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SEALING ABILITY OF THERACAL IN FURCAL PERFORATIONS IN PRIMARY MOLARS: AN IN-VITRO STUDY

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ABSTRACT

Objective: The current in-vitro study aimed for the evaluation of sealing ability of TheraCal LC material when used as furcation repair material in primary molars, compared to the gold standard MTA material.

Materials and Methods: 45 restorable human mandibular primary molars were allocated into two equal main groups (n=20) based on material used for furcal perforation (FP) repair; Group (1): repaired with premixed MTA material (NeoPUTTY), and Group (2): repaired with TheraCal LC. Group (3): included the five remaining teeth as negative control group with no furcal perforation. After restoration of access cavities with composite resin material, the teeth roots were immersed in 1% methylene blue dye solution for 72 h. After that, mounted teeth underwent a mesiodistal sectioning in a vertical direction. For microleakage assessment, the dye penetration method with stereomicroscopy followed by SEM were used.

Results: The mean values of dye penetration extent along dentinal walls were 1.30 ± 0.32 mm, 1.80 ± 0.32 mm and 0.11 ± 0.07 mm for groups 1, 2 and 3 respectively, with statistically significant difference. Although group 2 showed the highest value, a statistically non-significant difference was observed between tested groups regarding microleakage gap width.

Conclusions: NeoPUTTY MTA material has a significantly positive influence on the sealing ability when utilized as a furcation repair material in primary molars. TheraCal LC material failed to alternate the MTA for furcal perforation repair in primary molars as it has a poor sealing ability.

KEYWORD: Furcation repair, Microleakage, NeoPUTTY

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INTRODUCTION

Preservation of primary molars with arch integrity and functional efficiency awaiting the scheduled shedding time is considered one of the major aims in pediatric dentistry.[1] Iatrogenic furcal perforation may occur during pulpotomy access cavity procedure. Any pulp floor perforation can result in an imbalance of the dental structure.[2] If the furcal perforation is not appropriately repaired, there may result in permanent periodontal damage and/or tooth extraction.[1,3]

The repair process of a furcal perforation for multi-rooted primary molar teeth is a critical issue during pulp treatment.[1] There are many factors affecting the degree of tissue response to furcal perforation treated with different materials. These include the degree of periodontal tissue damage, sealing ability, cytotoxicity of the used material, bacterial contamination, and the time passed before furcal perforation repair as well as the size and location of furcal perforation.[4,5]

Furcal perforation can be managed with 2 approaches: surgical and non-surgical approaches. In the surgical approach, primary molar with a furcal perforation is extracted. In the non-surgical approach, healing and prognosis are dependent upon rapid intervention and the use of appropriate repair material. This approach is favored in children.[1,6] Ideally, repair materials for furcal perforations should exhibit the following characteristics: non-absorbability, biocompatibility, ease of manipulation and placement, resistance to blood contamination, radiopacity, antimicrobial properties, and the ability to induce osteogenesis, cementogenesis, and healing. Furthermore, they should exhibit strong sealing capability and bond strongly to radicular dentin.[7,8]

Different materials have been used for managing furcal perforations, including light-cured composite resin, silver amalgam, zinc oxide-eugenol cement, calcium hydroxide, resin cement, hydroxyapatite and glass ionomers.[9,10] But, none of the previously mentioned material had the ability of reestablishing the normal architecture predictably in perforated furcation. So, there is still a need for novel and ideal material for treating the furcal perforation.[11]

Calcium silicate-based materials have become of choice for repairing any type of dentinal defects. They create communication pathways between the root canal system and periodontal ligament.[12] Many calcium silicate-based materials are used to repair root perforations in both primary and permanent teeth due to their high sealing and regenerative abilities. Additionally, these materials are biocompatible and possess antibacterial properties.[13] Chemically, bioactive calcium silicate-based materials have been classified into four generations. Portland Cement and ProRoot MTA (Grey & White) are examples of Generation I. MTA Angelus represents Generation II. Generation III included materials such as Ortho MTA, MTA Plus, EndoSequence, Calcium Enriched Mixture (CEM) cement, Biodentine, and Bioaggregate. The final Generation IV involves the recently introduced light-cured MTA and TheraCal LC.[14,15]

Mineral trioxide aggregate (MTA) is a bioceramic material characterized by a high concentration of metal oxides. It remains the benchmark material for sealing various types of root perforations. MTA is biocompatible and bioactive, exhibiting significant sealing ability.[12] However, it has several disadvantages, including a prolonged setting time, low compressive and flexural strength, challenging handling properties, and the potential for high material loss due to its formulation as a powder/liquid system.[1, 12]

