EFFICACY OF HYDROXYAPATITE NANOPARTICLES IN DENTINAL TUBULE OCCLUSION AND RESISTANCE TO EROSIVE WEAR (SCANNING ELECTRON MICROSCOPIC STUDY)

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ABSTRACT

INTRODUCTION: Dentin hypersensitivity (DH) is a major dental problem that is manifested as sharp pain of short duration. The cause of DH is controversial; however, the most accepted theory is the hydrodynamic theory. Attempts were made for the treatment of DH as fluoride containing-toothpastes and mouthwashes. Recently, it was found that nanoparticles maybe used for the treatment of DH as they are biocompatible and bioactive materials.
OBJECTIVES: To investigate the efficacy of hydroxyapatite nanoparticles in occluding dentinal tubules and resisting erosive wear.
METHODOLOGY: Twenty-seven teeth, extracted for orthodontic purpose were used in the present study to obtain 27 dentin discs. Dentin discs were prepared by slicing the teeth from the mid-coronal part. Dentin discs were etched with 37% orthophosphoric acid for 20 seconds then washed with distilled water for 1 minute. Afterwards, they were randomly divided into 2 groups: Group I (Etched control), Group II (Hydroxyapatite nanoparticles): the etched dentin discs were treated with hydroxyapatite nanoparticles. After 7 days, Group II was divided into 2 subgroups; subgroup A: stored in artificial saliva and subgroup B: subjected to erosive challenge by 0.3% citric acid. Finally, dentin discs were analyzed by scanning electron microscope (SEM) and energy dispersive x-ray (EDX).
RESULTS: Group II-A showed more occluded dentinal tubules compared to group I and group II-B. The results of the EDX showed increase in calcium and phosphorous percentage in Group II-A than groups I and II-B.
CONCLUSION: Hydroxyapatite nanoparticles may be a promising treatment for dentin hypersensitivity.
KEYWORDS: dentin hypersensitivity, hydroxyapatite nanoparticles, dentin.
RUNNING TITLE: Hydroxyapatite nanoparticles in dentinal tubule occlusion and resistance to acid.

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INTRODUCTION

Dentin is a mineralized tissue which forms the bulk of the tooth. (1) It is made up of 67% inorganic, and 33% organic components. Histologically, it consists of dentinal tubules ranging from 0.8–2.5 μm in diameter, which are in charge of hydration and tooth sensory responses.(2) Moreover, dentin shields the dental pulp from microbes and other potentially dangerous stimuli.(3) In addition to serving as a passive mechanical barrier between the oral environment and the dental pulp, dentin also contributes to the overall protection of the hard and soft tissues. (4)

Dentin hypersensitivity (DH) is defined as a transitory, acute pain that is accompanied by thermal, mechanical, chemical, and osmotic stimulation. (5) It shows high prevalence worldwide. The prevalence of oral disorders has decreased, bringing DH to the forefront among other pathologies.(6)

Many hypotheses were made to explain DH. The most accepted theory is the hydrodynamic theory, which assumes that DH is due to the exposure of dentinal tubules. Fluid movement in response to stimuli activates nerve terminals in the pulp and causes temporary acute discomfort.(7)

Dentin hypersensitivity is often brought on by a combination of predisposing factors. The regressive changes to the teeth, such as attrition, abrasion, and erosion, may be the cause of enamel loss. Nevertheless, gingival recession is thought to be the most typical reason for DH. Vigorous brushing, poor oral hygiene, and periodontitis result in migration of gingival margin apically. Correspondingly, the thin covering of cementum is quickly destroyed, exposing the underlying tubules.[8]

For nerve desensitization, potassium nitrate is one of the active ingredients added in a toothpaste or mouthwash for treatment of DH. Furthermore, the occlusion of the dentinal tubules could be accomplished by using calcium hydroxide, fluorides, varnishes and restorative materials.[9]

In order to provide a long-lasting tubule occlusion, new biomaterials should promote sustained dentin remineralization.[6] The ability of toothpaste's active components to occlude dentinal tubules and survive the effects of acidic drinks became crucial. Therefore, scientists are presently looking for active substances that have a high resistance to acidic soft beverages and can create stable, long-term dentinal tubules occlusion.[10]

Recent studies have highlighted the value and demand of biomimetic oral health products. Consequently, nanotechnology has attracted a lot of researchers due to its distinctive qualities, such as tiny size, large surface area, and target-specific mechanisms of action procedures.[11]

