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A Comparative Evaluation of Sealing Ability and Diametral Tensile Strength of two Pulp Capping Materials " Sodium Hexa Meta Phosphate SHMP and Mineral Trioxide Aggregate MTA": An *in Vitro* Study

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ABSTRACT

Background: Indirect pulp capping is a preventative procedure that keeps the pulp alive by sealing the remaining damaged dentin with a bioactive substance. Mineral trioxide aggregate (MTA) is frequently utilised, however, its limitations have prompted the development of alternative materials such as sodium hexametaphosphate (SHMP). **Aim of the study:** To investigate and compare the sealing ability and diametral tensile strength (DTS) of SHMP and MTA as indirect pulp capping materials. **Materials and Methods:** Sealing ability was evaluated using methylene blue dye penetration and stereomicroscope in 24 extracted human permanent premolars (n=12/group). DTS was assessed using 20 disc-shaped specimens (n=10/group) with a universal testing machine. Statistical analysis was carried out with the Mann-Whitney U test ($p < 0.05$). **Results:** SHMP demonstrated significantly better sealing ability than MTA, with lower dye penetration scores (0.83 ± 1.11 vs. 2.75 ± 0.87; $p = 0.0003$). SHMP also showed significantly higher DTS than MTA (1.171 ± 0.217 MPa vs. 0.736 ± 0.309 MPa; $p = 0.0109$). **Conclusion:** Given the constraints of this in vitro investigation, SHMP exhibited enhanced sealing capability and diametral tensile strength relative to MTA, indicating its potential as an advantageous pulp capping substance.

Keywords: Sodium hexametaphosphate, mineral trioxide aggregate, Indirect pulp capping, Sealing ability, diametral tensile strength.

1. Introduction

Vital pulp treatment is a preventative procedure for teeth that have pulp tissue destruction due to deep dental caries, trauma, or an insufficient restoration. It is now recommended to eliminate caries selectively rather than totally. For teeth with no irreparable pulpitis or infections reaching the dental pulp, pulp capping should always be the first line of therapy (Kaur *et al.,* 2024).

An indirect pulp capping is a necessary pulp therapeutic technique that removes only infected dentin, leaving a thin covering of impacted dentin. Total elimination of damaged dentin may result in the pulp being exposed. The cavity base is lined with an appropriate capping substance in order to entirely seal versus microscopic leakage and to provide full lesion sterilisation and tissue regeneration (Selvendran *et al.,* 2022).

Several pulp capping agents have been used to promote healing and dentine regeneration. Inadequate PC material adaption and adherence to dentin results in voids and liquid fluctuations in dentinal tubular structure, which induce postoperative discomfort and pain. PC can be created from a

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number of ingredients, including calcium hydroxide (CH), tricalcium silica-based substances, and glass ionomer cement (Karadas *et al*., 2020).

Mineral trioxide aggregate (MTA) is biologically active, biocompatible, and antimicrobial substance known for its durability and sealing capabilities. It is frequently employed as a dressing material in pulp capping techniques. However, a number of drawbacks were revealed, including increased setting time, handling-related qualities, and enamel discolouration, making usage of this material is challenging. As a result, investigators continue to face the difficulty of finding a capping material with superior qualities (Khairy *et al*., 2026).

Sodium hexametaphosphate (SHMP) considered as a promising inorganic polyphosphate alternative. Poly(P) polymers are linear polymers present in a variety of bodily cells. They are composed of orthophosphate (Pi) residues joined together by extraordinarily energetic bonds. Poly(P) is essential for the proliferation and development of osteoblast as evidenced by its osteoinductive cellular activity and osseous calcifying activity. It also stimulates the maturation of human gingival fibroblast cells. SHMP stimulates development, differentiation, and reproductive potential in human dental pulp cells (HDPCs). As a result, it is a suitable option for pulp capping (Mohamed *et al*., 2025).

Microleakage is a leading reason for failure in IPT compounds. It is associated with the constituent's adaptability to cavity walls. This affects its capacity to permanently coat the cavity and shield it from liquids and microorganisms. The infiltration of dyes into sections of the dental structure is the most commonly adopted procedure for identifying microleakage (Patel *et al*., 2024).

Tensile strength is the amount of force necessary to break a material when two opposing forces are directed in the same straight line. Diametral tensile strength assessment was designed to investigate brittle materials with little to no plastic deformation. The primary benefit of diametral tensile strength analysis is that it provides information on the degree of resistance to fracture of restorative materials in clinical practice (Al-Shekhli *and* Al Aubi, 2018).