Recently, novel calcium silicate-based materials have been introduced into the market to improve the disadvantages of conventional endodontic materials used for repair of primary furcal perforations.[12] Among these materials are NeoPUTTY (Avalon Biomed Inc., Houston, TX, US) and TheraCal

LC (Bisco Inc, Schaumburg, IL, US) materials. NeoPUTTY is a novel premixed calcium silicate-based cement version of the NeoMTA Plus. It is composed of fine tricalcium silicate material in addition to calcium aluminate, dicalcium silicate, calcium sulfate, grossite, and tricalcium aluminate with tantalum oxide used as a radiopacifying agent. No mixing is needed and it is designed to set in presence of moisture. It offers a ready-to-use material for immediate placement without any waste, saving costs and time. Moreover, it is a bioactive and bioceramic material with better handling properties, promoting hydroxyapatite formation to induce the healing.[16]

On the other hand, TheraCal LC is a light-cured resin-modified calcium silicate-based material. It can be used easily because of its efficient syringe placement and its easy light-curing. The manufacturer recommends placing TheraCal LC in 1 mm layers and curing for 20 sec.[17] It consists of calcium silicate (type III Portland cement), strontium glass, fumed silica, barium sulfate ($BaSO_4$), barium zirconate ($BaZrO_3$), and resin-containing Bisphenol A-glycidyl methacrylate (Bis-GMA) and Polyethylene glycol dimethacrylate (PEGDMA).[16,18] Since TheraCal LC has enhanced mechanical properties and low solubility, the manufacturer recommends using it as a restorative liner and base and also in direct and indirect pulp capping techniques inducing secondary dentin bridge and apatite-like precipitate formation for protection of dental pulp complex.[18] In addition, it was recommended as an alternative promising material for pulpotomy of primary teeth instead of MTA.[19]

The most appropriate repair material for primary root perforation therapy remains to be questionable.[9] As an attempt to answer this controversial question and search for an idea effective material for the repair process of furcal perforation in primary molar teeth, this in-vitro study was performed. The present research aimed at evaluating the sealing capability of TheraCal LC material when utilized as a furcation repair material in primary molars, compared to the gold standard MTA biomaterial (NeoPUTTY). The major null hypothesis tested was there would be insignificant difference in the sealing abilities between TheraCal LC and MTA repair materials for the repair process of furcal perforation in primary molars.

MATERIALS AND METHODS

This study followed all guidelines by the Local Research Ethics Committee of the Faculty of Dentistry, Mansoura University, and received approval no. A0701024PP. The following procedures were followed in the study:

1. Teeth selection:

Firstly, based on a previous study by Makhlouf et al.[4], a power analysis test was performed to calculate the sample size. Using G power program 3.1.9.4 based on effect size of 0.98 using 2-tailed test, alpha error = 0.05 and power = 90.0%, the sample size was 45 in total divided into 2 main study groups each with 20 samples, in addition to 5 samples as negative control group. A total of 45 restorable mandibular primary molars were selected. They were selected according to the criteria listed in (Table 1).[11,12] They were collected from Department of Pediatric Dentistry and Dental Public Health, Faculty of Dentistry, Mansoura University after patient written informed consent and receiving permission from the patients and their parents.[1] At cemento-enamel junction (CEJ) level, the buccolingual and mesiodistal dimensions with root lengths of teeth were measured with a digital caliper. The average similarity in size and shape was selected to achieve the least variation.

2. Teeth cleaning, disinfection and storage:

All selected teeth were firstly cleaned as recommended by the 1993 Centers for Disease Control and Prevention (CDC).[20] This entails using

TABLE (1) Criteria for study teeth selection.

Inclusion criteria	Exclusion criteria
1. Freshly extracted molar teeth with sufficient root length for retention in acrylic resin.	1. Molar teeth with previous pulp therapy.
2. The extraction was because of caries, eruption guidance or ectopic eruption of successors, not based on the purpose of the study.	2. Molar teeth with perforation in the furcation area.
3. Molars teeth with homogenous dimensions and morphology.	3. Molar teeth with developmental anomalies.
4. Molars with intact coronal vertical walls at least 2 mm on three sides.	4. Molars with fused, widely-curved roots or the roots had atypical shapes.
5. Molars with intact pulp chamber.	
6. Molars with no visible root caries.	

a brush and soap detergent enzyme, followed by rinsing under water for 60 sec. Any dirt, caries and defect or amalgam restorations were removed using high and low speed burs with water spray. In addition, root scaling was performed to remove any peri-radicular calculus or residues to obtain smooth surfaces. Teeth were properly examined under blue light trans-illumination with magnifying eye loop to assure that teeth are cracks free.[1] Then, all selected teeth underwent disinfection in 1:10 diluted 5.25% sodium hypochlorite (Clorox Bleach, Clorox Co., Egypt) for 7 days. Finally, they were washed under water and stored in normal saline at room temperature during all testing period.[7,11,12]