Moreover, nanoparticles have antibacterial properties, biocompatible, and has a physio-chemical stability over time.[12] The unique and diverse physicochemical characteristics possessed by nanoparticles, including their large surface area, mechanical strength, optical activity, and chemical reactivity, make them ideal candidates for a wide range of applications. The combination of these characteristics in nanoparticles provides a unique advantage over other materials, making them valuable tools in various fields, including biomedicine, environmental science, and electronics.[13] However, the evidence for their effectiveness in dentinal tubule occlusion and resistance to erosive wear is scant and inconclusive. Unfortunately, no hypersensitivity therapy has been demonstrated to be entirely successful for all patients.[14]

Consequently, it is mandatory to develop an occlusion agent that promotes the development of a deep and compact mineralization occlusion layer. [4] The optimal desensitizing agent should not irritate or jeopardize the dental pulp's structural integrity, be painless, both during and after application, be simple to use, show quick results, be long-lasting or permanent, and not harm the teeth or gingiva.[15]

Hence, the present study was conducted to investigate the efficacy of hydroxyapatite nanoparticles in occluding dentinal tubules and resisting erosive wear.

MATERIALS AND METHODS

Study sample:

Twenty-seven dentin discs were obtained from 27 premolars. These premolars were devoid of any carious lesions or restorations, extracted for orthodontic purpose were used in this study. Teeth were obtained from the Oral and Maxillofacial Surgery Department, Faculty of Dentistry, Alexandria University.

The study was conducted after receiving the approval of the Ethical Committee at Faculty of Dentistry, Alexandria University. (IRB NO: 00010556) (IORG 0008839)

Grouping (randomization technique):

The randomization scheme used to allocate the twenty-seven premolars was generated by using the website (http://www.Randomization.com). The dentin discs were randomly divided into 3 groups.

Group I: (n= 9) Etched control group.

Group II-A: (n= 9) Hydroxyapatite nanoparticles group.

Group II-B: (n= 9) Hydroxyapatite nanoparticles group subjected to erosive challenge.

Preparation of Dentin Disc

Preparation of dentin discs was done by using a Microtome (Micracut 150, Metkon® metallography, Turkey), 2.5 mm of occlusal enamel, down the cusp tip, was removed, [16] discs were obtained from mid-coronal part, [17] of 2.0 mm (±0.2 mm) thickness by making a horizontal cut (from mesial to distal) at the cemento-enamel junction of each tooth.[16]

Simulating Dentin Hypersensitivity

The obtained dentin discs were etched with 37% orthophosphoric acid for 20 seconds to open the tubules, to create a dentin hypersensitivity model [16] and to remove the smear layer.[18] They were then washed with distilled water for 1 minute.[16]

Preparation of Carboxymethyl cellulose (CMC) dental hydrogel scaffold loaded with Hydroxyapatite Nanoparticles [15]

The Hydrogel was prepared by using carboxymethyl cellulose mixed with glycerol in a beaker using magnetic stirrer until homogeneous. A solution of distilled water was combined and continuously mixed for 1 hour. Addition of the Hydroxyapatite Nanoparticles powder (Purchased from Nanotech, Dreamland, El-Wahaat Road, 6th October, Giza, Egypt) to the CMC hydrogel was done., then the nanoparticles were mixed with the CMC dental hydrogel scaffold. Finally, a gel form of Hydroxyapatite Nanoparticles was established.

Simulated Tooth Brushing technique

Dentin discs were brushed by a custom made Brushing simulator (Dental Biomaterials Department, Faculty of Dentistry, Alexandria University, Alexandria, Egypt) with the CMC hydrogel that is loaded with hydroxyapatite nanoparticles for 2 minutes, three times per day, for 7 days.[15] Post-brushing, the dentin discs were washed with distilled water for 1 min and then returned to their respective containers containing artificial saliva. [7]

Erosive Challenge [19]

Dentin discs were immersed in 10 mL of 0.3% citric acid solution (pH=2.6) for 2 minutes, 4 times per day, for 5 days without stirring at room temperature. Between challenges dentin discs were immersed 60 minutes in artificial saliva. After each episode of erosion, the dentin discs were rinsed with distilled water and gently dried with absorbent paper.

