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Eggshell nanoparticle as dentin remineralization therapy: A narrative review

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Abstract

Background: The 2018 Basic Health Research states that 88.80% of Indonesians have dental caries. Dental caries is a multifactorial disease that causes demineralization of dental hard tissues, if the caries defect involves enamel and dentin areas, it is called dentin caries. Proper treatment can slow down the demineralization process through remineralization efforts. An alternative treatment that can be done is to use nanoparticles. Nanoparticles are very small fragments of material with a diameter of less than 100 nm. Eggshells contain high calcium which is the reason it was chosen as an agent for remineralizing dentin in the form of nano-hydroxyapatite.

Objectives: This scientific review aims to describe the effectiveness of eggshell nanoparticles as dentin remineralization agents.

Methods: The type of research used was a narrative literature review. Secondary data were obtained from several online database articles, such as PubMed, ScienceDirect, and Google Scholar.

Discussion: Eggshell hydroxyapatite nanoparticles can release calcium, phosphorus, and fluoride ions that help remineralization in dentin. Eggshell hydroxyapatite nanoparticles can serve as a reservoir for the remineralization phase to maintain a supersaturation of calcium (Ca2+) and phosphate (PO4) ions. The presence of nano-hydroxyapatite can also increase the speed of dissolution and early occlusion in dentinal tubules. Eggshell hydroxyapatite nanoparticles have good buffering properties against acids because they have a larger surface area to react with citric acid so that they more effectively neutralize acid pH. In addition, hydroxyapatite nanoparticles have good biocompatibility due to their low cytotoxic level.

Conclusion: Eggshell hydroxyapatite nanoparticles are effective in enhancing dentin remineralization.

Keywords: Caries; Nanoparticles; Eggshell; Dentin Remineralization

1 Introduction

The 2018 Basic Health Research revealed that 88.8% of the Indonesian population suffers from dental caries. Dental caries is a process of tooth hard tissue damage that runs chronically. Caries can be caused by various factors so it is called a multifactorial disease, one of the causes is the result of fermentation of oral microorganisms[1]. Carbohydrate metabolism by oral bacteria will produce acid so that it releases calcium and phosphate ions in hydroxyapatite crystals or what is called the demineralization process[2]. The remineralization process, in contrast to demineralization, is a mineral deposition process with saturation of calcium and phosphate ion concentrations at neutral oral pH. If the balance between the demineralization and remineralization processes is disturbed, the caries process will continue[3].

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The progression of caries disease can be inhibited by increasing remineralization. Commonly used remineralizing agents include fluorides such as silver diamine fluoride, casein derivatives such as casein phosphopeptide-amorphous calcium phosphate, and tricalcium phosphate. When caries has reached dentin, it is called media caries or dentin caries[1]. Dentin is a hard tissue structure of the tooth consisting of type 1 collagen and hydroxyapatite. The dentin remineralization process involves the formation of a new collagen matrix and hydroxyapatite crystals which are more complex than enamel remineralization[4]. Dentin remineralization agents are classified into two groups, namely fluoride-based and non-fluoride-based. Non-fluoride dentin remineralization agents are further differentiated based on their mechanism of action, one of which is biomimetic systems that mimic the natural biomineralization process such as scaffolds. Scaffolds interact with the environment and respond to tissue cells through release of growth factors. Scaffolds can be produced from inorganic composite materials, synthetic or natural polymers, and nanoparticles[5]. Hydroxyapatite is increasingly developed in the form of nano-hydroxyapatite along with technological advances in the field of nanoparticles. Nano-hydroxyapatite has a structure, morphology, and crystallinity similar to biological apatite. Nano-hydroxyapatite can serve as a calcium and phosphate reservoir that enhances ion diffusion in demineralized areas[6]. One of the natural materials rich in calcium is eggshells with calcium carbonate (94%), calcium phosphate (1%), magnesium carbonate (1%), and organic substrate (4%). The high calcium content is the reason eggshells were chosen as dentin remineralization agents in the form of nano- hydroxyapatite[7]. Therefore, further review on the effect of eggshell hydroxyapatite nanoparticles (EnHAp) as dentin remineralization therapy is needed. Therefore this article aims to explore the characterization of eggshell hydroxyapatite nanoparticles (EnHAp) and examine their effects in enhancing dentin remineralization.