3. Teeth preparation:

The preparation of all selected natural teeth included horizontal sectioning or amputation in mid-root using diamond disc (SS White Dental, Inc., US). Standard coronal access cavity was prepared for each tooth using low-speed diamond ball bur (MANI INC., Japan) under cooling water. The entire pulp chamber was deroofed using the endo-Z diamond bur (MANI INC., Japan) to create divergent walls. Root canal orifices were located with an endodontic explorer (SIGMA, Pakistan). Molars were rinsed with water and air-dried.[1,12]

Acid etching procedure was done at the canal orifices and at the apex of each root using a 37% phosphoric acid gel (Etch Plus, Dental Plus Co., Egypt) for 15 sec. This was followed by rinsing under running water for 15 sec and air-dried for 5 sec. Then, a thin coat of a light-cured universal adhesive (Clara Bond, ZERODENT, Turkey) was applied in 2 thin layers with a micro brush, air-thinned for 10 sec and light-cured with a LED light-curing unit for 20 sec (Elipar DeepCure-S, 3M ESPE Dental, US). The canal orifices and the apex of each root underwent sealing with a light-cured radiopaque flowable composite resin material (RubyFlow, Inci Dental, Turkey) that was cured for 30 sec using the LED light-curing unit. All the teeth were prepared by the same operator.[1,12]

4. Teeth grouping:

The selected prepared teeth were numbered from 1 ascending to 45. Forty teeth were allocated into two equal groups (n=20) based on the material utilized for proposed furcal perforation repair; Group (1): 20 perforated teeth repaired with premixed MTA material (NeoPUTTY, Avalon Biomed Inc., USA), and Group (2): 20 perforated teeth repaired with a light-cured resin-modified calcium silicate based material (TheraCal LC, Bisco Inc, US). Group (3): included the five remaining molar teeth that served as a negative control group in which no furcal perforation was made.

5. Preparation of perforations:

First, 2 layers of clear nail varnish/polish were applied to the external surfaces of each molar.[7] Then, standardized artificial perforations were prepared in the center of the floor of pulp chamber for each molar tooth of the selected forty teeth, using a round diamond bur size 12 (BR-46, 1DERFUL, Sky Dent Corp., USA) mounted into a high-speed handpiece under cooling water.[12] They were enlarged using a round diamond bur size 16 (BR-40, 1DERFUL, Sky Dent Corp., USA). The final size of the perforation was enlarged by Peeso reamer bur; No. 6 size, 32 mm length, and 1.7 mm tip (Denco Medical Co., Ltd., China) making the perforation diameter equal to that of the bur. All the perforations were prepared by the same operator. For simulation of the periodontal environment, molars were soaked into a wet sponge up to their cervical sections.[21]

6. Furcal perforation repair:

For Group (1), perforations were repaired using the NeoPUTTY MTA material in accordance to manufacturer's guidelines. Adequate amount of this premixed MTA material was placed directly into perforation site and compacted using a hand plugger size 2 (SIGMA, Pakistan). For Group (2), perforations were repaired using TheraCal LC material in accordance to the manufacturer's guidelines. It was injected directly into the perforation area in not more than 1 mm increments and was light-cured for 20 sec. On the completion of repair procedure, the materials were covered with moistened cotton pellets with saline solution. The repaired molars were placed in the incubator (Foc Incubator, Japan) at 37°C for 72 h to allow the material to completely set.[12,18] All procedures were carried out by the same operator under an operating dental loop with 3.5x magnification.

7. Teeth restoration:

The repair materials were firstly tested with a scratch test using a probe/explorer number 23 (SIGMA, Pakistan). Access cavities were filled with a radiopaque nano-hybrid composite resin material (RubyFill, shade A2, Inci Dental, Turkey) following the same bonding procedures (etchant and adhesive application) mentioned earlier during flowable composite application at the canal orifices and at the apical ends of all roots.[8] This procedure included the negative control group in which no furcal perforation was made.

8. Microleakage testing:

1. Teeth dye immersion:

A special container (Qlux Ideas, Turkey) was used for support while teeth being dipped in the dye solution. Teeth were covered with a layer of nail varnish/polish then were held from their cervical parts with a wax sheet to avoid complete immersion into the dye. Only roots were immersed in a 1% methylene blue dye solution for 72 h at room temperature up to their cervical sections. This was followed by rinsing for 10 min with water, then dried for 24 hours.[8]

2. Teeth marking:

Using a thin water-proof marker pen (0.7 mm), 2 straight lines were drawn from the center of the furcal perforation on the mesiodistal sides of each molar. The junction of lines at the occlusal level produced a landmark to locate the median line at which the tooth was cut into 2 halves.

