

Comparative Evaluation of The Effect of Nano-Hydroxyapatite Incorporation on Water Sorption, Water Solubility, And Compressive Strength of Type I Glass Ionomer Cement and Resin Luting Cement: An In Vitro Study

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ABSTRACT: The study evaluated the effect of nano-hydroxyapatite (nano-HAp) incorporation on water sorption, water solubility, and compressive strength of Type I glass ionomer cement (GIC) and resin luting cement. Four groups were evaluated: GIC control, GIC with 10% nano-HAp, resin cement control, and resin cement with 2% nano-HAp. Water sorption, solubility, and compressive strength were assessed using standardized procedures. Nano-HAp incorporation reduced water sorption and solubility and increased compressive strength in both materials ($p < 0.05$). Resin cement demonstrated lower sorption and solubility and higher compressive strength than GIC. Within study limitations, nano-HAp showed favorable effects on the tested properties.

KEYWORDS: Nano-hydroxyapatite; Type I glass ionomer cement; Resin luting cement; Water sorption; Water solubility; Compressive strength; Dental luting materials; Nanoparticles.

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I. INTRODUCTION

Dental luting cements are essential materials in prosthodontics and are primarily used for the fixation of indirect restorations. Their clinical performance depends on adequate mechanical strength, adhesion, dimensional stability, resistance to dissolution, and compatibility with the oral environment. Continuous exposure to saliva and oral fluids can influence the physical and mechanical properties of these materials through water sorption, solubility, and degradation. Therefore, development of luting cements with improved mechanical and physicochemical properties remains an important area of research.

Glass ionomer cement (GIC) is widely used as a luting material because of its chemical adhesion to tooth structure, fluoride release, biocompatibility, and relatively simple manipulation. However, conventional GIC has limitations such as comparatively low mechanical strength and susceptibility to moisture-related degradation. These limitations have encouraged the incorporation of reinforcing and bioactive fillers into GIC to improve its performance.¹

Hydroxyapatite (HA) is a calcium phosphate biomaterial that closely resembles the inorganic mineral component of natural bone and teeth. Its biocompatibility, bioactivity, and potential to promote mineralization

make it attractive for dental applications. When incorporated in nanoscale form, hydroxyapatite provides a greater surface area and may interact more effectively with the cement matrix. Incorporation of hydroxyapatite and fluorapatite nanoparticles into GIC has been reported to influence its mechanical properties, supporting their potential as reinforcing agents.²

Further investigations have demonstrated the influence of nano-hydroxyapatite (nHA) on the mechanical and adhesion properties of GIC.³ The incorporation of HA into conventional and hybrid GICs has also been shown to affect their diametral tensile strength, indicating that HA may modify the mechanical behavior of glass ionomer materials.⁴

Apart from mechanical properties, water sorption and solubility are important parameters for evaluating the durability of dental cements. Excessive water sorption may result in dimensional changes and alteration of the cement matrix, whereas increased solubility can cause loss of components and progressive deterioration. Experimental GICs containing hydroxyapatite or calcium fluorapatite have been evaluated for both mechanical properties and water sorption.⁵ Studies involving different concentrations of nHA have also demonstrated variations in sorption and solubility, emphasizing the importance of nanoparticle concentration in determining the physicochemical behavior of modified cement.⁶

More recent research has focused on naturally obtained and green-synthesized hydroxyapatite. Green-synthesized HA nanoparticles incorporated into GIC have been investigated for their effects on compressive strength and antimicrobial properties.⁷ Naturally synthesized nHA has also been incorporated into glass ionomer luting cement and evaluated for its effect on compressive strength.⁸ These findings indicate the potential of naturally derived nHA as a reinforcing material for luting applications.

Of particular relevance, naturally obtained HA nanoparticles have been incorporated into resin luting cement and GIC, with water sorption and solubility evaluated following modification.⁹ This provides a direct basis for further investigation of naturally obtained nHA in dental luting materials. However, limited evidence is available regarding the simultaneous evaluation of compressive strength, water sorption, and solubility following incorporation of naturally obtained nHA into luting cement.

Therefore, the present study aims to evaluate the effect of naturally obtained nanohydroxyapatite incorporation on the compressive strength, water sorption, and solubility of dental luting cement, thereby assessing its potential as a reinforcing and bioactive material for prosthodontic applications.

II. MATERIALS AND METHODOLOGY

Study Design

An in vitro experimental study was conducted to evaluate the effect of incorporating naturally obtained nano-hydroxyapatite (nano-HAp) on the water sorption, water solubility, and compressive strength of Type I glass ionomer cement (GIC) and resin luting cement.

Study Groups and Specimen Distribution

Two dental luting materials were evaluated: Type I GIC and resin luting cement. Each material was divided into a control subgroup without nano-HAp and an experimental subgroup containing nano-HAp.

The study consisted of four subgroups:

Group I – GIC control: Type I GIC without nano-HAp (0%); $n = 10$.