Until currently present, minimal in vitro investigation has been performed to determine both the sealing ability and mechanical features of SHMP as a pulp-capped substrate. Accordingly, the current study is intended to investigate the sealing ability and diametral tensile strength of SHMP and MTA·

Null hypothesis (H_o) of the present investigation suggested that no statistically significant difference is present among SHMP and MTA as pulp capping materials regarding sealing ability and diametral tensile strength.

2. Materials and Methods

The Ethics Committee of the Minia University Faculty of Dentistry gave its approval to the current investigation "approval number (1030/2025)". Informed consent was obtained from the patients proving their acceptance that their extracted teeth were used for research purposes.

A power analysis was carried out to provide adequate power for two-sided statistical tests examining differences between MTA and SHMP groups regarding dye penetration in permanent premolars and diametral tensile strength. Using an estimated effect size (d) of 0.5, an alpha (α) level of 0.05, and a beta (β) level of 0.20 (80% power), the required sample size was determined to be: 24 samples for dye Penetration Test (12 per group) and 20 samples for diametral Tensile Strength Test (10 per group). Calculations were performed using R software with the pwr package. Allocating separate samples for each test accommodates the destructive nature of certain assessments and ensures reliable data collection.

2.1. Sealing Ability test:

This in vitro study was conducted on extracted permanent premolar teeth that were collected from the outpatient clinic of Minia University Dental Hospital (MUDH). A total of 24 extracted human permanent premolar teeth with intact crowns with no caries or cracks, planned for extraction for orthodontic purpose were used (n=12). Surface debridement was done using ultrasonic scalers (Maxpiezo 6+ Guilin Refine Co, Ltd, China), and until they were needed, they were stored at room temperature in distilled water.

Cavity preparations were performed according to Patel *et al.* (2024)· A Class I cavity was prepared, ensuring that its width did not exceed one-fourth of the intercuspal distance. The cavity depth extended 0.5–1 mm apical to the dentinoenamel junction (DEJ). A diamond round bur (Stardent Equipment Co. Limited, China) attached to a high-speed hand piece (Dentsply Sirona ,North Carolina, U.S) with coolant was used .Cavity standardization was done using rubber base index. (Zetaplus, Zhermack SpA, Italy)

The two tested components were handled according to the manufacturers' recommendations and immediately introduced into the prepared cavities. They were applied at a thickness of 1.5 mm. Following the material's original set the cavities were filled with composite. After that, each sample received two coats of nail polish, on all exposed surfaces of the crown except the restoration and 1 mm from the margins of the restoration. The tooth's apex was sealed using sticky wax (Cavex set up Regular, Holland BV, The Netherlands).

Then, A 5% methylene blue dye (Oxford Lab Fine Chem LLP, Maharashtra, India) was used to soak the teeth, then, they were kept in an incubator (Biotech Company, Egypt) at 37±1°C for 24 hours, After the storage period, teeth were rinsed for 30 seconds under running water. The teeth were sectioned longitudinally in a mesiodistal direction into two halves using a diamond disc (AZDENT, Zhengzhou, China) mounted on a high-speed handpiece under water cooling. One half of each tooth was examined by a stereomicroscope (Olympus, Tokyo, Japan) with (20x ,25x,40x ,45x) magnification, to determine the extent of dye diffusion.

The portion of the sectioned tooth with the highest microleakage was given a score. According to the International Standards Organization rules (ISO), the degree of microleakage utilising dye penetration was assessed on a four-grade scale.

0 = no dye penetration.

1 = Dye penetrated into the enamel portion of the cavity wall.

2 = Dye penetrated into the cavity wall's dentin, but not the pulpal floor.

3 = dye penetration, which involves the pulpal floor of the cavity (ISO), 2003. [8]

2.2. Disposal of teeth

After completion of the study, the teeth were disposed via a medical waste disposal company.

2.3. Diametral Tensile Strength test

Disk-shaped samples (6 mm × 3 mm) were prepared in split metallic molds for diametral tensile strength determination.

Each ingredient was combined per the manufacturer's recommendation and packed in the moulds within a couple of minutes after mixing. The filled molds were then positioned between two glass plates and subjected to gentle pressure to ensure complete filling and specimen uniformity.