3. Teeth mounting:

To stabilize the teeth and facilitate handling during sectioning process, specimens were mounted into acrylic resin blocks. Each molar tooth was embedded vertically along its long axis within pink acrylic resin block. The selected teeth were mounted individually in a cylindrical plastic ring filled with self-curing acrylic resin material utilizing a 1-arm dental laboratory parallelometer device (Surveyor B2, Bio-Art Co., Brazil). This type of surveyor was utilized to allow appropriate centralization and alignment of each restored tooth in the ring (16 mm internal length and 20 mm internal diameter) during blocks fabrication.

To represent the alveolar bone surrounding the tooth, a flowable soft mixture of pink, self-curing acrylic resin (Acrostone cold cure denture base material, Acrostone Co., Egypt) was used. The tooth was secured in this position until the acrylic resin was fully-polymerized. After complete setting of the acrylic resin material, the blocks were removed from the ring and the teeth were cleaned, polished and stored until testing time. All the steps were performed by the same operator.

4. Teeth sectioning:

Through the marked median line, the mounted teeth underwent mesiodistal sectioning in a vertical direction (parallel to the tooth's long axis) with a diamond linear precision saw blade mounted in a water-cooled, low-speed (1500 rpm with 25 mm/min feed rate) sectioning machine (Pico155, PACE Technologies, USA). The block was fixed firmly in its precise position through a suitable holder.

5. Microleakage assessment:

After the sectioning process completed, the dye penetration test was utilized for both Groups (1) and (2) to estimate the maximum linear dye penetration distance along the dentinal walls. Both mesial and distal measurements were recorded. The extent and degree of microleakage was further evaluated with a calibrated stereomicroscope (SZ61TR, Model SZ2-ILST, Olympus Co., Japan) up to 20x magnification evaluating the level of dye penetration.[8] Considering Group (3) specimens, after composite resin restoration, dye immersion, and sectioning, only photographs were taken and documented for each specimen.

For a highly-defined assessment and measurement of the maximum and minimum gaps between the repair material and the tooth structure, Scanning Electron Microscopy (SEM) was used. Clean dry specimens were sputter-coated with a layer of gold (30 nm-thick) for 3 min at 40 mA with the aid of a Sputter Coating Evaporator (SPI Module-Sputter Gold/Carbon Coater, SPI Supplies, Structure Probe, Inc., USA). The specimens were then subjected into a SEM (JSM-6510LV, JEOL Ltd., Japan) up to 300000x magnification. The SEM mages were transported to the computer and the gap was measured in microns utilizing a special software.[22]

9. Statistical analysis:

Data were analyzed by IBM SPSS (Statistical Package for Social Sciences) statistical software (V 20, IBM Co., USA). Normality tests, including the Shapiro-Wilk and Kolmogorov-Smirnov tests, revealed that data regarding dye penetration followed a normal distribution. Accordingly, the mean ± standard deviation of the averages of dye penetration distances at mesial and distal walls of perforation site were calculated for each group and compared at 0.05 level of significance using ANOVA and Tukey's multiple comparison post Hoc tests. The data regarding gap width at the dentin/material interface represented abnormal distribution. Thus, independent samples Mann-Whitney test was utilized to compare the mean ± standard deviation between the NeoPutty and TheraCal LC groups at $p \leq 0.05$ level of significance.

RESULTS

(A) Assessment of dye penetration extent along dentinal walls using stereomicroscopy:

Representative stereomicroscopic images (up to 20x magnification) for assessment of the extent of dye penetration along dentinal walls are illustrated in (Figure 1A) for Group (1) specimens that were repaired with NeoPUTTY MTA material and (Figure 1B) for Group (2) specimens that were repaired using TheraCal LC material. It was found that the mean values of dye penetration extent along dentinal walls were 1.30±0.32 mm, 1.80±0.32mm, and 0.11±0.07 mm for group 1, group 2 and group 3, respectively. The highest mean value of dye penetration was recorded for perforated primary molar teeth repaired with TheraCal LC material,