Group II – GIC experimental: Type I GIC incorporated with 10% nano-HAp; $n = 10$.

Group III – Resin cement control: Resin luting cement without nano-HAp (0%); $n = 10$.

Group IV – Resin cement experimental: Resin luting cement incorporated with 2% nano-HAp; $n = 10$.

Separate specimens were prepared for water sorption and solubility testing and compressive-strength testing, with 10 specimens per subgroup for each test.

Preparation and Incorporation of Nano-Hydroxyapatite

The required quantity of naturally obtained 100nm nano-HAp was accurately measured according to the predetermined concentration for each experimental group. Nano-HAp was incorporated at 10 wt% for GIC and 2 wt% for resin luting cement.

For the GIC experimental group, the predetermined amount of nano-HAp was added to the GIC powder and triturated using a clean, dry mortar and pestle. The powder was mechanically blended to promote dispersion of the nano-HAp throughout the cement powder and to minimize visible agglomeration. The control GIC group was prepared without the addition of nano-HAp. Following powder preparation, the cement was mixed with its liquid component according to the manufacturer's instructions.

For the resin luting cement experimental group, the required amount of nano-HAp powder was accurately weighed relative to the resin cement paste using an analytical balance to obtain a 2 wt% concentration. The resin cement base and nano-HAp powder were transferred onto a clean mixing pad. The

materials were initially blended slowly to wet the powder and subsequently mixed using a clean plastic or metal spatula for approximately 20–30 seconds. Care was taken to promote distribution of the nano-HAp and minimize visible agglomeration.

The mixed resin cement was allowed to rest briefly to minimize entrapped air before specimen fabrication. The control resin cement group was prepared without the addition of nano-HAp.

Specimen Preparation for Water Sorption and Solubility

Disc-shaped specimens were prepared using standardized molds.

For Type I GIC, specimens measuring 10 mm in diameter and 1 mm in thickness were prepared.

For resin luting cement, specimens measuring 15 mm in diameter and 1 mm in thickness were prepared.

The freshly prepared materials were placed into the respective molds and adapted to obtain specimens of uniform dimensions. After setting or polymerization according to the manufacturer's instructions, the specimens were removed from the molds, finished, and inspected for visible defects. Specimens showing cracks, voids, or other irregularities were excluded from testing.

Water Sorption and Solubility Testing

Water sorption and solubility were evaluated following the procedure described in the reference study and based on ISO 4049.

The specimens were placed in a desiccator containing freshly dried silica and maintained at $37 \pm 1^\circ\text{C}$ for 22 hours. They were then transferred to a second desiccator maintained at $23 \pm 1^\circ\text{C}$ for 2 hours. The specimens were weighed using an electronic balance with an accuracy of 0.1 mg. The desiccation and weighing procedure was repeated until a constant mass was obtained.

The constant initial mass was recorded as m_1 .

The diameter and thickness of each specimen were measured using a Vernier caliper. Measurements were taken at the center and at four equally spaced locations. The volume of each specimen was calculated using:

$$V = \pi \times (d/2)^2 \times h$$

where V is the volume of the specimen, d is the mean diameter, h is the mean thickness, and $\pi = 3.14$.

The specimens were individually immersed in distilled water for 7 days.

After 7 days, the specimens were removed from the distilled water, rinsed, gently air-dried, and weighed within 1 minute. This mass was recorded as m_2 .

The specimens were subsequently returned to the desiccation procedure and conditioned until a constant mass was obtained. The final constant mass was recorded as m_3 .

Water sorption was calculated using:

$$\text{Water sorption (Wsp)} = (m_2 - m_3) / V$$

Water solubility was calculated using:

$$\text{Water solubility (Wsl)} = (m_1 - m_3) / V$$

The results were expressed in $\mu\text{g}/\text{mm}^3$.

Preparation of Specimens for Compressive Strength

Separate cylindrical specimens were prepared for compressive-strength testing, with 10 specimens prepared for each subgroup.

The specimens were fabricated using standardized cylindrical molds measuring 4 mm in diameter and 6 mm in length.

The four study subgroups were evaluated: GIC control (0% nano-HAp), GIC with 10% nano-HAp, resin luting cement control (0% nano-HAp), and resin luting cement with 2% nano-HAp.

For the experimental groups, nano-HAp was incorporated into the respective cement using the procedures described above. The freshly prepared materials were transferred into the cylindrical molds and adapted to obtain specimens of uniform dimensions.

The specimens were allowed to set or polymerize according to the manufacturer's instructions. After setting, the specimens were carefully removed from the molds and inspected for cracks, voids, or other visible defects. Specimens with visible defects were excluded from testing.

Compressive Strength Testing

Compressive strength was evaluated using a universal testing machine. Each cylindrical specimen measuring 4 mm in diameter and 6 mm in length was positioned centrally between the loading plates, with its long axis aligned with the direction of the applied load.