Characterization of Hydroxyapatite Nanoparticles [10]

Transmission Electron Microscope (TEM) was used to observe the particle shape and measure particle size of Hydroxyapatite Nanoparticles suspension.

Characterization of Carboxymethyl cellulose (CMC) dental hydrogel scaffold loaded with Hydroxyapatite Nanoparticles

Scanning electron microscope was used to measure the particle size and to observe the shape and distribution of CMC dental hydrogel scaffold loaded with Hydroxyapatite nanoparticles.

Scanning Electron Microscopic Assessment of dentin discs [20]

The specimens underwent examination using Scanning Electron Microscope to observe the surface structure of dentin discs in various groups. The samples were affixed to the specimen holder using silver paint, and then coated to prepare them for examination.

Energy Dispersive X-ray Analysis [20]

Energy dispersive X-ray analysis was employed to contrast the differing percentages of calcium and phosphorus present in the dentin discs across the various groups.

Statistical Analysis

The data collected via EDX was subjected to analysis using the ANOVA test to evaluate the overall distinctions among the three groups.

RESULTS

A) TEM results

Characterization of hydroxyapatite nanoparticles

This transmission electron micrograph that displays the dispersion of hydroxyapatite nanoparticles. These nanoparticles are rod-shaped and have a length that varies between 100 ± 30 nm, while their diameter ranges from 20 ± 5 nm.

B) SEM results

Group I: Etched control group

Dentin discs in the etched control group revealed exposed dentinal tubules with few closed dentinal tubules. (Figure 2)

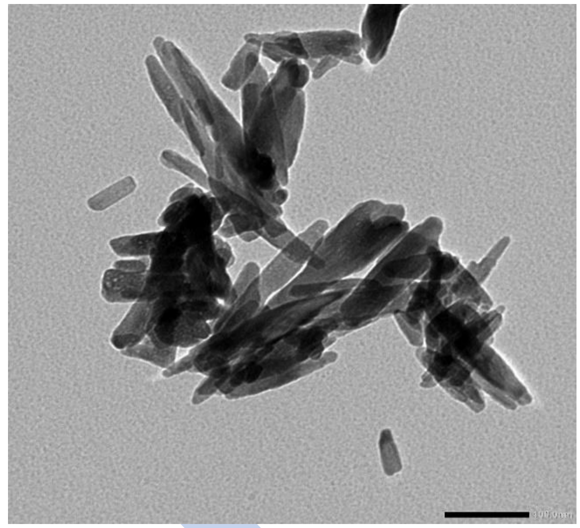

Figure 1: Transmission electron micrograph of the hydroxyapatite nanoparticles dispersion showing the rod-shaped nanoparticles. (Scale bar 100 nm)

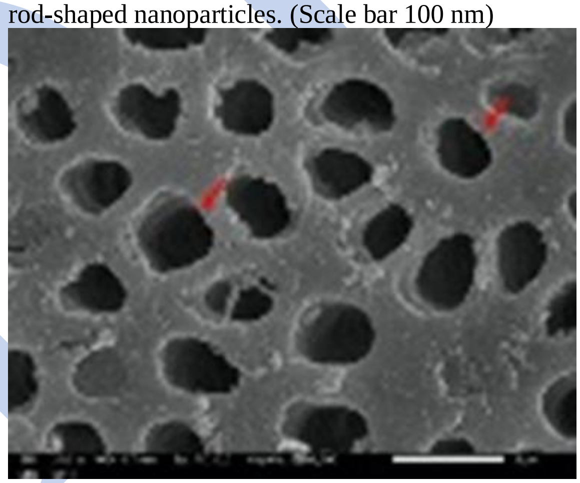

Figure 2 : Scanning electron micrograph of etched control group (Group I) showing exposed dentinal tubules. (x5000).

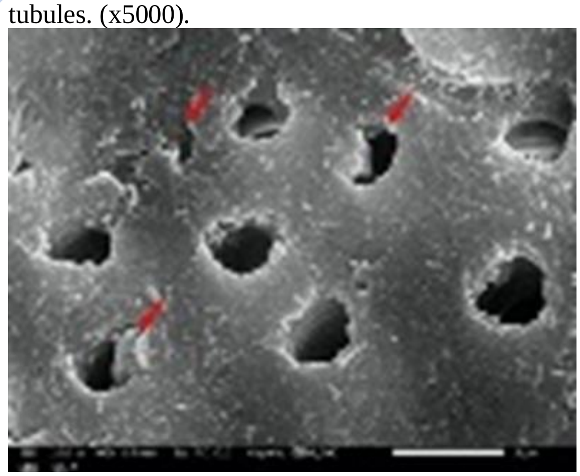

Figure 3: Scanning electron micrograph of hydroxyapatite nanoparticles group (Group II-A) showing superior tubule occlusion. (x5000).

