PERSPECTIVES

Electrodeposited biomimetic hydroxyapatite coating, a potential evolution for dentin hypersensitivity

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Dentin hypersensitivity (DH) can be defined as a short sharp pain arising from exposed dentin in response to stimuli—typically thermal, evaporative, tactile, osmotic or chemical—and cannot be ascribed to any other dental defect or disease.1 For decades, various materials have been applied but the effectiveness cannot last for long. Electrodeposition (ELD) of a hydroxyapatite (HAP) coating, a substance that is similar to the mineral composition of teeth and bone, has been successfully used on dental implants to improve their biocompatibility and on enamel to restore caries lesions.2 The strong bond strength and excellent mechanical properties make it suitable for use in occluding the dentinal tubules and relieving DH. Here, we present a hypothesis that the enamel-mimicking composite coating prepared by ELD could be a novel approach for curing of DH, and it may also be a new strategy for the restoration of dentin caries.

DH has long been a troublesome problem for both patients and dentists. It has been reported to affect as much as 57% of the adult population in certain regions.3 Furthermore, the prevalence is still increasing as people retain their teeth longer and consume more acidic foods and beverages. Besides causing acute pain, DH may deter a person from maintaining adequate oral hygiene, further compromising their oral health. The cause of DH has been widely explained by the hydrodynamic theory. This theory postulates that the loss of enamel caused by erosion, abrasion or attrition, etc., results in exposure of patent dentinal tubules. DH occurs when a stimulus, whether thermal, evaporative, tactile, osmotic or chemical, causes fluid to flow through patent tubules and activate the pulpal nerves. Thus, effective treatments for hypersensitive dentin should involve agents that either occlude dentinal tubules or modify nerve sensitivity.

There are a surprisingly large number of treatment options for relieving DH, which can be divided into those of an invasive or non-invasive nature. Invasive procedures may include lasers, the application of resins or crowns, pulpectomy and gingival surgery. Non-invasive agents frequently used can be classified as follows: nerve desensitizers, protein precipitants, tubule sealants and tubule-occluding agents. Potassium salts are most commonly used as nerve desensitizers, but their effectiveness is transient and patients have to repeatedly apply them. Gluma, formaldehyde and other protein precipitants must be applied with extreme caution due to their strong tissue fixation. Tubule sealants and tubule-occluding agents, such as adhesives, resins, fluoride varnish and strontium chloride, have been applied to relieve DH by occluding the dentinal tubules.4 As the occluding materials formed are neither constituents of teeth nor can they adhere to the dentin effectively, unfortunately all of these attempts are relatively short-lived. Thus, bioglass, nano-hydroxyapatite and other apatitic minerals, which are similar to the components of teeth, have also been studied. As the
primary mechanism still relies on mechanical occlusion, however, the materials are easily removed and pain recurr
in most cases. So an ideal method that can immedi-
ately and permanently alleviate this painful condition is yet
to be discovered.

It is well known that carbonate-containing hydroxypaptite crystals are composed of more than 95%wt. of mature enamel and are organized into a unique hierarchical architecture to provide enamel with extraordinary mechanical and antiabrasion properties. So, fabricating structures similar to dental enamel on the damaged dentin maybe the final solution for alleviating DH.

Various methods have been investigated for the in vitro synthesis of enamel-like HAP, such as a hydrothermal technique, sol–gel methodology and a biomimetic method. All of the attempts, however, either require a long reaction time or have to be synthesized under the conditions of high temperature, high pressure and extreme acidic pH, none of which are viable in a clinical setting.

ELD is the process of ion deposition from solution onto the cathode by electrolysis. ELD of HAP coating can be used to coat irregular surfaces and can be carried out under relatively mild conditions. Additionally, ELD could improve the bond strength of the substrate/coatings and also control the thickness, chemical composition, microstructure and crystallinity of the coatings. The key to this technique is that continuous electrochemical reactions can increase the local pH near the cathode resulting in super saturation of calcium phosphate mineral phases, aiding amelogenin self-assembly and then promoting apatite crystal growth.

ELD of HAP coatings have successfully been applied to dental implants. As reported, 1 μm to 10 μm preferential (002) orientation HAP coatings with tight contact with the substrate has been prepared by ELD on human enamel at a current density of 0.5 mA/cm² at 55 °C in 1 hour. In addition, the biomimetic coating prepared from ameloge-
in and calcium phosphate precipitates by ELD exhibited excellent mechanical properties, for example elastic modulus, hardness, fracture toughness and scratch resis-
tance that were the same as those for enamel. Here we put forward a hypothesis that the electrodeposited biomimetic coating could be considered a physiologically compatible way for curing of DH.

First, Ishikawa found that the electrical resistance of sensitive dentin is about 15–50 KΩ, which is in the range of semiconductor. That is to say, sensitive dentin is a semi-
conductor that could serve as an electrode.

Second, as the average tubule diameter of hypersensi-
tive dentin is 0.83 μm, if the 1–10 μm coating could be deposited on the peritubular dentin as well as on the intertubular dentin, it could thoroughly occlude the dentinal tubules. In addition, fluoride iontophoresis, a technique in which fluoride can be transferred deep into the dentinal tubules under an electrical charge, has been successfully utilized in the clinic for curing of DH. Larger particle precipitation and deeper fluoride penetration that could obstruct dentinal tubules has also been observed in iontophoresis-treated teeth. So we can infer that obstruction of dentinal tubules by precipitation of electrical current-driven ions, such as fluoride, calcium and phosphorus, is practicable.

Third, crystals of HA coating arranged their (002) face parallel to the tooth surface which have the preferential orientation similar to enamel apatite could tightly combine themselves to the enamel surfaces. If properly prepared, HAP coatings with preferential orientation similar to dentin that exhibit strong bond strength would also be obtained. Besides, the deposits deep in the dentinal tubules could form many tags that are attributed to the micromechanical interlocking of the coating. Therefore, this biomimetic coating with excellent mechanical properties would be resistant to oral challenges and maintain its effect for a long time.

Besides occluding dental tubules by HAP coating, the application of electrical current may produce paresthesia of the nerves and also form reparative dentin, which can inhibit the passage of stimuli from exposed dentin to the pulp.

In the end, the safety thermal threshold of teeth is 20–50 °C, and it has been stated that oral cells become nonviable above 55 °C. Gangarosa et al also indicated that fluoride iontophoresis at a maximum current of 1 mA is effective and biologically safe. To sum up, ELD of a HAP coating is possible and safe for human use.

Before it can be used clinically, more efforts should be made to examine ELD. First, fundamental research is needed to confirm the best parameters, such as tempera-
ture, current density, etc. Second, efforts to improve the process, e.g. the use of pulse deposition, need to be undertaken. With its evident advantages, the coating, which can repair the lost enamel biomimetically, conve-
niently and at low cost, has the potential to relieve DH immediately and permanently.

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