A compressive load was applied at a crosshead speed of 1 mm/min until fracture occurred. The maximum load at fracture was recorded in Newtons (N).

Compressive strength was calculated using the following equation:

Compressive strength (MPa) = F/A

where F represents the maximum load at fracture in Newtons and A represents the cross-sectional area of the specimen in square millimeters.

Statistical Analysis

The data obtained for water sorption, water solubility, and compressive strength were subjected to statistical analysis.

III. RESULTS

The present study demonstrated statistically significant differences among all four groups for water sorption, water solubility, and compressive strength ($p < 0.05$). Water sorption was highest in the Type I GIC control group (82.64), followed by Type I GIC with 10% nano-HAp (73.26), resin cement control (41.37), and resin cement with 2% nano-HAp (31.58). Thus, incorporation of nano-HAp was associated with reduced water sorption in both cement types.

A similar pattern was observed for water solubility, with mean values of 33.48 for Type I GIC control, 23.91 for GIC with 10% nano-HAp, 20.14 for resin cement control, and 14.86 for resin cement with 2% nano-HAp. The differences between all groups were statistically significant.

For compressive strength, the Type I GIC control showed a mean value of 88.42, which increased to 112.76 after incorporation of 10% nano-HAp. Resin cement showed higher values overall, increasing from 176.54 in the control group to 203.68 with 2% nano-HAp. The overall difference was statistically significant ($p = 0.000$), and Tukey post-hoc analysis demonstrated significant differences between every pair of groups.

Overall, nano-HAp incorporation was associated with decreased water sorption and solubility and increased compressive strength in both Type I GIC and resin luting cement. The resin cement groups demonstrated lower water-related changes and greater compressive strength than the corresponding GIC groups under the conditions of this in-vitro study.

IV. Discussion

The present in-vitro study evaluated the effect of incorporating nanohydroxyapatite (nano-HAp) into two dental luting materials, namely Type I glass ionomer cement (GIC) and resin luting cement, with respect to compressive strength, water sorption, and water solubility. Type I GIC was selected because of its established use as a luting material and its favorable properties such as adhesion to tooth structure, fluoride release, and biocompatibility. However, its comparatively lower mechanical strength and susceptibility to moisture-related changes remain important limitations.^{1,2} Resin luting cement was included because of its favorable mechanical characteristics and established use in adhesive luting procedures.³ The incorporation of nano-HAp was investigated because hydroxyapatite is a calcium-phosphate biomaterial closely related to the mineral phase of dental hard tissues and has been investigated as a bioactive and reinforcing component in dental materials.^{3,4}

The concentrations selected in the present study were 10% nano-HAp for Type I GIC and 2% nano-HAp for resin luting cement. These concentrations were selected based on previous investigations in which nano-HAp was incorporated into GIC and resin luting cement at different concentrations. Mariappan et al. evaluated naturally obtained nano-HAp in Type I GIC and resin luting cement and demonstrated changes in their water-related properties following incorporation.³ Thbayh et al. also demonstrated that the concentration of nano-HAp can influence the physicochemical behavior of GIC, indicating that the effect of nanoparticles is dependent on the amount incorporated.⁶

The first parameter evaluated was compressive strength, which is an important mechanical property for luting materials because the cement layer is exposed to functional stresses after cementation. In the present study, the mean compressive strength of Type I GIC increased from 88.42 in the control group to 112.76 following incorporation of 10% nano-HAp. The overall difference among the four groups was statistically significant ($p < 0.001$). Post-hoc analysis also demonstrated statistically significant differences between the individual groups.

The increase in compressive strength may be related to the reinforcing effect of the nano-HAp particles within the GIC matrix. The nanoscale dimensions provide a relatively large surface area for interaction with the surrounding cement components, while the particles may also occupy microscopic spaces within the matrix and contribute to more effective stress distribution. The improvement observed in the present study is consistent with investigations evaluating nano-HAp as a reinforcing component of GIC. Karthik et al. reported an increase in compressive strength following incorporation of naturally synthesized nano-HAp into GIC, while Ilancheran et al. investigated green-synthesized nano-HAp-containing GIC and also evaluated its compressive-strength behavior.^{2,4}

The increase from 88.42 to 112.76 represents an improvement of approximately 27.5% in compressive strength. This finding indicates that the 10% nano-HAp formulation used in the present study modified the

mechanical behavior of Type I GIC under the conditions tested. However, the improvement should not be interpreted as evidence that a higher concentration would necessarily result in further strengthening. Nanoparticle concentration, particle distribution, particle characteristics, and interaction with the cement matrix can influence the final mechanical response.^{6,14}

This concentration-dependent behavior is important because previous investigations have not demonstrated identical responses at all nano-HAp concentrations. Bilić-Prcić et al. observed that marine-derived hydroxyapatite produced different mechanical responses depending on the GIC formulation and concentration, with some formulations showing reductions in mechanical properties after incorporation.¹⁵ Kutuk et al. similarly demonstrated that the incorporation of hydroxyapatite or calcium fluorapatite influenced the mechanical characteristics of experimental GICs, although the response depended on the formulation evaluated.¹⁷ Thus, the increase observed in the present study may be related specifically to the interaction between the selected nano-HAp concentration and the Type I GIC used.