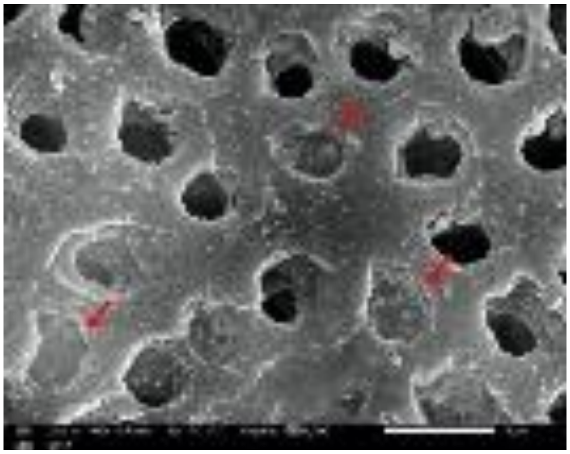

Figure 4: Scanning electron micrograph of hydroxyapatite nanoparticles group post-citric acid challenge (Group II-B) showing partial tubule occlusion. (x5000).

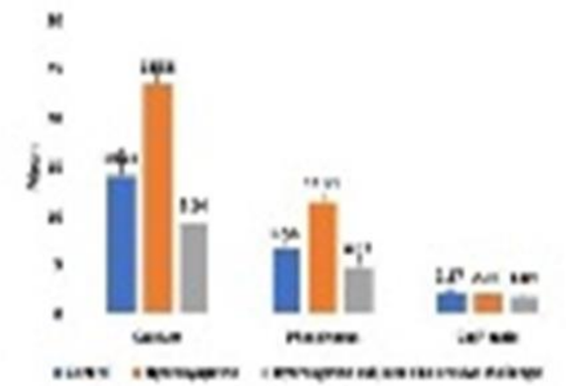

Figure 5: Energy Dispersive X-ray microanalysis represented in a bar graph comparing Ca, P, Ca/P ratio among the study groups.

* Statistically significant difference in the calcium and phosphorous levels between the three groups.

* Statistically significant difference in Ca/P ratio between the etched control group and the hydroxyapatite group subjected to erosive challenge

No statistically significant difference in the Ca/P ratio between etched control group and hydroxyapatite group.

No statistically significant difference in the Ca/P ratio between hydroxyapatite group and hydroxyapatite group subjected to erosive challenge.

Group II-A: Hydroxyapatite Nanoparticles group

Dentin discs in the Hydroxyapatite Nanoparticles group showed that most of the dentinal tubules were obliterated. (Figure 3)

Group II-B: Hydroxyapatite Nanoparticles group subjected to erosive challenge

Dentin discs in the Hydroxyapatite Nanoparticles group subjected to erosive challenge showed partial tubule occlusion. (Figure 4)

C) Energy Dispersive X-ray results

Different surface elemental compositions of calcium and phosphorous were found in the various groups, according to the energy dispersive x-ray analysis, that was summarized by means and standard deviation. (Figure 5)

There was statistically significant increase in calcium and phosphorous levels in the hydroxyapatite nanoparticles group in relation to the other two groups, with p value <0.0001.

Energy Dispersive X-ray results showed that the highest mean value of calcium in group II-A was 23.58. The level of phosphorous was the highest in group II-A with mean value of 11.51. Ca/P ratio was the highest in group I with mean value of 2.17, followed by group II-A 2.05 and the least 1.89 in group II-B.