2 Methods

The type of research used was a narrative literature review. Secondary data were obtained from several online database articles, such as PubMed, ScienceDirect, and Google Scholar. The literature search used the keywords 'eggshell nanoparticle' OR 'eggshell nanohydroxyapatite' AND 'dentin remineralization' from 2019 - 2024.

3 Results

Eggshell hydroxyapatite nanoparticles (EnHAp) can release calcium, phosphorus, and fluoride ions that help remineralization in dentin. EnHAp can serve as a reservoir for the remineralization phase to maintain supersaturated conditions of calcium (Ca2+) and phosphate (PO4) ions continuously. The presence of nano-hydroxyapatite can also increase the speed of dissolution and early occlusion in dentinal tubules. EnHAp has good buffering properties against acids because it has a larger surface area to react with citric acid so that it more effectively neutralizes acid pH. In addition, EnHAp has good biocompatibility due to its low cytotoxic level[8,9]. A recapitulation of the literature is attached in the table below.

Table 1 List of literatures

Author	Type of Research	Results
Onwubu et al., 20198	Experimental Test	Nano-hydroxyapatite synthesized from eggshell waste (EnHAp) exhibited excellent dentinal tubule occlusion, with an occluded area ratio of 97.3%, significantly higher than eggshell powder and calcined eggshell powder (p < 0.001). FTIR and XRD analyses confirmed the successful synthesis of EnHAp with an average particle size of approximately 65 nm. These findings indicate that EnHAp is a promising material for the treatment of dentinal hypersensitivity due to its superior occlusion capability.
Abou and Bakhsh, 202110	Experimental Test	Toothpaste containing eggshell toothpaste (ESTP) and Titanium dioxide nanoparticles-containing eggshell toothpaste (TNPs-ESTP) can be an alternative material to overcome hypersensitivity in dentin. This is proven by observing dentinal tubules using Scanning Electron Microscopy (SEM). using Scanning Electron Microscopy (SEM). Scanning was done after application of toothpaste for 2 weeks and 1 month and the results wereobtained results dentinal tubule closure with this period.
Huaman et al., 202211	Experimental Test	Testing toothpaste with EnHAp content. The nHAP content was 3%, 7%, and 15% and observations were made using SEM and CRM. observations using SEM and

		CRM. The results obtained are that the use of nHAP toothpaste from eggshell shells can potential for remineralization. There are good formulations at 7% and 15% EnHap.
Milla et al., 202312	Experimental Test	The synthesized hydroxyapatite has an average grain size of 243.4 ± 5 nm, this size is ideal as a composite filler material. The synthesis process was successful with a purity of 98.5%, although there was a silica contaminant of 1.5%. FTIR analysis showed eight major peaks indicating important functional groups, including P-O and O-H bonds, as well as $Ca(OH)_2$ formation. With high purity and crystallinity, hydroxyapatite from chicken eggshell has great potential as a medical biomaterial.
Moharam and Hassan, 202313	Experimental Test	.Eggshell powder (ESP) and nano-hydroxyapatite (nHA) have demonstrated effectiveness in the remineralization process. ESP enhances alkalinity and increases the availability of ions essential for remineralization, while nHA, due to its solubility and biocompatibility, facilitates the filling of micropores in demineralized enamel. Additionally, MI Paste containing casein phosphopeptide–amorphous calcium phosphate (CPP–ACP) acts as an ion reservoir that supports enamel remineralization.
Wu et al., 202314	Experimental Test	Synthesized nano-hydroxyapatite demonstrated strong potential for biomedical applications, particularly in dentin remineralization. Its high bioactivity in simulated body fluid (SBF) and small crystallite size, comparable to natural mineral components, enable effective interaction with dentin. The incorporation of elements such as magnesium and strontium further enhances remineralization and tissue growth. Moreover, the good biocompatibility of hydroxyapatite supports its application in dentin tissue repair and regeneration, highlighting its promise for dental tissue remineralization and restorative therapies.
Elline et al., 202215	Experimental Test	Eggshell nanoparticles with collagen and EGCG promote proliferation and differentiation of dental pulp cells. In addition, it shows cell viability of more than 50% by MTT assay toxicity test. Therefore, eggshell nanoparticles are non- toxic and biocompatible materials.
Karthikeyan et al., 202416	Experimental Test	The combination of eggshell hydroxyapatite nanoparticles with carboxymethyl chitosan interacts synergistically so that calcific deposits for remineralization are increased. In addition, the combination of scaffold both increase DSPP, DMP-1 and VEGF markers
Baskar et al., 202217	Experimental Test	The scaffold combination of eggshell and carboxymethyl chitosan increased the proliferation of human dental pulp stem cells on day 7 and increased DSPP markers on day 21. Crystal eggshell nano-hydroxyapatite inside carboxymethyl chitosan microporous enhances the chemotatic properties of the scaffold resulting in increased adhesion