A similar improvement was observed in the resin luting cement. The mean compressive strength increased from 176.54 in the control group to 203.68 after incorporation of 2% nano-HAp, with a statistically significant difference among the groups ($p < 0.001$). This represents an increase of approximately 15.4% compared with the corresponding control. The improvement may be associated with reinforcement of the resin matrix by the nano-HAp particles and improved stress transfer between the filler and surrounding polymeric phase.

The finding is comparable with the observations of Reddy et al., who evaluated the mechanical properties of resin luting cement modified with tooth-colored nanoparticles.⁷ Assad et al. also investigated the incorporation of hydroxyapatite and 45S5 bioactive glass into resin cement, demonstrating that bioactive filler incorporation can modify the mechanical and physical behavior of resin-based luting materials.¹⁰ These findings support the concept that the incorporation of particulate fillers can alter resin cement properties, although the direction and magnitude of the effect depend on the type and concentration of the filler.

The resin luting cement demonstrated higher absolute compressive-strength values than Type I GIC in both control and nano-HAp groups. The control values were 176.54 and 88.42, while the modified groups demonstrated 203.68 and 112.76, respectively. This difference may be related to the inherent composition and matrix structure of the two cement systems. Therefore, the present findings indicate an improvement within each cement following nano-HAp incorporation rather than suggesting that the addition of nano-HAp eliminates the inherent differences between GIC and resin cement.

The second property evaluated was water sorption. Water sorption is particularly important for luting materials because they remain exposed to saliva and other oral fluids during clinical service. Water uptake can alter the internal structure of a cement and may contribute to dimensional changes and progressive material degradation.³ In the present study, the mean water sorption of Type I GIC decreased from 82.64 in the control group to 73.26 following incorporation of 10% nano-HAp. In resin cement, the value decreased from 41.37 to 31.58 following incorporation of 2% nano-HAp. The difference among the groups was statistically significant ($p < 0.001$).

The reduction in water sorption may be associated with modification of the internal matrix following nano-HAp incorporation. The nanoparticles may occupy spaces within the cement and reduce the pathways available for water penetration. Improved interaction between the nano-HAp particles and cement matrix may consequently restrict water diffusion. The finding is supported by Mariappan et al., who observed reduced water sorption following incorporation of naturally obtained nano-HAp into both Type I GIC and resin luting cement.³ Hussein also demonstrated that nanoparticle modification could influence the water sorption behavior of GIC under different storage conditions.⁸

The reduction in water sorption was approximately 11.4% in GIC and 23.7% in resin cement. The magnitude of the reduction was therefore greater in the resin cement group. This difference may be related to the distinct chemical nature and baseline water interaction of the two cement systems. The resin cement groups demonstrated lower water sorption than the corresponding GIC groups both before and after nano-HAp incorporation. This observation is consistent with the differences in matrix composition between resin-based cement and conventional GIC.

The concentration of nano-HAp may also influence water sorption. Thbayh et al. reported that different nano-HAp concentrations produced different sorption and solubility responses in GIC.⁶ Kutuk et al. evaluated hydroxyapatite- and calcium fluorapatite-containing experimental GICs and also considered water sorption together with mechanical properties.¹⁷ These findings indicate that water-related behavior cannot be attributed only to the presence or absence of nano-HAp; the concentration and interaction of the particles with the cement matrix also need to be considered.

The third parameter investigated was water solubility. Solubility reflects the amount of material or soluble components that can be lost following exposure to water and is therefore relevant to the long-term stability of luting cements. Excessive dissolution can progressively compromise the integrity of the cement.³ In

the present study, water solubility decreased from 33.48 in the Type I GIC control to 23.91 following incorporation of 10% nano-HAp. In resin cement, the corresponding reduction was from 20.14 to 14.86 after incorporation of 2% nano-HAp. The overall difference among the groups was statistically significant ($p < 0.001$).

The post-hoc analysis demonstrated statistically significant differences between the individual groups. The difference between the GIC control and GIC with 10% nano-HAp was significant, while a significant difference was also observed between the resin cement control and nano-HAp-modified resin cement. The comparison between GIC containing 10% nano-HAp and resin cement control demonstrated $p = 0.011$, while most other pairwise comparisons demonstrated $p < 0.001$.