DISCUSSION

Exposure of the microscopic channels, the dentinal tubules, which form the mineral-bearing tissue of the dentin, can result in dentin hypersensitivity (DH). DH is a common problem, with reported prevalence rates reaching as high as 74%.[21] It is mainly attributed to the hydrodynamic theory, which postulates that pain is caused by the rapid movement of the dentinal fluid within the dentinal tubules in response to external stimuli, including thermal, tactile, evaporative, osmotic, and chemical triggers.[22]

One approach commonly utilized in clinical practice to manage DH is the occlusion of dentinal tubules. Agents facilitate the creation of an intratubular precipitate or an artificial smear layer on the dentin surface, effectively blocking the tubules from being exposed. The deposition of a thin coating layer not only results in the occlusion of the tubules, but also promotes remineralization of the exposed dentin surface. However, so far none of the agents falling into this category have been recognized as a universally accepted best practice for occluding dentinal tubules[23] There are multiple products that can be utilized for treating DH, which can be either recommended by dentists or self-administered by patients. However, the most prevalent approach involves the use of toothpaste for managing DH.[24]

Dentifrices formulated for desensitization have the capacity to rapidly and effectively alleviate DH.[25] Several techniques have been developed for the clinical management of DH, including lasers, ions and salts, fluoride iontophoresis, dentin sealers, and periodontal soft tissue grafts. Recently, innovative biomaterials such as nano-hydroxyapatite crystals have been proposed as a potential treatment for DH.[26]

Dentin, which forms a major part of teeth, contains an inorganic component mainly composed of hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$]. This mineral compound is primarily responsible for the hardness and durability of dentin, contributing to its strong and resilient nature. [3] The hydroxyapatite present in dentin consists of crystallites that are needle-shaped, 3 nm thick, and approximately 60 nm long.[27] Hydroxyapatite nanoparticles are non-toxic, biocompatible, and possess many similarities with the natural hydroxyapatite present in the structure of teeth.[28]

Hence, the present study aimed to investigate the efficacy of hydroxyapatite nanoparticles in blocking the dentinal tubules and its capacity to resist erosive wear.

In the current study, a model of DH was established by sectioning 2 mm thick dentin discs obtained from the mid-coronal region of the tooth. Dentin discs were subjected to a 20-second etching with 37% orthophosphoric acid to expose dentinal tubules and simulate DH,[20] This approach is consistent with the method employed by Khan AS et al. (2020) in their study, where they simulated DH using the same technique to compare the occluding efficacy of two experimental dentifrices.[7]

The outcomes of the current investigation did not support the null hypothesis, as the application of hydroxyapatite showed a beneficial effect in treating DH and enhancing resistance to erosive wear.

The scanning electron microscopy (SEM) findings for the etched control group (Group I) revealed exposed dentinal tubules, thereby confirming the DH model. These observations are consistent with those of AS Khan et al. (2020), who evaluated the dentinal tubule occlusion capacity of a novel dentifrice on dentin discs that were etched with 37% orthophosphoric acid to mimic a DH model. Their study reported that the group treated with artificial saliva did not exhibit any tubule occlusion.[7] Furthermore, the study also verified the effective removal of the smear layer, aligning with the findings of a previous study conducted by K Kripal et al. (2019). They investigated the dentinal tubule occlusion capacity of propolis varnish on dentin discs, which were initially treated with 37% orthophosphoric acid to remove the smear layer. The acid etching process was crucial in opening up the dentinal tubules and ensuring their readiness for further analysis, free from the interference of the smear layer.[29]

Conversely, the SEM micrographs of the hydroxyapatite nanoparticle group (Group II-A) demonstrated superior tubule occlusion, and although some tubule openings were not completely obstructed, but their diameters were reduced. The reason behind this phenomenon is that the hydroxyapatite nanoparticles penetrated the exposed dentinal tubules, obliterating them, thus creating a coating similar to the smear layer. This is in accordance with A Sadiasa et al. (2013), who evaluated the efficacy of a Carboxymethyl cellulose (CMC) dental hydrogel loaded with 30% hydroxyapatite for treating DH. They achieved this by etching dentin discs with 6% citric acid and subsequently treating them with the fabricated hydrogel. They concluded that the surface of the dentin discs exhibited irregular layers of crystal-like deposits, effectively plugging the opened dentinal tubules after 7 days of therapy. The addition of hydroxyapatite to the hydrogel supplied additional calcium and phosphate ions throughout the mineralization process, facilitating the occlusion of the dentinal tubules.[15]

Hydroxyapatite nanoparticles exhibit improved durability against wear and abrasion.[30] When macroparticles are transformed into nanoparticles, their surface area increases substantially. This increase in surface area results in a marked increase in the reactivity of the nanoparticles, ultimately resulting in greater efficacy.[31] Nanoparticles have the ability to readily penetrate into dentinal tubules that are approximately 2-3μm in diameter, effectively occluding the tubules.[32] Achieving a balance between the benefits of remineralization and reactivity while maintaining stability in the oral environment, is a crucial goal for effectively managing dental hypersensitivity.[10]

