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Objective and quantitative assessment of caries lesion activity

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ABSTRACT

Objectives: Evaluate the ability of objectively measured specular reflection, roughness, and fluorescence change during dehydration to assess caries lesion activity.

Methods: One hundred ninety-five ground/polished 3 × 3 × 2 mm sound human enamel specimens were divided into three groups and demineralized using a multispecies microbial caries model for 3, 6, or 9 days; and then remineralized with 1100 ppm-F as NaF solution for 10 days using a pH-cyclic model. Reflection (amplitude: %), roughness (Ra: μm), fluorescence change during dehydration (ΔQ: % × mm^2), and microfocus computed tomography [μ-CT: lesion volume (μm^3)] were measured for sound, demineralized and remineralized enamel. The surface was hydrated and fluorescence images were acquired at 1 s intervals for 10 s (ΔQ_{10}). During image acquisition, surface was dehydrated with continuous compressed air. Changes-in-ΔQ per second (ΔQ_D: % × mm^2/sec) at 5 (ΔQ_{D5}) and 10 s (ΔQ_{D10}) were obtained.

Results: Reflection decreased from sound to demineralized groups ($p < 0.0001$); remineralized groups were higher than demineralized groups ($p < 0.001$), but not different from sound ($p > 0.32$). Roughness increased from sound to demineralized groups ($p < 0.0001$) and remineralized groups were also higher than sound ($p < 0.0001$). ΔQ_{10}, ΔQ_{D5} and ΔQ_{D10} increased from sound to demineralized groups ($p < 0.0001$), and remineralized groups decreased compared to demineralized groups ($p < 0.05$), but was higher than sound ($p < 0.0001$). The correlations of μ-CT with reflection, roughness, and ΔQ_{10} were −0.63, 0.71, and 0.82, respectively ($p < 0.0001$).

Conclusions: Reflection, roughness and ΔQ could distinguish between sound and demineralized enamel. Reflection and ΔQ were able to distinguish between demineralized and remineralized enamel.

Clinical significance: Determination of caries activity, whether a lesion is active or inactive, is an essential and critical component of caries diagnosis. However, especially for enamel lesions, it is difficult to estimate without longitudinal follow-up. Reflection, roughness and fluorescence change during dehydration have the potential to measure caries lesion activity at a-single-appointment.

1. Introduction

Although the prevalence of dental caries has decreased, the disease is prevalent in all age groups [1]. A systematicreview and metaregression showed that in 2010, untreated caries in permanent teeth was the most prevalent condition worldwide, and untreated caries in deciduous teeth was the 10th most prevalent condition [2]. A lesion considered to be progressive, where the lesion continues to demineralize, would be described as an active caries lesion. A lesion that has stopped further progression (stagnant/remineralized) is referred to as an inactive/arrested caries lesion [3]. Determination of caries lesion activity, whether a caries lesion is active or inactive/arrested caries lesion, is an essential and critical component of appropriate caries diagnosis. Therefore, activity assessment is of paramount importance for correct clinical decision-making for management of caries lesions at the time of examination and treatment planning process. However, the activity of non-cavitated enamel lesions (white-spot lesions) is difficult to estimate with currently available methods without longitudinal examinations. Previous studies demonstrated objective evaluation of caries lesion activity [4–6]. An infrared camera was used to measure the

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temperature descent at the demineralized enamel surface during dehydration [4]. The results indicated that positive correlations were found between the parameters of the infrared camera and those of the gold standard. Pulse thermography was used to measure the thermal response of sound, demineralized and remineralized enamel [5]. By measuring the spatial thermal decay time, this method has the potential to quantify differences among these three stages of enamel surface status. Near-infrared reflectance imaging was used to measure the degree of enamel remineralization and determine its correlation with the rate of water loss [6]. It appeared that near-infrared imaging is suitable to detect enamel remineralization during dehydration. Despite the success of these studies, one of the limitations was their cross sectional design. None of the studies demonstrated the ability of these methods to follow longitudinally sound, demineralized and remineralized stages.