The reduction in water solubility may be related to improved integrity of the modified cement matrix. Incorporation of nano-HAp may reduce the accessibility of water to susceptible components and consequently limit their dissolution. The finding is consistent with Mariappan et al., who reported reduced water solubility after incorporation of naturally obtained nano-HAp into both Type I GIC and resin luting cement.³ Murugan et al. also discussed the influence of nano-HAp incorporation on the properties of GIC, supporting the potential of nano-HAp to modify the behavior of the cement matrix.⁹

The reduction in solubility was approximately 28.6% in GIC and 26.2% in resin cement. Unlike compressive strength, where the magnitude of improvement was greater in GIC, the percentage reduction in solubility was relatively similar between the two modified materials. This suggests that nano-HAp influenced the interaction of both cement systems with water, although the underlying mechanisms may differ because of their different matrix compositions.

The resin cement groups demonstrated lower water solubility than the corresponding GIC groups. This was evident in both the control groups and nano-HAp-modified groups. The difference is consistent with the different chemical structures of resin-based and acid-base cement systems. Mariappan et al. similarly reported lower water sorption and solubility values for resin luting cement compared with Type I GIC.³ The present findings therefore suggest that nano-HAp modified the water-related properties of both materials while maintaining the inherent differences between the two cement systems.

The findings of the present study should also be interpreted in relation to the other properties investigated in previous nano-HAp studies. Hydroxyapatite-containing GIC has been evaluated not only for mechanical strength but also for antimicrobial activity, fluoride release, adhesion, and microleakage.^{4,13} Such studies indicate that modification of GIC can influence several properties simultaneously. However, improvement in one property should not automatically be assumed to occur in all other characteristics. For example, formulations containing hydroxyapatite and zinc oxide have demonstrated changes in mechanical and biological properties together with changes in fluoride release.⁵

The use of different sources and forms of hydroxyapatite is another factor that may explain variations among studies. Naturally obtained hydroxyapatite can differ in composition from highly purified synthetic material because naturally derived preparations may contain trace elements and variations in crystallinity.³ The present study specifically evaluated the nano-HAp formulation incorporated into the selected cement systems; therefore, the findings should be related to the material used rather than generalized to all forms of hydroxyapatite.

The present findings are also relevant to previous investigations of modified resin cements. Reddy et al. demonstrated that nanoparticle incorporation can influence the mechanical behavior of resin luting cement, while Assad et al. showed that incorporation of bioactive fillers can alter several properties of resin-based cement.^{7,10} The increase in compressive strength observed in the present study therefore appears to represent a response of the resin matrix to the incorporated nano-HAp under the experimental conditions used.

At the same time, the literature demonstrates that nano-HAp incorporation does not produce a uniform response in every cement formulation. Some investigations have reported improved mechanical behavior, whereas others have observed reductions at particular concentrations or with particular GIC formulations.^{15,17} This variation emphasizes that the performance of nano-HAp-modified cement depends on the interaction between particle concentration, particle characteristics, cement composition, and testing conditions. Therefore, the favorable results obtained in the present study should be interpreted specifically for the 10% nano-HAp Type I GIC and 2% nano-HAp resin luting cement evaluated.

The present study demonstrated a consistent trend across the three investigated properties. Compressive strength increased, while water sorption and water solubility decreased following nano-HAp incorporation in both cement systems. For Type I GIC, the changes were from 88.42 to 112.76 for compressive strength, 82.64 to 73.26 for water sorption, and 33.48 to 23.91 for water solubility. For resin luting cement, the corresponding changes were from 176.54 to 203.68, 41.37 to 31.58, and 20.14 to 14.86.

Thus, within the conditions of the present in-vitro investigation, incorporation of 10% nano-HAp into Type I GIC and 2% nano-HAp into resin luting cement was associated with improvement in compressive strength and reduction in water sorption and water solubility. The findings are supported by previous

investigations of nano-HAp-modified GIC and resin-based luting materials, although differences reported among studies emphasize the influence of material composition and nanoparticle concentration.^{2,3} The results therefore provide experimental evidence that nano-HAp can modify important mechanical and physicochemical properties of dental luting materials, while further studies involving aging, thermal cycling, fatigue, different nano-HAp concentrations, and clinical conditions would be necessary to determine the long-term significance of these changes.

LIMITATIONS

The present study has a few limitations. It was an in-vitro study, and therefore the findings may not completely represent the behavior of the materials under actual intraoral conditions. Only compressive strength, water sorption, and water solubility were evaluated, while other clinically relevant properties were not assessed. In addition, only 10% nano-HAp for GIC and 2% nano-HAp for resin cement were investigated; therefore, the effect of other concentrations could not be determined. Further long-term studies involving aging and clinically relevant loading conditions are recommended.

V. Conclusion

Within the limitations of this in-vitro study, incorporation of nano-hydroxyapatite into Type I GIC and resin luting cement resulted in **reduced water sorption and water solubility and increased compressive strength** compared with their respective control groups. The resin cement groups demonstrated lower water sorption and solubility and higher compressive strength than the corresponding GIC groups. Thus, nano-HAp incorporation showed a favorable influence on the evaluated physicochemical and mechanical properties of both luting materials under the conditions tested. Further studies using different nano-HAp concentrations, longer aging periods, and clinically relevant conditions are required to establish their long-term performance.