4 Discussion

4.1 Characterization of Eggshell Hydroxyapatite Nanoparticles

Calcium phosphate is the main mineral of bones and teeth. One form of calcium phosphate is hydroxyapatite (HA). HA can be found in eggshells in the form of nanoparticles. HA derived from eggshells can be processed using simple methods. There are various methods to produce HA crystals, such as precipitation, hydrothermal, mechanochemical, biomimetic deposition, sol-gel, and electrodeposition methods. Among these methods, the hydrothermal method is the most commonly used for the synthesis of hydroxyapatite from eggshells because it is proven to be the most practical method[12].

Characterization of EnHAP carried out by various analytical methods shows that all HA samples have a single phase with different levels of crystallinity. Hydrothermally synthesized HA has higher crystallinity than the precipitation method. FE-SEM analysis shows that HA consists of rod-shaped nanoparticles with particle length increasing with hydrothermal reaction time. The crystallite size of hydrothermal HA is also larger according to Scherrer analysis. FTIR spectra indicated the presence of OH- and (PO4)(3-) vibrations, as well as carbonate characteristics indicating ABcarbonate-substitution type. ICP-AES analysis detected magnesium (Mg) and strontium (Sr) elements that are important for bone metabolism. DTA/TGA showed phase change and mass loss related to water desorption and decarboxylation. Bioactivity tests in Simulated Body Fluid (SBF) showed HA could form apatite precipitates indicating good bioactivity, while cell culture tests showed good adhesion to osteoblast cells, suggesting high biocompatibility potential. This characterization confirms that nHAP from eggshell has similar properties to natural HA and has potential for biomedical applications such as bone substitutes and drug delivery[14]. In addition, eggshell nanoparticles also have biocompatible properties. Toxicity test with MTT assay showed cell viability results above 50%. Therefore, EnHAp can be said to be non-toxic and safe to use[15].

4.2 Mechanism of Dentin Remineralization by Eggshell Nanoparticles

The mechanism of dentin remineralization using EnHAp involves a series of important interconnected processes. Eggshells that are rich in calcium carbonate when processed into nHAP will provide a source of calcium and phosphate which are crucial for the remineralization process. When nanoparticles are applied to demineralized dentin, they interact with the dentin matrix to help repair the damaged structure through the binding of ions from the nanoparticles to the dentin surface. In addition, under moist conditions, nHAPs serve as nuclei for the formation of new apatite crystals that stimulate remineralization by replenishing areas of mineral loss. Nanoparticles also have the potential to increase the proliferation and differentiation of osteoblast cells that play an important role in mineral tissue formation and repair. The bioactive properties of HA may enhance the ability of dentin to regenerate and repair itself. Overall, the use of EnHAp shows significant potential in enhancing the dentin remineralization process and supporting overall dental health[13, 14].

4.3 Efficacy of EnHAp in Dosage Forms

4.3.1 Efficacy of EnHAp in Toothpaste Preparations

Toothpaste is a commonly used dental cleaning product to remove plaque, reduce the risk of tooth decay, and maintain oral hygiene. Nowadays, toothpastes are increasingly formulated with natural ingredients, including eggshell nanoparticles. The efficacy of eggshell toothpaste was assessed by its ability to seal dentinal tubules and remineralize intertubular dentine[10].

Research conducted by Abou and Bakhsh found that eggshell toothpaste has the potential to be a cost-effective therapy for dentin remineralization. This was proven by experiments conducted by comparing three toothpastes, namely eggshell toothpaste (ESTP), titanium dioxide nanoparticles-containing eggshell toothpaste (TNPs-ESTP), and biorepair. After treatment for 2 weeks and 1 month, the order of toothpaste with the highest dentinal tubule closure was obtained, namely biorepair, TNPs-ESTP, and ESTP. Ions that have been released can become a place for increased crystals and mineralization so that dentinal tubule blockage occurs over time[10].