In addition, Al-Maliky MA et al. (2014) found that the chemical reactivity of hydroxyapatite nanoparticles allows for their electrostatic attachment to the negatively charged terminals of demineralized intra-tubular collagen fibrils, due to their nanoscale size.[33] Following the loss of minerals from dentin, collagen fibers become exposed and are subsequently broken down by enzymes that exist within the body. This process can significantly compromise the mechanical strength and resilience of the dentin structure.[34] At the nanoscale level, the mechanical properties of dentin are governed by the process of intrafibrillar mineralization. The presence of calcium ions can initiate the self-assembly of oligopeptides, leading to the formation of an amorphous precursor and subsequent intrafibrillar mineralization of reconstituted collagen fibrils.[35]

Moreover, the diameter of nanohydroxyapatite particles falls within the nanometer scale, which is significantly smaller than that of the dentinal tubules. In general, reducing the particle size of a material leads to an increase in both its surface area and chemical reactivity. When comparing equal masses of the same material in nano- and micrometer particle diameters, the surface area and chemical reactivity of the nanoparticles are roughly 1000 times greater.[33]

Additionally, due to their larger surface area, hydroxyapatite nanoparticles have a greater capacity to form strong bonds with both proteins and bacterial or plaque fragments. Their exceptional biological activity and reactivity allow them to effectively bind to the apatite in dentin and tooth enamel.[36]

Furthermore, DW Elkassas (2016) investigated how the utilization of nanohydroxyapatite, self-assembling peptides, and resin-modified glass ionomer (RMGI) technologies compared to traditional sodium fluoride varnish affected the degree of occlusion of dentinal tubules. They concluded that the process of remineralization began as circumferential intra tubular peripheral deposits after 24 hours.[37] Afterward, these nanoparticles acted as biologically active templates, drawing in significant amounts of Ca2+ and PO4 from the remineralization solution and encouraging the occlusion of dentinal tubules.[33]

Moreover, E Bologa et al. (2020) applied three commercial nanohydroxyapatite desensitizing toothpastes: Karex, Biorepair Plus Sensitive, and Dr. Wolff's Biorepair on etched dentin discs, and demonstrated different percentages of tubule occlusion. The groups that were washed with Karex (applied to group 1) and Biorepair Plus Sensitive (applied to group 2) exhibited superior tubule occlusion compared to the other groups, indicating significant closure of the tubules through mineral depositions.[17]

Nonetheless, SEM results of the hydroxyapatite nanoparticles group that was subjected to erosive challenge (group II-B) showed more occluded dentinal tubules than the etched control group (group I) but less than those found in hydroxyapatite nanoparticles group (group II-A). The use of CMC dental hydrogel scaffold loaded with hydroxyapatite nanoparticles effectively occluded the exposed dentinal tubules and demonstrated resistance against erosive challenges, maintaining tubule occlusion even after brushing cycles.

In this research, we examined the erosion-resistant properties of hydroxyapatite nanoparticles when subjected to conditions simulating exposure to citric acid at a pH level commonly encountered in acidic beverages.[38]

This aligns with a recent study by Monteiro Filho G et al. (2023), who investigated the impact of an experimental varnish containing 20% nano-hydroxyapatite and 5% stannous chloride on erosive-abrasive wear caused by 0.3% citric acid on bovine dentin. The study revealed that the experimental varnish containing nano-hydroxyapatite achieved statistically significant results, with more occluded dentinal tubules compared to the etched control group.[39]

This is due to the fact that nano-hydroxyapatite provides a foundation for the remineralization of dentin following erosion.[36] Moreover, nano-hydroxyapatite particles are recognized for their properties that closely resemble biological apatites, distinguishing them from larger synthesized hydroxyapatite particles.[40]

The findings of the present study were also confirmed by Ashraf R and Aidaros N (2021), who revealed that dentin discs treated with a nano sea shell paste capable of producing hydroxyapatite were subsequently exposed to an acid challenge, exhibited greater dentinal tubule occlusion compared to the etched control group. However, the level of tubule occlusion was found to be lower than the group that did not undergo an acidic challenge.[10]