References

- [1]. Al-Hammadi S, Li M, Madfa AA, Al-Shehari WA, Qaid TA, Pan S. Mechanical and biological enhancement of glass ionomer cement through nanofiller integration: a preliminary study for improved restorative applications. *Sci Rep.* 2026. 10.1038/s41598-026-59123-4.
- [2]. Karthik SM, Divekar K, Deshpande A, Jadhav P. Effect of incorporation of naturally synthesized nanohydroxyapatite on compressive strength of glass ionomer luting cement – an in vitro study. *Int J Drug Deliv Technol.* 2026;16(1s):630-634. 10.25258/ijddt.16.630-634
- [3]. Aradya, Anupama & Mariappan, Anusuya & Marballi Basavaraju, Ravi & Malahalli, Vijaya & gowda, Raghavendraswamy & Rajashekar, Dhakshaini. (2025). Incorporation of Naturally Obtained Hydroxyapatite Nanoparticles in Resin Luting Cements and Glass Ionomer Cement to Valuate Water Sorption and Solubility: An In Vitro Study. *International Journal of Prosthodontics and Restorative Dentistry.* 15. 27-35. 10.5005/jp-journals-10019-1488.
- [4]. Ilancheran, Priyan & .P, Jessy & Maiti, Subhabrata & Shanmugam, Rajeshkumar. (2024). Green Synthesis, Characterization, and Evaluation of the Antimicrobial Properties and Compressive Strength of Hydroxyapatite Nanoparticle-Incorporated Glass Ionomer Cement. *Cureus.*2024;16(4) e58562. 10.7759/cureus.58562.
- [5]. Fabrication and characterization of reinforced glass ionomer cement by zinc oxide and hydroxyapatite nanoparticles. *Heliyon.* 2024;10:e39063 10.1016/j.heliyon.2024.e39063.
- [6]. Thbayh KK, AlBadr RM, Ziadani KM, Fiser B. Expanding potential dental applications of glass ionomer cement by incorporating with nano-hydroxyapatite. *Karbala Int J Mod Sci.* 2023;9(1).10.33640/2405-609X.3285.
- [7]. Reddy TVK, Varghese EJ, Venkatesh V. Comparative evaluation of mechanical properties of resin luting cement with tooth-colored nanoparticles: an in vitro study. *World J Dent.* 2022;13(4):341-347.10.5005/jp-journals-10015-2064.
- [8]. Hussein F. Evaluation of water sorption and solubility of nano titania enriched glass ionomer cement considering the storage solution and time. *Open Dent J.* 2022;16:e187421062210070.
- [9]. Murugan R, Yazid F, Nasruddin NS, Anuar NNM. Effects of nanohydroxyapatite incorporation into glass ionomer cement (GIC). *Minerals.* 2022;12(1):9. 10.3390/min12010009
- [10]. Assad C, et al. Effect of hydroxyapatite and 45S5 bioactive glass addition on a dental adhesive resin cement. *Int J Appl Glass Sci.* 2021;12:78-88. 10.1111/ijag.15850
- [11]. Wan Jusoh WN, Matori KA, Mohd Zaid MH, Zainuddin N, Ahmad Khiri MZ, Abdul Rahman NA, et al. Incorporation of hydroxyapatite into glass ionomer cement formulated based on alumino-silicate-fluoride glass ceramics from waste materials. *Materials (Basel).* 2021;14(4):954. 10.3390/ma14040954
- [12]. Mechanical, antibacterial, biocompatible and microleakage evaluation of glass ionomer cement modified by nanohydroxyapatite/polyhexamethylene biguanide. *Dent Mater J.* 2021. 10.4012/dmj.2021-096
- [13]. Kheur M, Kantharia N, Lakha T, Kheur S, Al-Haj Husain N, Özcan M. Evaluation of mechanical and adhesion properties of glass ionomer cement incorporating nano-sized hydroxyapatite particles. *Odontology.* 2020;108:66-73. 10.1007/s10266-019-00427-5
- [14]. Mechanical properties of glass ionomer cements after incorporation of marine derived hydroxyapatite. *Materials (Basel).* 2020. 10.3390/ma13163542
- [15]. Singer L, Bierbaum G, Kehl K, Bourauel C. Evaluation of the flexural strength, water sorption, and solubility of a glass ionomer dental cement modified using phytomedicine. *Materials (Basel).* 2020;13(23):5352. 10.3390/ma13235352
- [16]. Kutuk ZB, Koc Vural U, Yalcin Cakir F, Miletic I, Gurgan S. Mechanical properties and water sorption of two experimental glass ionomer cements with hydroxyapatite or calcium fluorapatite formulation. *Dent Mater J.* 2019;38(3):471-479.10.4012/dmj.2018-085
- [17]. Influence of hydroxyapatite nanoparticles on the properties of glass ionomer cement. *J Mater Res Technol.* 2019;8(1):344-349.10.1016/j.jmrt.2018.01.010