The molds were preserved in an incubator (Biotech Company, Egypt) at 37±1°C and 100% humidity until final setting. Following that, the molded specimens were carefully separated from the molds and evaluated for any defects or edge chipping. Thus, only specimens without any evident faults were chosen for evaluation.

Individual specimens were transferred to a universal testing machine (Instron Industrial Products, Norwood, USA) and pressed diametrically with a load of 5 KN. A compressive load was applied at a crosshead speed of 1 mm/min until specimen fracture occurred. Only specimens that fractured into two equal halves were included, whereas unequally fractured specimens were excluded. The diametral tensile strength (MPa) was calculated using the following equation:

2.4. Diametral tensile strength = 2P / πDt

Where P is the maximum applied load (N), D is the specimen diameter (mm), and t is the specimen thickness (mm).

2.5. Statistical analysis

Statistical analyses were conducted using R software (version 4.4.0). Continuous data were reported as mean ± SD and minimum–maximum values. Ordinal data were presented using descriptive statistics and distributions of frequencies. The normality was tested using the Shapiro-Wilk test. Differences between groups were analyzed using the Mann–Whitney U (Wilcoxon rank-sum) test. A p-value < 0.05 was considered statistically significant.

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3. Results

3.1. Sealing Ability \Dye Penetration test:

Sodium hexametaphosphate (SHMP) demonstrated substantially lower dye penetration scores than mineral trioxide aggregate (MTA). The mean dye penetration score was (0.83 ± 1.11) in the SHMP group compared with (2.75 ± 0.87) in the MTA group. The Mann-Whitney U test / Wilcoxon rank-sum test revealed a statistically significant variation in dye penetration ratings (W = 130, p = 0.0003), confirming that SHMP exhibited significantly better sealing ability than MTA.

Table 1: Dye Penetration Scores of SHMP and MTA.

Material		Mean ± SD	Min–Max	p-value
Mineral Trioxide Aggregate (MTA)	12	2.75 ± 0.87	0–3	0.0003*
Sodium Hexa metaphosphate (SHMP)	12	0.83 ± 1.11	0–3	

SD = standard deviation, p-value=probability of value,
*statistical significant difference where p-value < 0.05 .

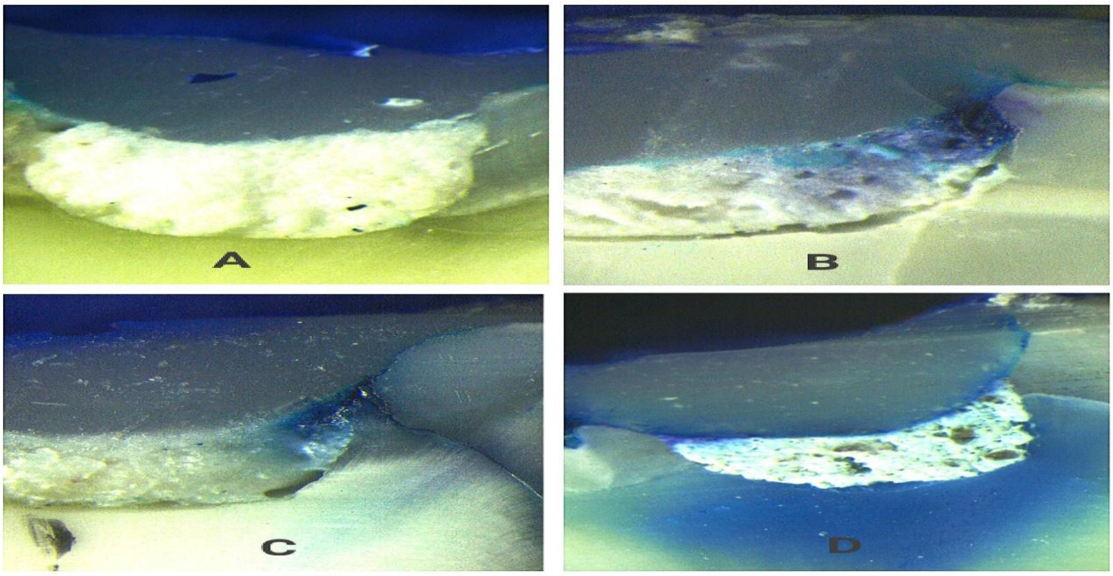

Fig. 1: Dye penetration scores

A= Score 0, no dye penetration
B= Score 1, dye penetrated into enamel only
C= Score 2, dye penetrated into dentin without reaching the pulpal floor
D= Score 3, dye penetration involving the pulpal floor.

