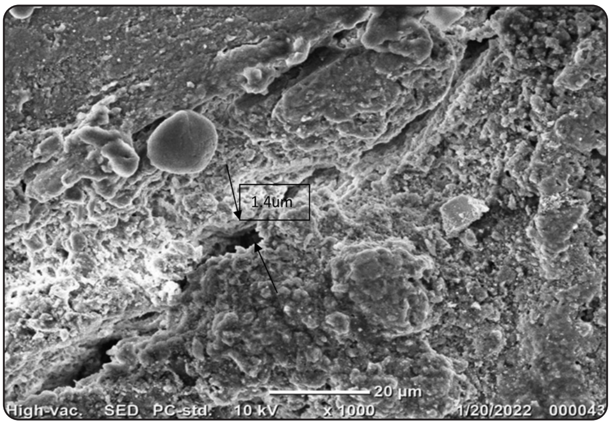

Fig. (3): SEM image of Biodentine samples under 1000X magnification.

TABLE (3) Mean, Standard deviation (SD) values of adaptation at 2000x magnification (µm) for different groups.

Adaptation at 2000x magnification (µm)			p-value
Nano-biodentine	Biodentine	MTA	
1.76±0.12[A]	2.27±0.15[B]	2.90±0.27C	**<0.001***

Significant ($p \le 0.05$).

It was also identified under 2000X Magnification. Data showed a significant difference between groups (p<0.001). The lowest value was found in Nano-biodentine (1.76±0.12), followed by Biodentine (2.27±0.15), while the highest value was found in MTA (2.90±0.27). Different groups had significantly different values from one another, according to post hoc pairwise comparisons (p 0.001). **(Table 3) (Figure 4-6)**

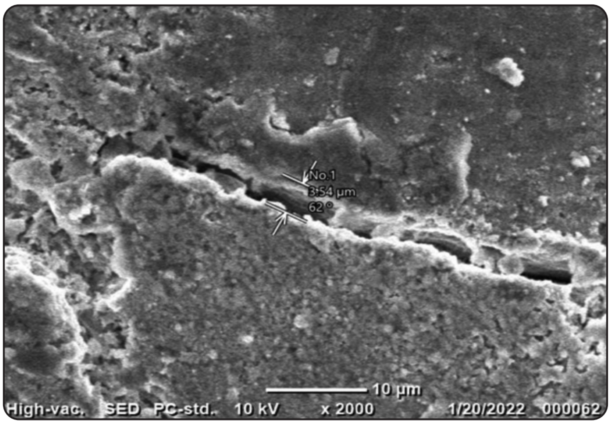

Fig. (4) SEM image of Nano-Biodentine samples under 2000X magnification.

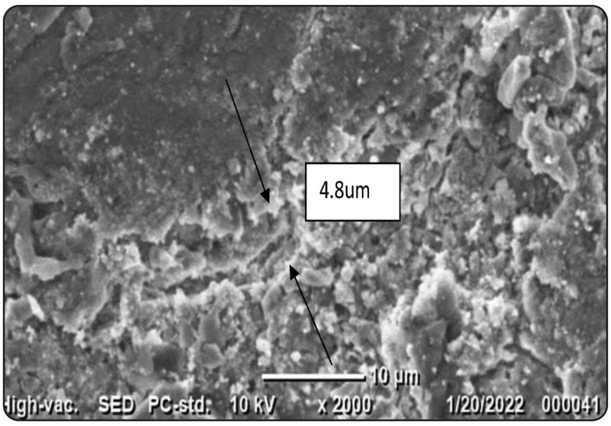

Fig. (5) SEM image of MTA samples under 2000X magnification.

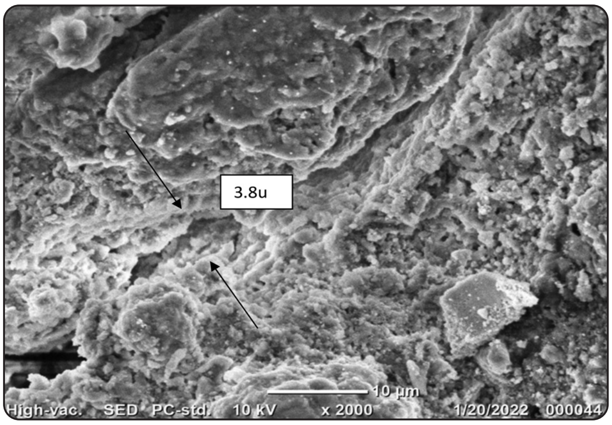

Fig. (6) SEM image of Biodentine samples under 2000X magnification.