Figure 1 : GC FUJIFILM Type I GIC



Figure 2 : Dentsply Calibra Resin Cement



Figure 3 : Nano HA crystals



Figure 4: Mixing nano-HA with GIC



Figure 5 : Mixing nano-HA with Resin cement

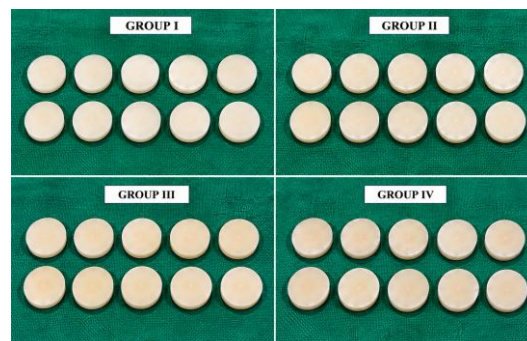


Figure 6 : Samples for water solubility & sorption

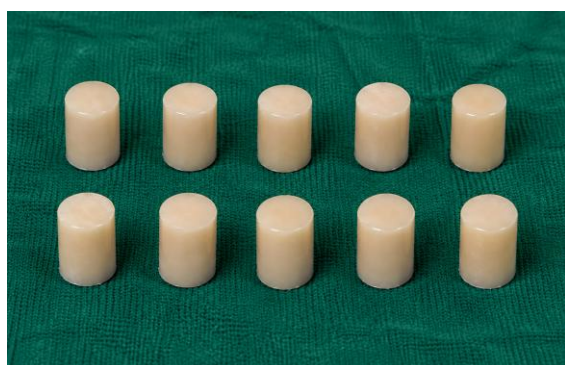


Figure 7 : Samples for compressive strength



Figure 8 : Water solubility & sorption testing



Figure 9 : Compressive strength test on UTM

Table 1 : comparison of water sorption among study groups

Groups	Mean	Std.dev	Std.error	fvalue	pvalue
Type I GIC Control	82.6400	2.30872	.73008	1131.74	0.000*
Type I GIC + 10% nano-HAp	73.2600	2.48267	.78509		
Resin Cement Control	41.3700	2.46029	.77801		
Resin Cement + 2% nano-HAp	31.5800	1.94981	.61658		

Oneway anova $p < 0.05$ * significant

Table 2 : multiple comparison of water sorption using posthoc

Groups		Mean Difference	Std. Error	pvalue
Type I GIC Control	Type I GIC + 10% nano-HAp	9.38000*	1.03317	.000
	Resin Cement Control	41.27000*	1.03317	.000
	Resin Cement + 2% nano-HAp	51.06000*	1.03317	.000
Type I GIC + 10% nano-HAp	Type I GIC Control	-9.38000*	1.03317	.000
	Resin Cement Control	31.89000*	1.03317	.000
	Resin Cement + 2% nano-HAp	41.68000*	1.03317	.000
Resin Cement Control	Type I GIC Control	-41.27000*	1.03317	.000
	Type I GIC + 10% nano-HAp	-31.89000*	1.03317	.000
	Resin Cement + 2% nano-HAp	9.79000*	1.03317	.000
Resin Cement + 2% nano-HAp	Type I GIC Control	-51.06000*	1.03317	.000
	Type I GIC + 10% nano-HAp	-41.68000*	1.03317	.000
	Resin Cement Control	-9.79000*	1.03317	.000

Posthoc tukey $p < 0.05$ * significant

Bar diagram 1 : Multiple comparison of water sorption

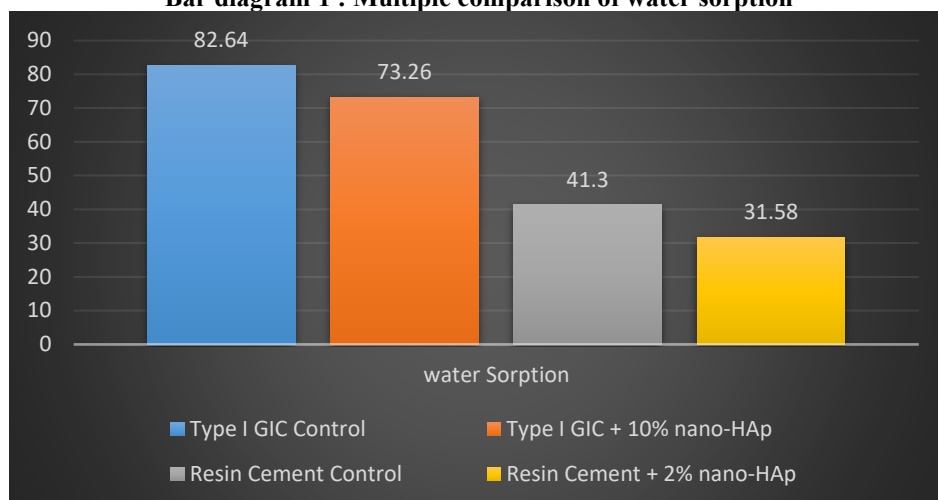


Table 3 : comparison of water solubility among study groups

Groups	Mean	Std.dev	Std.error	fvalue	pvalue
Type I GIC Control	33.4800	3.12307	.98760	95.579	0.000*
Type I GIC + 10% nano-HAp	23.9100	3.57263	1.12976		
Resin Cement Control	20.1400	1.55970	.49322		
Resin Cement + 2% nano-HAp	14.8600	.93069	.29431		