Experimental tests conducted by Huaman et al using eggshell toothpaste with 3%, 7%, 15% EnHAP formula, biorepair, and without EnHAP. The samples used were 50 healthy premolars and 2 analysis methods were used, namely Scanning Electron Microscopy (SEM) and Confocal Raman Microscope (CRM). The samples were divided into 5 test groups with Group 1 being conventional toothpaste containing 3% EnHAP, group 2 containing 7% EnHAP, group 3 containing 15% EnHAP, group 4 with biorepair, and group 5 with toothpaste without EnHAp. Before the trial, the samples were divided into 3 categories, namely T0, samples stored in distilled water, T7, samples applied toothpaste with VITIS Sonic S20 electronic brush for a duration of 3 minutes every 24 hours and carried out for 7 days. While T15 is a sample that is stored for 7 days in distilled water and then on day 15 is done after the second erosion cycle using Coca-cola commercial drinks. Based on SEM observations, dentin tubule closure was obtained on EnHAp with 3%, 7%, and 15% formulas after brushing for 7 days. While the CRM observation obtained high remineralization in the 3% EnHAp formula at 15 days. Based on experimental tests, it was found that EnHAp with 7% and 15% formulations were effective in closing dentinal tubules and became stable over time. The content of HA in the form of nanoparticles can facilitate direct distribution into the dentinal tubules. These findings suggested that the presence of EnHAp as a biological apatite for dentin surfaces can create a chemical bond between new and old enamel crystals as a protection against acids[11].

4.3.2 Efficacy of Eggshell Nanoparticles in Scaffold Preparation

Dentin and pulp regeneration are influenced by several factors such as anatomical location, complex neurovascular innervation, limited blood supply to the pulp, and the proliferation ability of odontoblast cells after the mitotic phase. One of the technological developments for these problems is scaffolds. Karthikeyan et al found that the scaffold combination of EnHAp and carboxymethyl chitosan (CMC) with a composition ratio of 1:5 increased dentin sialophosphoprotein (DSPP) and remineralization. In mineralization test with alizarin red staining. The observed absorption and intensity of EnHAp were higher than those of synthetic nano-hydroxyapatite. The synergistic effect of

EnHAp-CMC formed a multifunctional polyelectrolyte complex as well as a higher surface area and reactivity that enhanced the calcific deposit. In addition, it was found that the EnHAp-CMC scaffold increased DSPP, DMP-1, and VEGF. DSPP and DMP-1 are markers of odontoblastic differentiation that play an important role in dentinogenesis formation, maturation, and mineralization, while VEGF is a factor involved in pulp angiogenesis[16].

Baskar et al showed increased proliferation and gene expression of DSPP and VEGF in human dental pulp stem cells (hDPSCs) with EnHAp-CMC scaffold. On day 7, an increase in proliferation of hDPSCs was observed, followed by a marginal increase in cell proliferation. This could be due to the high microporosity structure of CMC with EnHAp crystals inside increasing the chemotactic potential of the scaffold so that adhesion between the scaffold surface and hDPSCs increased. Then, on day 21, a significant increase in DSPP was observed compared to day 7 and day 14[17]. The significant increase in DSPP expression on day 21 is related to odontoblast maturation and differentiation. Elline et al combined EnHAp with collagen and EGCG in a hydrogel scaffold. The combination of these ingredients in a scaffold increased the proliferation and differentiation of dental pulp cells[15].

5 Conclusion

Hydroxyapatite nanoparticles derived from eggshells have been shown to improve the dentin remineralization process, both in the form of toothpaste preparations and in the form of scaffold preparations. Research shows that the use of these nanoparticles can help improve tooth structure and strength, thus providing a promising solution in the field of dentistry, especially to overcome the problem of demineralization in teeth. With their high biocompatibility, these nanoparticles are not only safe to use, but can also support overall dental health.

Compliance with ethical standards

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Disclosure of conflict of interest

No Conflict of interest to be disclosed

References

[1] Sikri VK. Textbook of Conservative and Restorative Dentistry. New Delhi (India): CBS Publishers & Distributors Pvt. Ltd; 2020.

[2] Vitiello F, Tosco V, Monterubbianesi R, Orilisi G, Gatto ML, Sparabombe S, et al. Remineralization Efficacy of Four Remineralizing Agents on Artificial Enamel Lesions: SEM-EDS Investigation. Materials. 2022 Jun 22;15(13):4398.

[3] Yoshihara K, Nagaoka N, Nakamura A, Hara T, Hayakawa S, Yoshida Y, et al. Three-dimensional observation and analysis of remineralization in dentinal caries lesions. Scientific Reports. 2020 Mar 9;10(1).