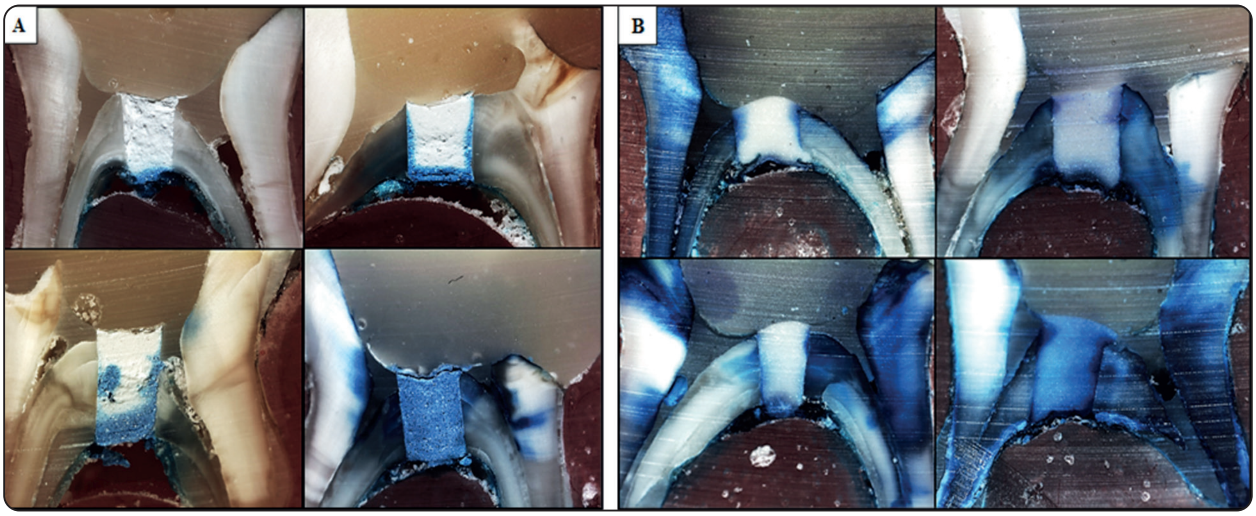

Fig. (1) Representative stereomicroscopic images for assessment of dye penetration extent; (A) for group (1) specimens and (B) for group (2) specimens.

TABLE (2) Descriptive statistics (Mean ± SD) and One-way ANOVA test for comparison of dye penetration extent in millimeters (mm) among tested groups.

	Group			P-value
	(1) NeoPUTTY	**(2) TheraCal LC**	**(3) Control**	
Dye penetration extent (Mean ± SD)	1.30 ± 0.32[a]	1.80 ± 0.32[b]	0.11 ± 0.07[c]	P=0.000*

- *significance at p-value ≤ 0.05. - SD: Standard Deviation. - Mean values (± SD) with different superscripted letters represent significant difference.

whereas the lowest mean value was measured for negative control morals in which no furcal perforation was made. One-way ANOVA test showed that there was a significant difference between tested groups in terms of mean values of dye penetration extent (p=0.000). (Table 2)

Tukey's post Hoc test was utilized for pairwise comparison of dye penetration extent values among tested groups. It showed that there were significant differences among all studied groups. In other words, a significant difference was found among the mean values for both repair materials used and between each of them with the negative control morals. As a result, the NeoPUTTY MTA material had a significantly positive influence on the sealing ability when utilized as a furcation repair material in primary molar teeth. (Table 2)

(B) Assessment of microleakage gap width between the repair material and the tooth structure using SEM:

Representative SEM images (up to 1000x magnification) for assessment of the maximum and minimum gaps between the repair material and the tooth structure after 1, 2, and 3 days of dye immersion are illustrated in (Figure 2) for Group (1) specimens that were repaired with NeoPUTTY MTA material and for Group (2) specimens that were repaired using TheraCal LC material. It was found that the mean values of microleakage gap