The fundamental hypothesis of this current study is that enamel caries lesion activity is measurable and it can be determined by monitoring changes in the degree of tooth surface porosity. This hypothesis is based on several observations. At the surface level, the initial stage of demineralization is characterized by development of microchannels and surface softening [7–10]. As demineralization progresses over time, these microchannels become wider and longer [11]. When enamel surfaces are hydrated/wet and in an inactive stage, these surfaces should be smoother than surfaces that have microchannels. In addition, when light rays strike a smooth surface, the reflected rays are parallel to each other. This is known as specular reflection and surfaces that cause specular reflection appear shiny. Dehydrated/dried surfaces and those presenting microchannels result in an irregular, rough surface that reflects light rays in various directions. This causes the surface to appear dull (non-glossy) as seen in active caries lesions. Ando et al. [12], demonstrated as the surfaces demineralized, reflection (appearance) measured by optical reflectometry was decreased and roughness (texture) measured by surface profilometry was increased. These results suggest the possibility of characterizing enamel demineralization objectively and quantitatively by measuring specular reflection and roughness.

When non-cavitated enamel lesions are hydrated/wet, microchannels are filled with water and the amount of water is larger in active lesions (demineralized enamel) than in inactive lesions (remineralized enamel). The difference between the refractive index of water (1.33) and that of enamel crystal (1.62) is minimal, and the air has a lower refractive index (nearly 1.0). When the non-cavitated lesion, in either an active or inactive stage, is dehydrated with air filling porous areas, the amount of light scattering increases. As the surface dehydrates, the lights scattering is more pronounced in demineralized enamel (active stage) than in remineralized enamel (inactive stage). Thus, the hypothesis of this study was that the rate of vaporization of water in the lesion body during dehydration, as measured by fluorescence change determined by quantitative light-induced fluorescence (QLF) technique, would indicate caries lesion activity (Fig. 1). The rate of evaporation (vaporization) would be more pronounced in active lesions than in inactive lesions; therefore, the change-in-QLF variables per second (ΔQLF_D) during dehydration would be distinctly different between active and inactive lesions. Studies have demonstrated the possibility of the QLF technique to assess caries porosity as a surrogate of caries lesion activity [13,14]. Ando et al. [15], demonstrated in extracted human teeth that during the first few seconds of dehydration by continuous-compressed air, the change-in-QLF variables per second (ΔQLF_D) for active lesions was larger than those of inactive lesions. This suggests that ΔQLF_D during the first few seconds of dehydration by continuous compressed air might be able to differentiate between active (demineralizing) and inactive (remineralized) caries lesions at the time of examination. Pilot clinical study also revealed that QLF variables, such as lesion size and ΔQ, during dehydration indicated increments for lesions designated as active and minimal change for lesions defined as inactive [16].

These previous studies demonstrated that reflection, roughness and QLF variables during dehydration could monitor/follow progression of demineralized enamel. Moving towards the next step, it is important to demonstrate these techniques could monitor regression of demineralized enamel (remineralization). Therefore, the primary objective of this study was to evaluate whether enamel caries lesion activity could be determined objectively by specular reflection and roughness. The secondary objective was to evaluate the validity and reliability of objective and quantitative means of real-time fluorescence imaging

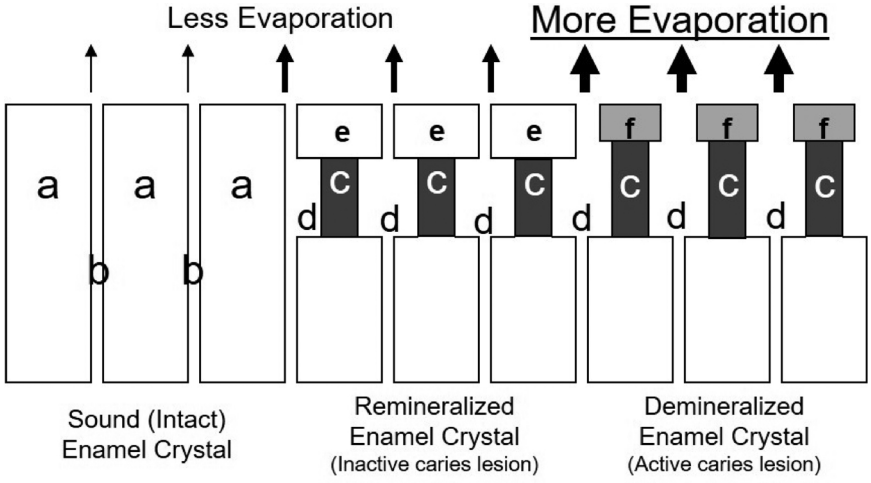

Fig. 1. Schematic diagram of surface dehydration hypothesis of this study at the lesion body level.