DISCUSSION

Full masticatory function and natural aesthetics depend on the integrity of the natural dentition. Dental therapy is necessary to avoid any disruption of this balance. The perforation of the root canal system is one of the various procedural mishaps that a clinician may experience when performing endodontic treatment. Perforations can happen at any time, whether it's during the preparation of the access cavity, which can result in lateral or furcal perforations, or during the instrumentation of the root canal, which can result in canal perforations at the cervical, mid-root, or apical levels. The location, size, time between the occurrence and the repair of the perforation, the efficacy of the restorative material to close the hole, and the periodontal health of the tooth are some of the factors that affect the long-term prognosis of a perforated tooth.[7]

Furcation perforation is one of the procedural mishaps which can cause an inflammatory response in the periodontium with the most common cause of furcation perforation being iatrogenic because of the improper use of rotary burs during the preparation of endodontic access and search for root canal orifices. The severity of the periodontal tissue damage, the size and location of the perforation, the bacterial contamination, and the cytotoxicity and sealing capacity of the repair materials all affect the affected tooth's prognosis. Large perforations make it difficult to completely seal the perforation with a sealing material because it permits irritants to continuously infiltrate the area of the furcation. Perforations near the gingival sulcus cause lingering inflammation and sulcular epithelium to creep into the defect. Furcal perforations, which are positioned coronally, have more severe consequences than those that are located in the middle and apical third of a canal.[8]

The choice of the sealing material utilised, which is an important consideration, might affect how the perforation is treated. The optimum perforation repair material should be easy to manipulate and easy placed, can withstand occlusal load without dimensional chamges, stimulate bone healing, mineralization, and cementogenesis, biocompatible, bactericidal, and not influenced by blood contamination. However, unitl this day, no material has met all of these ideal criteria.[9]

For a good long-term prognosis, endodontic materials should be resistant to dislocating forces. The use of bioceramic materials in endodontics has increased recently. Mineral trioxide aggregate (MTA) is used for perforation repair, root end filling, pulpotomy, apexification, and regenerative procedures, a hydraulic cement (CSC) based on calcium silicate. MTA has a number of appealing qualities, including biocompatibility, high sealing ability, and the capacity to set in moist environments. Additionally, it possesses adequate marginal adaptation and a strong bond to dentine.[10]

However, MTA has numerous glaring drawbacks, including a lengthy setting time, poor initial washout resistance, and challenging handling characteristics.

Therefore, the development of newer materials for perforation repair is necessary. The most recent CSC examined, Biodentine (Septodont, Saint Maur des Fosses, France), it showed to have better physical characteristics and a faster setting time than MTA. Tricalcium silicate, calcium carbonate, and zirconium oxide make up the majority of the biodentine powder, while calcium chloride, employes as a setting accelerator, a hydro soluble polymer, and water reducing/super plasticizing ingredient, make up the liquid. This biomaterial has been approved for coronal and radicular restorations and is regarded as a biocompatible and bioactive dentine alternative.[11]

The creation and development of innovative biomaterials with unique biological, chemical, and physical features can benefit from nanotechnology. Materials with nanoparticles are easier to work with, more fluid, and have a good impact on the hydration process, which leads to effective root canal filling.[6]

Nano-biodentine (NBD), which has a higher solubility and surface area than regular biodentine and a shorter setting time, has shown improved chemical reactivity in various tests. The fact that a given mass of a substance in nanoparticle form is significantly more reactive than a similar quantity of the material composed of bigger particles supports this. It was shown that the higher the hydroxyl (OH) and calcium (Ca2+) release, which is associated to the higher solubility measured for BD, the more soluble the material is. By releasing calcium ions, the nanoparticles' setting accelerator effect works as seeds, stimulating the nucleation of calcium silicate and speeding up the hydration process, which also aids in speeding up the reaction time.[12,13,14]

Thus, the present in-vitro study evaluated the push-out bond strength and adaptation of Nano-biodentine in comparison to Biodentine and MTA Angelus in the repair of furcation perforations.

In order to closely replicate the intraoral conditions, thirty extracted maxillary molars with separated roots and completely formed apices were collected. All samples were devoid of root resorption, restorations, and previous root canal therapy. In order to rule out any samples with preexisting root fractures, cracks, or root carries, the root surfaces were examined with a dental operating microscope at 10x.[9]

Teeth were inserted in epoxy resin material to simulate the periodontal ligament support followed by decoronation and the teeth were sliced to obtain 2 mm discs from just below the cemento-enamel junction. If the thickness of the discs is increased due to an increase in the area of friction, the bond strength may be overestimated.[1]

The pulp chamber floor was then perforated in the centre using a number 4 round carbide bur in a high speed hand-piece. Each perforation's depth was determined by the 2mm thickness of the dentin-cementum which was obtained using the disc slicing each samples to be perfectly identical, while its width was regulated by the burs' identical diameter. No further entrance of the bur nor any instrument was allowed inside the perforation area to prevent any change in the dimension of the perforation ensuring the unification of all samples with the same size.[15]

The hypothesis of the current study was not fulfilled, because Nano-biodentine showed significantly higher bond strength and higher adaptation compared to the other materials.