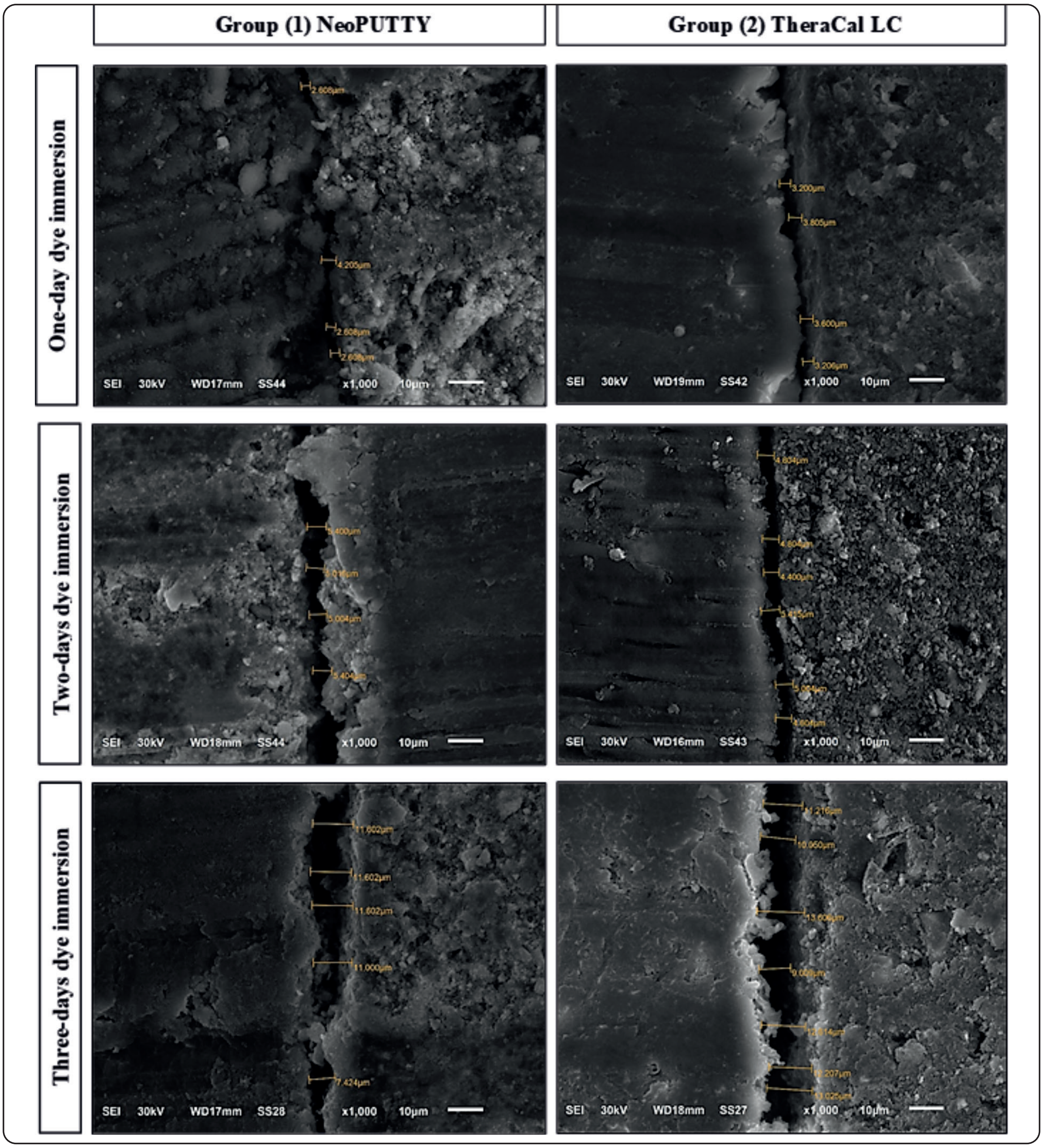

Fig. (2) Representative SEM images (1000x) for assessment of microleakage gap width between both studied repair materials and the tooth structure after 1, 2, and 3 days of dye immersion.

width at the dentin/repair material interface for both tested groups were 7.40±6.90 μ for group (1) and 7.96±6.22 μ for group (2). This means the highest mean value of microleakage gap width was recorded for perforated primary molars repaired using TheraCal LC material, while the lowest mean value was found when perforated primary molars repaired using NeoPUTTY MTA material. Mann-Whitney test revealed a non-significant difference between tested groups regarding mean values of microleakage gap width (p=0.134). (Table 3)

TABLE (3) Descriptive statistics (Mean ± SD) and Mann-Whitney test for comparison of microleakage gap width in microns (μ) among tested groups.

	Group		**P-value**
	(1) NeoPUTTY	**(2) TheraCal LC**	
Gap width (Mean ± SD)	7.40 ± 6.90	7.96 ± 6.22	P=0.134

*- *significance at p-value ≤ 0.05. - SD: Standard Deviation.*

DISCUSSION

The major null hypothesis tested was there would be insignificant difference in the sealing abilities between TheraCal LC and MTA repair materials for the repair process of furcal perforation in primary molars. No significant difference was found between tested groups regarding the mean values of microleakage gap width (p=0.134). However, a significant difference existed between tested groups regarding the mean values of dye penetration extent along dentinal walls (p=0.000). Therefore, the tested hypothesis was rejected.