[4] Asadi M, Majidinia S, Bagheri H, Melika Hoseinzadeh. The Effect of Formulated Dentin Remineralizing Gel Containing Hydroxyapatite, Fluoride, and Bioactive Glass on Dentin Microhardness: An In Vitro Study. International Journal of Dentistry. 2024 Jan 1;2024(1).

[5] Jin W, Wu H, Shi J, Hu Z, Zhou Y, Chen Z, et al. Biomimetic mineralized collagen scaffolds enhancing odontogenic differentiation of hDPSCs and dentin regeneration through modulating mechanical microenvironment. Chemical Engineering Journal [Internet]. 2023 Mar 15 [cited 2023 Mar 8];460:141800. Available from: https://www.sciencedirect.com/science/article/pii/S1385894723005314

[6] Juntavee A, Juntavee N, Hirunmoon P. Remineralization Potential of Nanohydroxyapatite Toothpaste Compared with Tricalcium Phosphate and Fluoride Toothpaste on Artificial Carious Lesions. Pagano S, editor. International Journal of Dentistry. 2021 Mar 20;2021:1-14.

[7] Karthikeyan BS, Mahalaxmi S. Biomimetic dentin remineralization using eggshell derived nanohydroxyapatite with and without carboxymethyl chitosan - An in vitro study. International Journal of Biological Macromolecules [Internet]. 2024 May 15;270:132359. Available from: https://doi.org/10.1016/j.ijbiomac.2024.132359

[8] Onwubu SC, Mhlungu S, Mdluli PS. In vitroevaluation of nanohydroxyapatite synthesized from eggshell waste in occluding dentin tubules. Journal of Applied Biomaterials & Functional Materials. 2019 Apr;17(2):228080001985176.

[9] Bologa E, Stoleriu S, Iovan G, Ghiorghe C A, Nica I, Andrian S, Amza O E. Effects of Dentifrices Containing Nanohydroxyapatite on Dentinal Tubule Occlusion-A Scanning Electron Microscopy and EDX Study [Internet]. Mdpi.com. 2020. Available from: https://www.mdpi.com/2076-3417/10/18/6513/review_report

[10] Abou Neel EA, Bakhsh TA. An Eggshell-Based Toothpaste as a Cost-Effective Treatment of Dentin Hypersensitivity. European Journal of Dentistry [Internet]. 2021 Aug 24; Available from: https://pubmed.ncbi.nlm.nih.gov/34428838/

[11] Huamán-Mujica K, Castañeda-Vía J, Bermúdez García V, Dominguez J, Landauro C, Quispe-Marcatoma J et al. Dentinal tubules obliteration using a toothpaste with nano-hydroxyapatite obtained from chicken eggshell. Journal of Stomatology. 2022;75(3):147-154. doi:10.5114/jos.2022.119082

[12] Milla LE, Hartami E, Priyanto R, Adrian AGW. Synthesis and Characterization of Eggshell Based Hydroxyapatite Nanoparticles: X-ray Diffraction and Spectroscopy Analysis. Malaysian Journal of Medicine and Health Sciences. 2023 Apr 18;2636- 9346

[13] Moharam L, Hassan S. Effect of eggshell powder and nano-hydroxyapatite on surface roughness and microhardness of bleached enamel. Contemporary Clinical Dentistry. 2022

[14] Wu SC, Hsu HC, Wang HF, Liou SP, Ho WF. Synthesis and Characterization of Nano-Hydroxyapatite Obtained from Eggshell via the Hydrothermal Process and the Precipitation Method. Molecules [Internet]. 2023 Jan 1;28(13):4926. Available from: https://www.mdpi.com/1420-3049/28/13/4926

[15] Elline E, Ismiyatin K, Budhy TI, Bhardwaj A. The potential of eggshell hydroxyapatite, collagen, and EGCG (HAp-Col-EGCG) scaffold as a pulp regeneration material. The Saudi Dental Journl. 2022;34(8):715-722.

[16] Karthikeyan BS, Madhubala MM, Rajkumar G, et al. Physico-chemical and biological characterization of synthetic and eggshell derived nanohydroxyapatite/carboxymethyl chitosan composites for pulp-dentin tissue engineering. International Journal of Biological Macromolecules. June 2024;271(1).

[17] Baskar K, Karthikeyan BS, Gurucharan I, et al. Egg shell derived nanohydroxyapatite incorporated carboxymethyl chitosan scaffold for dentine regeneration: A laboratory investigation. International Endodontic Journal. 2022;55(1):89-102.