In the current study results showed that Nano-biodentine had the highest push-out bond strength, followed by biodentine and MTA had the least pushout bond strength.

Nano-biodentine had a significantly higher bond strength compared to biodentine and MTA. This was also collaborated by Yamini et. Al.[1] They also stated that because Nano-Biodentine had a higher solubility and surface area than regular Biodentine, it was more chemically reactive and set up more quickly. This is supported by the observation that a given mass of a substance in nanoparticle form is much more reactive than a corresponding mass of the same material composed of larger particles. Additionally, they came to the conclusion that a material's OH and Ca2+ release increases with its solubility, which is consistent with the increased solubility seen for biodentine. As a result, nano-materials produced more Ca2+. The sowing effect, also known as the setting accelerator effect of the nanoparticles, functions as seeds and accelerates the nucleation of calcium silicate, increasing the hydration process.

Biodentine had significantly higher push-out bond strength when compared to MTA. Similar results were found by other studies. Guneser et. al stated that Biodentine was more resistant to dislodgement forces than MTA, they mentioned that the biomineralization ability of Biodentine, most likely through the formation of tags, may be the reason of that dislodgement resistance. Nagas et al also added that the creation of dentinal bridges brought on by crystal growth within the dentinal tubules may further strengthen the stronger bond between biodentine and dentine, increasing micromechanical retention. Akman et. al ascribed his findings to biodentine's capacity to build biomimetic remineralization and the deposition of calcium phosphate on its surface, suggesting a high rate of calcium release with continual creation of apatite crystals, making it a scaffold for clinical healing.[16,17,18]

Badami et al also found that the amorphous calcium phosphate (ACP) layer was created by Biodentine, and since the Ca/P ratio of this layer is comparable to MTA, it can be said that Biodentine has a stronger attachment to root dentin. Also in a comparative study between Biodentine and MTA, it was found that the force necessary to dislodge Biodentine from root dentine is much more than the force needed to separate MTA. When compared to MTA, calcium ion released in Biodentine demonstrate a noticeably larger release of free calcium ions.[19, 20]

However, another study found that MTA had a higher or similar bond strength compared to biodentine such as Aggarwal et. al who stated that after 7 days, MTA and Biodentine had similar push-out bond strengths in uncontaminated samples. This difference in the results may be attributed to the difference in the sample size and the fact that contaminated samples by blood were also used.[21]

As for the marginal adaptation of the materials to dentine, results of the current study showed that nano-biodentine had the highest adaptation followed by Biodentine and the least was MTA.

Concerning the adaptation of nano-biodentine, scarce studies mentioned this novel material. El-Sayed et. al mentioned that nano-biodentine displayed the highest solubility compared to biodentine and bioactive glass materials. This might be inferred due to the increased surface area of nano-biodentine particles that results in a corresponding increase in chemical reactivity. This means that a given mass of a material in a nanoparticles form is much more reactive than the same mass of the material made up of larger particles. This in turn will reflect on the adaptability and sealing ability positively.[6]

Regarding biodentine, it had a significantly higher adaptation when compared to MTA. These results were also supported by other studies. Kamal et. al owed their discoveries to the calcium and silicon uptake by neighbouring root canal dentine by Biodentine and MTA in the presence of phosphate buffered saline, which led to the creation of a tag-like structure made of calcium and phosphate rich crystalline deposits. The layers rich in silicon and calcium grew thicker over time. Following 30 and 90 days, the calcium and silicon-rich layer was noticeably thicker in Biodentine than MTA, indicating that Biodentine had absorbed more dentine elements than MTA. These results support the idea that dentine interactions, such as intrafibrillar apatite deposition, which fill the gap caused by apatite production, help to reduce leakage.[22]

Moreover, Gelda et. al, that by using new predosed capsule in a mixing device, a noticeable improvement in the material's physical properties is seen, including its capacity to seal, and the improvement in the adaptation of biodentine. Additionally, Biodentine has the benefit of having a quicker setting time (12 min), which seals the interface early and reduces the chance of bacterial contamination by preventing further leaking. Also Alazrag et. al attributed their results to the small size of Biodentine particles which may enhance the adaptation at the cavity surface and filling interface.[23,24]

On the other hand also Alazrag et. al found that marginal adaptability and microleakage of MTA were better than that of Biodentine. This may be related to the method of sample preparation and method of evaluation. Warmansyah et al stated that both MTA and Biodentine were adapted marginally in a similar way at the perforation sites, though MTA seems to have a slight greater gap than Biodentine, it was of no statistical significance.[25,24]

CONCLUSION

Within the limitations of this study the following can be concluded:

- Nanoparticles incorporation helped increase the adaptation and bond strength of Biodentine.
- Biodentine presented a higher adaptation and bond strength than MTA.
- MTA as a perforation repair material showed inferior results when compared to Biodentine and its same counterpart.

Conflict of interest

The author denies any conflict of interest concerning with this study.

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