Oneway anova $p < 0.05$ * significant

Table4 : multiple comparison of water solubility using posthoc`

Groups		Mean Difference	Std. Error	pvalue
Type I GIC Control	Type I GIC + 10% nano-HAp	9.57000*	1.13614	.000
	Resin Cement Control	13.34000*	1.13614	.000
	Resin Cement + 2% nano-HAp	18.62000*	1.13614	.000
Type I GIC + 10% nano-HAp	Type I GIC Control	-9.57000*	1.13614	.000
	Resin Cement Control	3.77000*	1.13614	.011
	Resin Cement + 2% nano-HAp	9.05000*	1.13614	.000
Resin Cement Control	Type I GIC Control	-13.34000*	1.13614	.000
	Type I GIC + 10% nano-HAp	-3.77000*	1.13614	.011
	Resin Cement + 2% nano-HAp	5.28000*	1.13614	.000
Resin Cement + 2% nano-HAp	Type I GIC Control	-18.62000*	1.13614	.000
	Type I GIC + 10% nano-HAp	-9.05000*	1.13614	.000
	Resin Cement Control	-5.28000*	1.13614	.000

Posthoc tukey $p < 0.05$ * significant

Bar diagram 2 : multiple comparison of water solubility

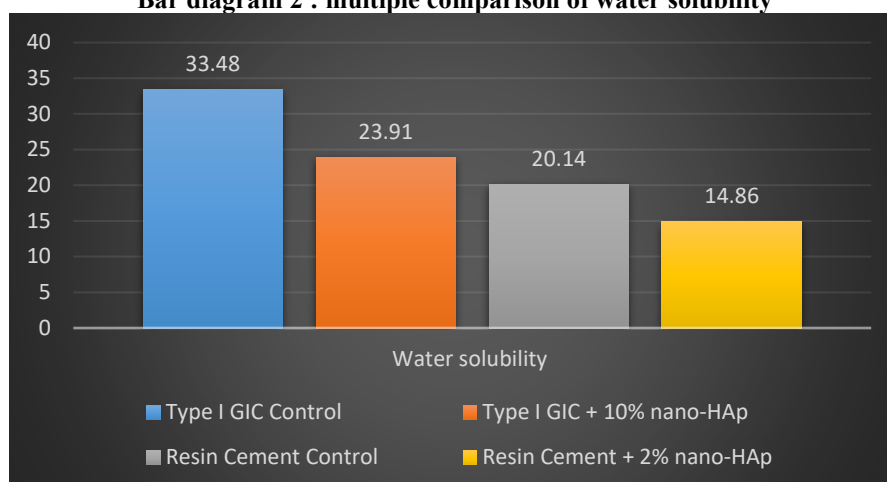


Table 5: comparison of compressive strength among study groups

Groups	Mean	Std.dev	Std.error	fvalue	pvalue
Type I GIC Control	88.4200	5.16169	1.63227	578.78	0.000*
Type I GIC + 10% nano-HAp	112.7600	6.38045	2.01768		
Resin Cement Control	176.5400	7.81905	2.47260		
Resin Cement + 2% nano-HAp	203.6800	8.45173	2.67267		

Oneway anova $p < 0.05$ * significant

Table 6 : multiple comparison of compressive strength using posthoc `

Groups		Mean Difference	Std. Error	pvalue
Type I GIC Control	Type I GIC + 10% nano-HAp	-24.34000*	3.16166	.000
	Resin Cement Control	-88.12000*	3.16166	.000
	Resin Cement + 2% nano-HAp	-115.26000*	3.16166	.000
Type I GIC + 10% nano-HAp	Type I GIC Control	24.34000*	3.16166	.000
	Resin Cement Control	-63.78000*	3.16166	.000
	Resin Cement + 2% nano-HAp	-90.92000*	3.16166	.000
Resin Cement Control	Type I GIC Control	88.12000*	3.16166	.000
	Type I GIC + 10% nano-HAp	63.78000*	3.16166	.000
	Resin Cement + 2% nano-HAp	-27.14000*	3.16166	.000
Resin Cement + 2% nano-HAp	Type I GIC Control	115.26000*	3.16166	.000
	Type I GIC + 10% nano-HAp	90.92000*	3.16166	.000
	Resin Cement Control	27.14000*	3.16166	.000

Posthoc tukey $p < 0.05$ * significant

Bar diagram 3 : multiple comparison of compressive strength