3.2. Diametral Tensile Strength test

SHMP demonstrated higher DTS values (1.171 ± 0.217 MPa) compared with MTA (0.736 ± 0.309 MPa). The mean difference in DTS between SHMP and MTA was 0.435 MPa, with a 95% confidence interval of 0.182 to 0.688 MPa. Normality assessment using the Shapiro–Wilk test showed non-normal distribution in the MTA group (p = 0.026), while the SHMP group showed borderline normality (p = 0.051). Therefore, the Mann–Whitney U test / Wilcoxon rank-sum test was performed to compare the groups. The variance was statistically significant (W = 16, p = 0.0109), indicating that SHMP had significantly higher DTS than MTA.

Table 2: Diametral Tensile Strength of SHMP and MTA.

Material	n	Mean ± SD (MPa)	Mean difference, 95% CI	p-value
(MTA)	10	0.736 ± 0.309	Reference	**0.0109** *
(SHMP)	10	1.171 ± 0.217	0.435 (0.182–0.688)	

DTS in MPa, SD =standard deviation, p-value=probability of value ,CI= confidence interval
*statistical significant difference where p-value < 0.05

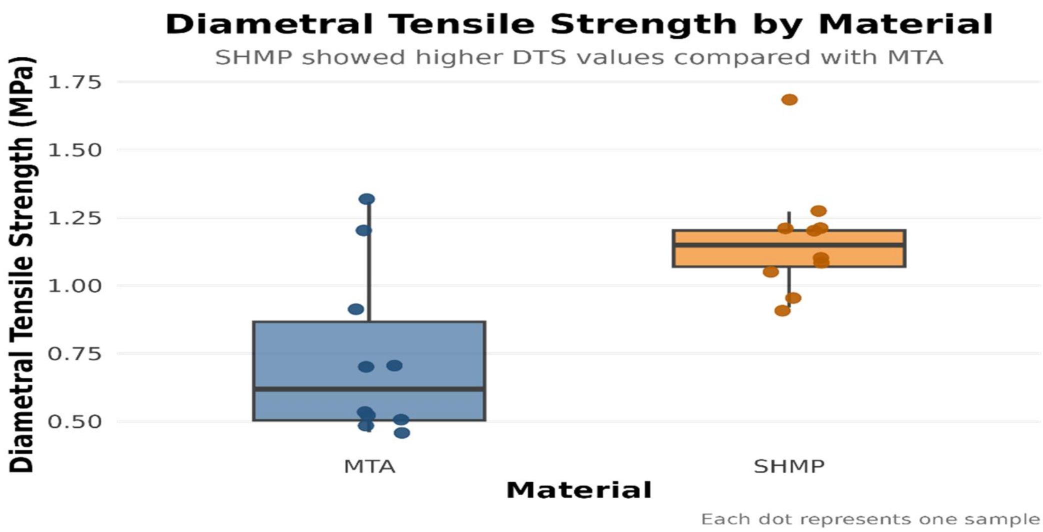

Fig. 2: PLOT BOX shows Diametral Tensile Strength Distribution by Material.

4. Discussion

Pulp capping material is a crucial aspect in determining treatment success. The optimum pulp capping ingredient needs to keep pulp integrity and encourage dentin replacement. They must be capable of providing an optimum seal, reducing microleakage, releasing fluoride, and bonding to dental tissues and restorative substances. They must have minimal solubility, dimensional stability, antimicrobial characteristics, radiopacity, and adequate strength (Motwani *et al*., 2021)**.**

In the current investigation, novel pulp capping material was used. Sodium hexametaphosphate (SHMP) is a promising substitute of non-organic polyphosphates (PP) (Mohamed *et al*., 2025). SHMP was compared to MTA a bioactive, biologically compatible, and anti-microbial substance noted for its durability and sealing qualities. It is frequently utilised as a preservative agent used in pulp capping processes (Khairy *et al*., 2026).

The current in vitro study examined the sealing ability and diametral tensile strength of SHMP and MTA. Sealing ability was determined using the methylene blue dye penetration technique and stereomicroscopic evaluation.