In our study, we used the premixed TheraCal LC material to overcome some of the drawbacks of MTA material. TheraCal LC is a recently introduced regenerative material with better handling and inductive properties and regenerative capacity.[23,24] It is available in the form of ready to use paste in a single syringe. It can be used easily because of its efficient syringe placement and its easy light-curing with hand mixing; instrument placement or trituration is not needed.[16,18,25] On the other hand, NeoPUTTY product was selected for this in-vitro study representing a novel premixed calcium silicate-based cement version of the NeoMTA Plus material with the same ready-to-use syringe form.[26,27]

The effective hermetic seal between the root canal and the periodontal ligament is an essential requirement for successful repair of furcal perforation. This sealing process is complex and is dependent upon several properties of the material used for repair including marginal adaptation, adhesion, solubility, and changes in material volume.[22] For this reason, we compared both the dye penetration extent along dentinal walls using stereomicroscopy and the microleakage gap width between the repair material and the tooth structure using Scanning Electron Microscopy (SEM). The gap size between dentin and the repair material, along with fluid leakage, provides a quantitative measurement of sealing efficacy of repair material. Marginal adaptation of the repair material assessed with SEM may thus provide information about the materials' sealing capability.[18,22]

In this study, the final size of the furcal perforation was enlarged by Peeso reamer bur; No. 6 size, 32 mm length, and 1.7 mm tip making the perforation diameter equal to that of the bur. The perforation size did not appear to affect the success rate.[1] It was assumed that furcal perforation size as an independent variable might not affect the success rate after the development of MTA and its application in repairing all perforation types because of its enhanced healing power.[28]

Research demonstrated that calcium silicate cements require sufficient moisture for 72 h to be ideally set to decrease the displacement during restoration and provide low solubility and enhance sealing capability. Therefore, in our study the specimens were covered with a wet cotton pellet and were kept untouched for 72 h.[4,84]

Many methods have been used to evaluate the leakage resistance and sealing properties of a repair material.[1] In this study, the roots of the primary molar teeth underwent immersion in a 1% methylene blue dye solution for 72 h up to their cervical sections. Dye penetration method remains the simplest and most cost-effective test to detect microleakage and sealing properties of restorative materials.[30] Also, the 1% methylene blue dye solution was commonly used as it enables a quantitative measurement of the penetration area through linear measurement means.[31] According to ISO standards, the solubility property is evaluated after 24 h, however longer analysis periods might be required.[18,32]

In our study, molar roots were immersed into methylene blue dye solution up to their cervical sections to exclude the possibility of dye leakage from their coronal portions. We assessed the dye migration from the outward entourage of the tooth, inwards, towards the pulp chamber and solely at the furcal level. In contrast, full immersion of teeth in methylene blue solution would put in question the seal strength of the coronal restoration, and thus another path of leak would affect the results.[4] Patel et al.[33] showed that micro-infiltration was more probable with MTA from the pulp chamber outward into the tooth entourage.

A diamond linear precision saw blade mounted in a water-cooled, low-speed sectioning machine was used in this research to provide a high-precision sectioning. So, cuts were created without destroying the composition, surface, and structure of specimens. During the sectioning process, the loss in the cut material did not exceed 0.25 mm, without deformation, stress or compression.[4,34]

It was found that the mean values of stereomicroscopic dye penetration extent along dentinal walls were 1.30 ± 0.32 mm for NeoPUTTY-repaired group, 1.80 ± 0.32 mm for TheraCal LC-repaired group, and 0.11 ± 0.07 mm for the negative control group in which no furcal perforation was made. Consequently, the NeoPUTTY MTA material proved that it had a significantly positive influence on the sealing ability when utilized as a furcation repair material in primary molar teeth.

Indeed, the direct comparison of our laboratory results to previously published studies was challenging. There is scarce data about the utilization of MTA as a repair material for furcal perforation in primary molar teeth. Most of studies were confined to permanent teeth that have been of much concern.[1] Besides, there are no, or rather the authors are unaware of, data available regarding the application of TheraCal LC material for primary tooth perforation repair.

Our findings could be expressed in compliance partially with the results of Alazrag et al.[18] who assessed the marginal adaptation and solubility of TheraCal LC versus MTA and Biodentine when utilized to repair the furcal perforation. TheraCal LC demonstrated the highest frequency distribution of gap presence followed by MTA similar to our readings. However, they found that the least soluble material after 7 days was TheraCal LC followed by MTA which is not compatible with our results. They concluded the superiority of the MTA over TheraCal LC in furcal perforation repair because of the low marginal adaptation of TheraCal LC.

Our results are correlated with Kamal et al.[35] study which evaluated the sealing capability of MTA as a repair material for furcal perforation using ultraviolet (UV) spectrophotometric analysis. MTA material showed the least dye absorbance values with superior sealing capability as compared to other materials. Also, Khatri and Shekh,[36] concluded that the sealing capability of MTA biomaterial was better.

