Structural and Elemental Three-Dimensional Analysis of Dentin Occlusion

Shiyou Xu[*1] and Long Pan[1]

[1.] Colgate-Palmolive Technology Center, Piscataway, NJ, USA.
*Corresponding author: Shiyou_Xu@colpal.com

Dentin hypersensitivity is the common diagnosis of short, sharp pain occurring in exposed dentin due to thermal, evaporative, tactile, osmotic, or chemical stimuli, etc. [1]. The dentin consists of a number of tubules that connect the dentin-enamel junction to pulpal nerve fibers, varying in size and orientation [1], [2]. Dentin tubules become exposed due to gingival recession or enamel erosion, leaving the pulpal nerve fibers at a risk of stimulation due to dentinal fluid movement or other pain provoking stimuli [1], [2]. The diagnosis of dentin hypersensitivity occurs most frequently in 20 to 30 year-olds, with more than 40 million people in the US reported to be effected [1]. Due to the prevalence and the large number of years, scientists have known about dentin hypersensitivity, there have been many treatments developed to combat it.

There are a number of treatments available for dentin hypersensitivity, either as over-the-counter or in-office, which can be classified according to mode of actions including: nerve desensitization, protein precipitation, tubule occlusion, neural action, anti-inflammatory effect, or covering the dentin surface, etc. [3]. One of the most effective treatments, of which Colgate holds a leading position, is the use of dentifrice in occluding the tubules (dentin occlusion) to create a barrier from foreign matter and stimuli.

To determine the efficacy of dentifrice used to occlude the dentin tubules, it is necessary to be able to see the tubules and image them for data analysis. This is difficult to accomplish as a result of the dentin tubules occurring on the micron scale. However, with the use of a scanning electron microscope (SEM), high resolution images can easily be procured. The SEM utilizes an electron beam to create images on the micron and nano scale and can be used concurrently with a focused ion beam (FIB) [4]. Several different functions can be accomplished using the FIB, such as milling, gas injection coating, and imaging. The most important use of the FIB is to mill specimen to obtain cross-sectional views of the specimen using the milling capabilities. Using the milling of the FIB to cut slices, a series of high resolution images can be taken of a specimen's cross-section that can be put together to create three-dimensional (3D) reconstructions of the specimen, which can be referred to as a structural 3D reconstruction. Further, a series of EDS mappings can also be obtained and put together to generate an elemental 3D reconstruction of certain elements inside the dentin tubules, which can referred to as an elemental 3D reconstruction.

In this paper, we present the structural 3D reconstruction and the elemental 3D reconstruction of dentin disks treated by two different tooth pastes (TPs).

FIG. 1a shows a typical cross-section view of a dentin tubule occluded with $CaCO_3$ particles which is the major ingredient of the TP. Since the contrast between $CaCO_3$ and the dentin disk is substantially low, as shown in FIG. 1b, the particles were highlight with green color to increase the contrast. Then, Dragfly$^@$ software was used to reconstruct the occlusion of the $CaCO_3$ particles in the dentin tubule using a serial of 51 cross-sectional images. As shown in FIG. 1c, the 3D structure of the $CaCO_3$ particles inside the dentin tubule was obtained. The 3D structure indicated that the dentin tubule was well occluded by $CaCO_3$ particles (TP), which is correlated to the superior efficacy of Colgate TP for treating dentin hyposensitivity. Other information, such as the compactness and occlusion depth, etc., can also be obtained from the 3D structure.

FIG. 2a and 2b show typical carbon (C) and silicon (Si) EDS mappings of the cross-section of the dentin tubules treated by another TP. The major ingredient of such a TP for occluding the dentin tubules is silica. These mapping images were converted into black-whited images with enough contrast to highlight Si. C was selected to represent the dentin disk. Then, a serial of 12 images were collected and used to reconstruct silica particles occluded in the dentin tubules; and a type structure is shown in FIG. 2c. FIG. 2d illustrates only the silica structures inside the tubules; and FIG. 2e illustrates only one silica plug. From these 3D structures, it is easily to claim that this TP is able to occlude the dentin tubules and thus treat the dentin hyposensitivity. Further, it can be confirmed that the material occluding the dentin tubules is the silica in the TP.

The two methodologies described here are new ways to visualize dentin occlusion; and allow collecting data to correlate the efficacy of the dentifrice with detailed structures and elemental distribution.

References:

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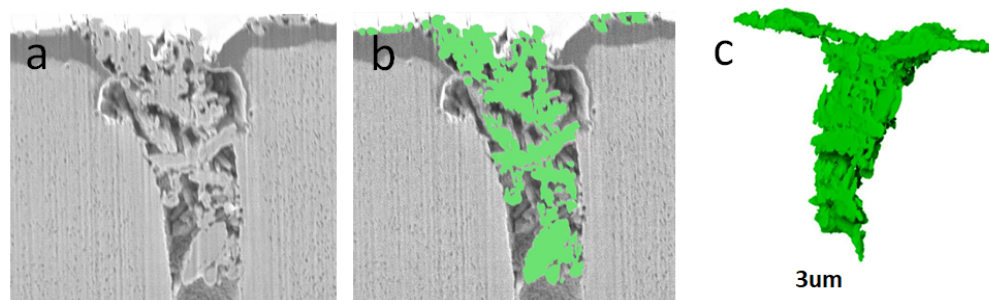
Figure 1. Structural 3D reconstruction: a. cross-sectional SEM image; b. with particle highlighted; and c. 3D structure of the particles occluded in a dentin tubule
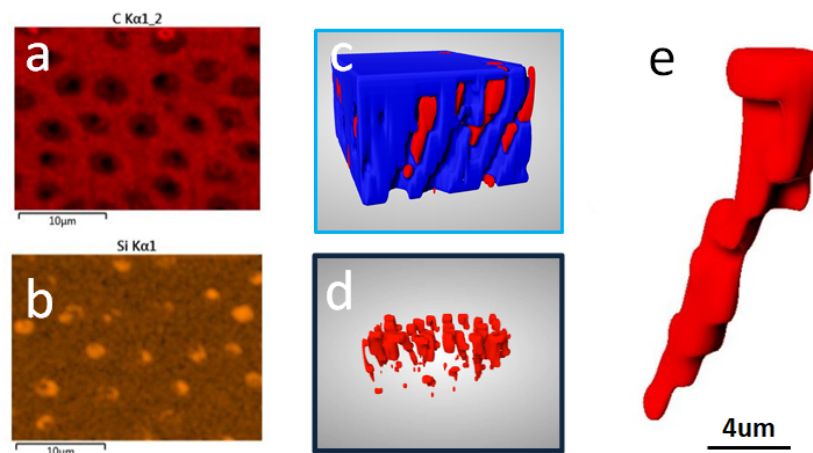
Figure 2. Elemental 3D reconstruction: a. and b. C and Si EDS mappings; c. Si (red) occluded in the dentin tubules (blue); d. Si self; and a single Si structure occluded in one dentin tubule.