Many dyes can detect microleakage, but methylene blue has proven to be particularly effective. It's a hydrophilic compound with a positive charge. Methylene blue dye is mostly employed for its simplicity of manipulation, low cost, and small molecular weight. It easily penetrates through gram-positive and gram-negative bacterial membranes, offering good and early indication of the non-sealed margins that would allow microleakage and perhaps cause failure (Bajabaa *et al*., 2021).

Null hypothesis of the current investigation was refused since the difference was statistically significant among mineral trioxide aggregate and sodium hexametaphosphate in the sealing ability and diametral tensile strength.

The results of the sealing ability test revealed that SHMP exhibited significantly superior sealing performance than MTA. Comparison between groups using the Mann–Whitney U test / Wilcoxon rank-sum test demonstrated a statistically significant variance in dye penetration scores (W = 130, p = 0.0003).

The biological properties of SHMP may account for its improved sealing ability and much decreased microleakage when compared to MTA. According to Mohamed *et al*. (2025), SHMP has been proven to stimulate dentin regeneration and promote the creation of a more organized dentin bridges with thicker predentin and odontoblastic layers. SHMP produced a better dentin bridge than that of MTA(Mohamed *et al*., 2025).

Furthermore, as reported by Seffahi *et al.* (2026), SHMP serves as a negative-charged polyphosphate compound that can participate in calcium phosphate mineralization and assist biomineralization processes. It is expected to have an intense attraction for hydroxyapatite molecules via many binding points. After being adsorbed, it can form stable structures with calcium (Ca2+), magnesium (Mg2+), potassium (K+), aluminium (Al3+), ferric (Fe3+) ions, and sodium ions (Na+), contributing to the formation of a reticular interfacial layer that limits acid diffusion while allowing remineralizing ions to diffuse inward.

The microleakage results of MTA in the current study were comparable with no significant difference to previous studies (Sneha *et al*., 2022 ; Koç, *et al*., 2021) which compared microleakage of mineral trioxide aggregate with other materials. On the other hand, Kamal *et al*. (2022) ; Karade *et al*. (2025) and Şachir *et al*. (2025) compared microleakage of MTA with some other materials recording results statistically different from this study, that may be attributed to many causes like using several methodological factors as differences in cavity preparation, including the size, depth, and configuration of the prepared cavities, differences in the experimental protocols, including the type and concentration of the dye, immersion time and the method used for microleakage assessment. Also, using different types of MTA and different consistency. There is little information about sealing ability of SHMP in previous studies.

The results of the diametral tensile strength test showed that SHMP had significantly higher DTS than MTA. The variation was statistically significant ($W = 16$, $p = 0.0109$) . Higher diametral tensile strength (DTS) observed for SHMP compared with MTA may be attributed to improved mechanical properties as reported by Franzin *et al*. (2022) Phosphate-based pulp capping materials have been shown to offer better mechanical qualities due to their microstructure. In particular, smaller phosphate particles provide a denser and more uniform microstructure, which improves mechanical performance.

Furthermore, as mentioned by Seffahi *et al.* (2026); Mohamed *et al.* (2025), Sodium hexametaphosphate (SHMP) has a high affinity for calcium ions and can serve as a nucleation template for calcium-phosphate deposition, encouraging the formation of denser and more ordered mineralised structures. Therefore, SHMP's potential for mineralisation could lead to improved physicochemical properties.

Diametral tensile strength results of MTA in the current study were comparable with no significant difference to Huang *et al.* (2008). However, Pintado *et al.* (2018); Mariyam *et al.* (2024) and Suganthakumar *et al.* (2025) assessed the diametral tensile strength of MTA with a few different materials and recorded results that were statistically different from this study. These differences may be attributed to variations in specimen dimensions, material composition, powder-to-liquid ratio, storage conditions (temperature, humidity, and storage medium), as well as variations in the testing protocol, including the crosshead speed of the universal testing machine and specimen preparation techniques. Few studies have investigated the diametral tensile strength of SHMP**.**

Limitations of the current study include: (1) This in vitro investigation was unable to properly imitate the clinical oral environment. (2)Only sealing ability and diametral tensile strength were evaluated; other physicochemical and biological properties were not investigated, (3) The only approach used to measure sealing performance was the methylene blue dye penetrating technique.

5. Conclusion

Within the constraints of this in vitro investigation, sodium hexametaphosphate (SHMP) demonstrated better sealing ability and diametral tensile strength than mineral trioxide aggregate (MTA), indicating its promise as a pulp capping material.

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