Our study found that NeoPUTTY novel MTA material had a greater sealing capability compared to TheraCal LC material. This result disagrees with a previous study that assessed the sealing capability of TheraCal LC and MTA with Biodentine. TheraCal

LC exhibited lower values of solubility and less microleakage compared to other materials.[37] Also, our results disagree with Makkar et al.[38] who reported that TheraCal LC exhibited less interfacial microleakage and superior sealing capability as compared with MTA and Biodentine.

Several studies demonstrated the biocompatibility and sealing capability of MTA as a repair material. MTA's cementogenic property is related to its capability of releasing a large amount of Ca^{+2}, which interact with phosphate groups in the surrounding tissue fluid forming hydroxyapatite on the surface.[22] According to manufacturer, NeoPUTTY is a premixed calcium silicate-based material induces the formation of hydroxyapatite onto the surface and achieves a biologic seal. It might thus function as a scaffold to enhance dentin formation. It absorbs dentinal fluids, releasing Ca^{+2} and hydroxide ions with apatite formation on the undersurface of MTA, enhancing its sealing capability.[22]

The materials placed in the furcation should have sufficient flow to fill and seal the perforations. The improved sealing ability of MTA-based materials can be attributed to the material's flow, which enables rapid application and complete filling of defect.[39] Additionally, the small size of NeoPUTTY particles, which accelerates adaptation at the cavity surface and filling interface, may clarify why NeoPUTTY has a superior adaption compared to TheraCal LC.[18] The smaller size particles allow NeoPUTTY to penetrate dentinal tubules, bond to dentin and form tag-like structures and increase the sealing efficacy.[8]

It was stated that MTA-based materials have demonstrated high success rates after using as a repair material for furcal perforation. This might be because of proper setting time which decreases material shrinkage after setting. Also, the sealing capability of MTA is not affected by wet environment as it is mainly composed of thin hydrophilic particles.[8] According to Shivakumar et al.,[39] the improved sealing ability may be attributed to addition of setting accelerators and plasticizers in the composition of the perforation repair material and thus shortening of the setting time.

A possible explanation for the higher level of dye penetration and poor marginal adaptation of light-cured TheraCal material is the expected problem of polymerization shrinkage encountered with its use due to presence of resin matrix and thereby causing bond failure.[8,16,18] In addition, the water sorption and porosity factors related to TheraCal material can play a role in the resulted higher value of dye penetration recorded for perforated primary molar teeth repaired with this TheraCal LC material compared to NeoPUTTY-repaired teeth.[40] The porosity of the sealing surface and the pore volume in the set TheraCal material could be higher than those of MTA material. This may explain the reason for its poor sealing efficacy.[39]

Conflicting results among different studied have to be carefully considered because of differences in designs, methodologies, material utilized, size of furcal perforation, tooth type, location, and follow-up period.[41] In addition, extrusion of repair material into the surrounding area might negatively affect the outcome of furcal perforation repair. Artificial materials like calcium sulfate have been utilized as a barrier to prevent such material extrusion, however, the use of barriers did not improve the outcome.[41,42]

One limitation of our study is that tooth sectioning through the perforation site might have caused cracks, fissures and also caused material drag to appear which may affect the apparent marginal adaptation of repair materials examined by SEM. However, this methodology has been frequently used in several studies that tested the sealing capability via assessing the marginal adaptation of the repair material.[22] Alternate methodologies for testing the sealing ability such as bacterial leakage model, protein leakage, computerized fluid filtration assessment, electro-chemical method, radioisotope method, metal solution tracer, reverse diffusion method, and 3D methods might be utilized for future assessment.[22,43]

Materials with novel compositions have to be thoroughly assessed before its clinical use.[22] In addition, as the results of this in-vitro study may not reflect the full clinical potential of the materials utilized for sealing the perforation defects, we suggest future in-vivo studies to assess the sealing efficacy of repair materials.[13] To determine its biologic and clinical efficacy, further researches on biocompatibility, solubility, Ca^{+2} release properties, and remineralizing potential are required. Before tested materials can be employed as a perforation repair material, more studies are required.[22]

CONCLUSIONS

Considering the conditions and outcomes of this study, the following conclusions were reached:

1. NeoPUTTY MTA material has a significantly positive influence on the sealing ability when utilized as a furcation repair material in primary molar teeth.
2. Compared to NeoPUTTY, TheraCal LC material has higher values of solubility with increased dye penetration extent and lower values of marginal adaptation with increased microleakage gap width.
3. TheraCal LC material is incapable of alternating the MTA for furcal perforation repair in primary molars because of its low sealing ability.

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