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Strontium effects on root dentin tubule occlusion and nanomechanical properties

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ABSTRACT

Objectives. Dentin hypersensitivity often is treated by promotion of dentin tubule occlusion. In this in vitro study we evaluated nanomechanical properties and degree of tubule occlusion conferred to sound and demineralized human root dentin following treatment with a 10% (w/w) strontium acetate solution and its relation to the treatment duration and delivery method.

Methods. 24 human cervical root dentin disks (8 groups of 3) were polished through 0.25 μm. 12 disks were subjected to an acid challenge (1% citric acid, pH3.8) for 2 min. The specimens were incubated in artificial saliva, treated by soaking or brushing with deionized (DI) water or a solution of 10% strontium acetate for 2 min twice a day for 28 days. The occlusion percent and nanomechanical properties were determined at the baseline, 5, 14 and 28 days. Cross-sectioned specimens were prepared to evaluate the depth affected by strontium acetate / dentin interaction by SEM. Statistical analysis was performed using linear mixed effects models.

Results. A 10% strontium acetate treatment over 5-28 days significantly increased tubule occlusion for normal root dentin and to a lesser extent for demineralized dentin and increased the AFM based nanomechanical properties of demineralized dentin. Brushing was more effective than soaking in recovery of properties of demineralized dentin when treated with strontium. No difference in tubuleocclusion was found between the two delivery methods.

Significance. Strontium acetate itself proved to have the ability to occlude dentin tubules and result in small changes in the mechanical properties of dentin.

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1. Introduction

Dentin hypersensitivity has become a significant oral health concern in developed countries, where an increased number of people retain their teeth longer [1] and people live longer. In the 20th century life expectancy increased almost 30 years [2]. Increased tooth tissue wear and loss due to abrasion, attrition, abfraction and erosion has become a greater concern. It is reported that non-carious tooth tissue loss occurred in up

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to 80% of children and in up to 43% of adults [3–5]. The Centers for Disease Control and Prevention (CDC) first added tooth wear as a part of the National Health and Nutrition Examination Survey (NHANES) in 2003–2004 [6]. Physical structure loss of the enamel, cementum or surrounding soft tissue will lead to exposed dentin. Once dentin is exposed it is subject to various physical and chemical challenges in the oral cavity. In most cases, sound (not caries affected) exposed dentin can adapt to the environment, probably by tubules naturally being occluded and asymptomatic. In some cases exposed dentin leads to dentin hypersensitivity. It is characterized by sharp short pain triggered by thermal, tactile, or chemical stimuli or evaporation, without any form of dental defect or pathology. There is no reported evidence of pulpal inflammation such as irreversible or reversible pulpitis [7,8]. Common histological findings are enlarged dentinal tubules that occur in areas with larger numbers of tubules per area, when compared with dentin without sensitivity [9,10].

Symptom management ranges from the use of over the counter products (OTC) containing active ingredients that either desensitize the nerve tissue at the base of the dentin tubule or by encouraging the promotion of dentin tubule occlusion. Professional treatments may also include fluoride varnish application to exposed root surfaces, placing a restoration, a gingival graft to cover the exposed roots, or even pulpotomy in severe cases. Improvement of dentin hypersensitivity symptoms is thought to be related to tubule occlusion and/or desensitizing the nerve. KNO_3 is the most commonly used active ingredient in OTC toothpastes. Pashley suggested KNO_3 works by potassium salt reducing the excitability of intradental nerves by altering the extracellular potassium concentration [11]. Occlusion agents are less widely employed but can be favored over nerve depolarization primarily due to the rapid onset of pain reduction associated with the occlusion approach [12]. Several chemicals such as fluoride help to deliver Ca and P into tubules [13], and strontium salts, either strontium chloride or strontium acetate, are found to be very effective in reducing dentin hypersensitivity [14]. Strontium also was reported to have the ability to improve radiodensity and if given prenatally it improves caries resistance [15,16].

Strontium has an atomic radius slightly larger than calcium, and readily substitutes for calcium in minerals. Strontium is known to be able to replace calcium in bone [17]. In the oral environment, strontium and other divalent cations with a similar charge-to-size ratio to calcium can readily substitute in the lattice of hydroxyapatite. Dedhiya et al. confirmed a calcium strontium apatite $Ca_6Sr_4(PO_4)_6\,(OH)_2$ is formed by the substitution of intracrystalline calcium in apatite by strontium [18]. Gedalia et al. reported a significant increase of radiodensity after immersing sound and etched dentin in a 25% (w/w) strontium chloride solution for 24 h. Increased radiodensity was due to formation of Ca–Sr apatite [15]. Strontium has shown high affinity to dentin and apatite similar to other metals used for treating hypersensitivity such as zinc and tin.

Epidemiologically, Curzon et al. reported that there was low caries prevalence where the drinking water contains fluoride and strontium [19]. This synergistic effect of strontium and fluoride was examined by Featherstone et al. [20]. They showed synthesized carbonated apatites precipitated with strontium and fluoride had improved crystallinity and markedly reduced acid reactivity. For low-carbonated apatite, strontium and fluoride together improved the property but fluoride alone did not improve crystallinity. Thuy et al. showed co-presence of appropriate levels of fluoride and strontium showed synergistic effects in remineralizing artificial enamel lesions [21]. These findings are the foundation of using strontium salts in remineralizing tooth paste [22,23].

Generally two approaches have been taken to evaluate the efficacy of proposed treatments. One is evaluating clinical pain improvement *in vivo*, the other is evaluating morphological or structural change *in situ* or *in vitro*. Reports are lacking on the modification of mechanical properties of dentin and tubule occlusion treated with occlusion agents purported to operate by a mineralization mechanism. It is possible that occlusion by mineralization could alter the nano-structure of dentin. In this *in vitro* study we evaluated nanomechanical properties and degree of tubule occlusion conferred to sound and demineralized human root dentin following treatment with a 10% (w/w) strontium acetate solution and its relation to the treatment duration (up to 28 days) and delivery method (brushed/soaked).

2. Materials and methods

Sound, single-rooted teeth were collected from subjects requiring extractions following a protocol approved by the UCSF Committee on Human Research. Teeth were sterilized by gamma radiation and stored in Hank's balanced salt solution (HBSS) until used [24]. Hypersensitivity most commonly presents on buccal cervical surfaces of permanent teeth thus those areas are recommended for clinical studies [25]. We elected to use the root dentin to meet the same recommendation. Dentin blocks from the buccal surface of the root, just below the dentin-enamel junction were prepared by cutting with a diamond saw under water (Buehler, Lake Bluff, IL), then polished with diamond suspensions on polishing cloths (Buehler, IL) to 0.25 μm. Surfaces were prepared to be parallel to the root surface so the dentin tubules were approximately perpendicular to the surface (Fig. 1). Teeth with visible abrasion of the cervical area were not used. Specimens were prescreened for tubule occlusion with AFM and those with more than 25% occlusion, assessed visually at baseline, were excluded from the study.

Experiment 1 tested *in vitro* strontium acetate treatment of dentin blocks in artificial saliva up to 28 days. Variables evaluated were the delivery method (soaking or with brushing), length of treatment (5–28 days) and condition of the dentin (sound or etched). We evaluated changes in tubule occlusion and nanomechanical property change with AFM. Experiment 2 evaluated strontium acetate interaction with sound dentin, utilizing SEM/EDX. Cross-sectioned specimens were prepared to evaluate the depth affected by strontium since the evaluation in experiment 1 was detecting the accumulated changes at the treated surface.

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