Hydroxyapatite nanoparticles can precisely conform to the extremely small cavities that result from acidic erosion of the enamel, resulting in an effective restoration of the enamel's integrity. Therefore, this mechanism can effectively slow down the progression of additional erosive demineralization, thereby contributing to the overall preservation of tooth structure.[30]

Furthermore, the results obtained from energy dispersive X-ray (EDX) analysis indicated a statistically significant difference in the concentration of calcium and phosphorus among the three groups, with the highest concentration observed in the hydroxyapatite nanoparticles group. This was confirmed by A Sadiasa et al. (2013), who revealed that the groups treated with hydroxyapatite nanoparticles exhibited more pronounced peaks of calcium and phosphorous.[15] Moreover, this is in accordance with E Bologa et al. (2020), who concluded that there was a noticeably higher concentration of calcium and phosphorous ions in the study groups that were treated with nanohydroxyapatite desensitizing toothpastes compared to the control group.[17]

The effectiveness of the nano-hydroxyapatite dentifrice may be attributed to the similarity of the particles to the natural hydroxyapatite. The observed outcome can also be attributed to the size of the particles, which facilitates greater contact with the tooth surface and may promote the reorganization of hydroxyapatite and the deposition of calcium and phosphate ions on the demineralized tissue.[41] Studies have shown that hydroxyapatite nanoparticles can act as a template during the remineralization process to facilitate mineral crystal nucleation and development, resulting in the formation of a structure similar to dentin.[42]

However, EDX results of the hydroxyapatite nanoparticles group that was subjected to erosive challenge (group II-B), although it exhibited a higher degree of dentinal tubule obliteration, it displayed lower levels of calcium and phosphorus minerals in comparison to the control group. The results were observed only in Group II-B, as it was the only group subjected to an erosive challenge. While the control group was exposed to a single treatment of 37% orthophosphoric acid for only 20 seconds, Group II-B underwent a more rigorous testing protocol, including immersion in a 0.3% citric acid solution for 2 minutes, 4 times a day, over a period of 5 days. This resulted in a total of 2,400 seconds of exposure to citric acid, which may have contributed to the observed decrease in calcium and phosphorus ions.

This was confirmed by Favretto CO et al. (2018), who conducted research to investigate the impact of incorporating microparticles or nanoparticles of sodium trimetaphosphate, along with fluoride, into toothpaste formulations, in terms of their ability to obliterate the dentinal tubules, pre- and post- citric acid challenge. They concluded that despite variations in mineral contents among different groups, the study found that both the placebo toothpaste and the toothpaste containing 1100 ppm of fluoride showed comparable ability to obliterate the dentinal tubules. Furthermore, they found that following the treatment and subsequent acid challenge, all groups exhibited lower quantities of calcium and phosphorus than those not exposed to the acid challenge. The group treated with nanoparticles of sodium trimetaphosphate and then subjected to citric acid challenge had lower calcium and phosphorous levels when compared the control group that was not subjected to erosive challenge, although it had complete tubular occlusion.[43] This is in accordance with our results in the present study and suggests that there may not be a direct correlation between dentinal tubule obliteration and mineral content.

The Ca/P ratio of the control group was measured at 2.17, suggesting that when dentin discs were immersed in artificial saliva, it resulted in the precipitation of calcium phosphate.[44] It is crucial to note that the Ca/P ratio acquired through EDX analysis cannot determine whether the calcium phosphate present is in a crystalline state (apatite) or an amorphous state. Therefore, caution should be taken when interpreting the connection between the Ca/P ratio and the category of calcium phosphate generated, since the precipitates formed on the surface of dentin may include varying amounts and types of calcium phosphates.[43]

In summary, based on all the SEM and EDX results from the current investigation provides credence to the idea that CMC dental hydrogel scaffold loaded with hydroxyapatite nanoparticles can shield dental pulp from exposed tubules and may lessen or perhaps completely eliminate DH.

CONCLUSION

Carboxymethyl cellulose dental hydrogel scaffold loaded with hydroxyapatite nanoparticles have been shown to be effective in occluding dentinal tubules, which can help reduce sensitivity in patients with dentin hypersensitivity. The present study has shown that these nanoparticles can penetrate deep into the tubules and form a stable mineral layer, providing long-lasting relief from dentin hypersensitivity.

Conflict of interest

We affirm that we have no conflicts of interest.

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