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Development of polarization dental imaging modality and evaluation of its clinical feasibility

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ABSTRACT

Objectives: In the evaluation of tooth color, the specular reflection caused by roughness or saliva on the tooth surface may cause artefacts in image analysis. In this study, a polarization dental imaging modality (PDIM) was developed to obtain cross-polarized images and, therefore, to address the problem of specular reflection. Its clinical validity was evaluated by performing 3 studies of shade tab selection for implant, plaque distribution detection, and evaluation of tooth whitening.

Methods: *In vivo* human tooth and shade guide color images were obtained, and the minimum color difference between them was calculated for the best color matching shade tab selection. A dental plaque disclosing agent was used to differentiate plaque regions on teeth, and plaque distribution was detected by applying the *K*-means algorithm. *In vivo* human teeth were treated with a commercial tooth whitening gel, and tooth whitening was quantitatively evaluated using the PDIM images.

Results: The PDIM produced repeatable glare-free tooth color images by effectively removing the specular reflection from the tooth surface. The cross-polarized tooth images were successfully utilized for shade guide selection, plaque detection, and tooth whitening by minimizing artefacts in the quantitative image analysis. The PDIM could simultaneously provide both qualitative and quantitative assessment of the tooth condition in clinical diagnosis.

Conclusions: The clinical feasibility of the PDIM was successfully verified in 3 clinical studies by showing its clinical efficacy as a new imaging modality.

1. Introduction

Accurate color evaluation is an important factor in aesthetic dental procedures such as tooth whitening. The discoloration of gums has also become a concern with the increasing frequency of cosmetic treatments.[1] The conventional method of evaluating tooth color is visual observation by the naked eye; however, it is impossible to obtain objective color information by this method, since any method for evaluating tooth color that involves a visual observation will provide exclusively subjective color information. Color measurement devices such as colorimeters and optical spectrometers have been used in dentistry in order to acquire quantitative color information for a specific narrow region.[2–5] However, these devices do not provide image information, and might have motion artefacts caused by hand-piece-type probes. Although the digital color imaging modality provides image information, it does not provide quantitative information on tooth color. Moreover, the specular reflection caused by saliva or

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roughness on the tooth surface might cause artefacts in image analysis.[6]

In this study, a polarization dental imaging modality (PDIM) and image analysis methods were developed to address the limitations of the currently available methods for tooth color evaluation so as to improve the efficacy of the evaluation of tooth color. Unlike colorimeters, optical spectrometers, and digital color cameras, the PDIM provides both quantitative and qualitative information on tooth color and minimizes motion artefact during image acquisition. Its primary advantage is to provide cross-polarized tooth color images that eliminate specular reflection from the tooth surface.[7] In this study, we evaluated its clinical validity by performing 3 studies of shade tab selection, detection of plaque distribution, and evaluation of tooth whitening.

2. Materials and methods

The protocol for this study and the informed consent form were approved by the institutional review board of Yonsei University Wonju Medical Center, Wonju, Korea.

2.1. *Polarization dental imaging modality*

Fig. 1 shows a PDIM that provides glare-free tooth color images by utilizing the principle of cross-polarization. It mainly consists of a digital color camera (Canon EOS 450D; Canon Inc., Tokyo, Japan) and a ring-shaped white LED light (HW321A; Siretech, Sungnam, Korea) around the camera (Fig. 1(a)). Two linear polarizers (Model A45-669; Edmund Industrial Optics, Barrington, NJ, USA) were mounted perpendicularly in front of the camera and the light source to enable cross-polarization (Fig. 1(b)).

In order to evaluate the advantage of cross-polarized images, 5 non-polarized and 5 cross-polarized tooth color images were acquired at a time interval of 5 min from a single subject in a dark room. The camera was set as follows: (1) shutter speed, 1/80 s for non-polarized images and 1/10 s for cross-polarized images, and (2) ISO 100 and f/5.6 for both images. Both types of tooth color images were converted into Commission Internationale de l'Eclairage (CIE) $L^*a^*b^*$ color images using a MATLAB program, in which the standard observer was 2-degree observer, and illumination was International Color Consortium (ICC) standard profile connection space illuminant with a 16-bit fractional approximation of D50. The tooth color images were quantitatively analyzed by calculating statistical CIE $L^*a^*b^*$ values from an identical tooth of interest. The repeatability of image acquisition was quantitatively evaluated by calculating percent relative standard deviations (PRSDs) as follows:

$$\text{PRSD}\ (\%) = 100 \times \left| \frac{\text{standard deviation}}{\text{average}} \right| \quad (1)$$

where lower PRSD means better repeatability in image acquisition.

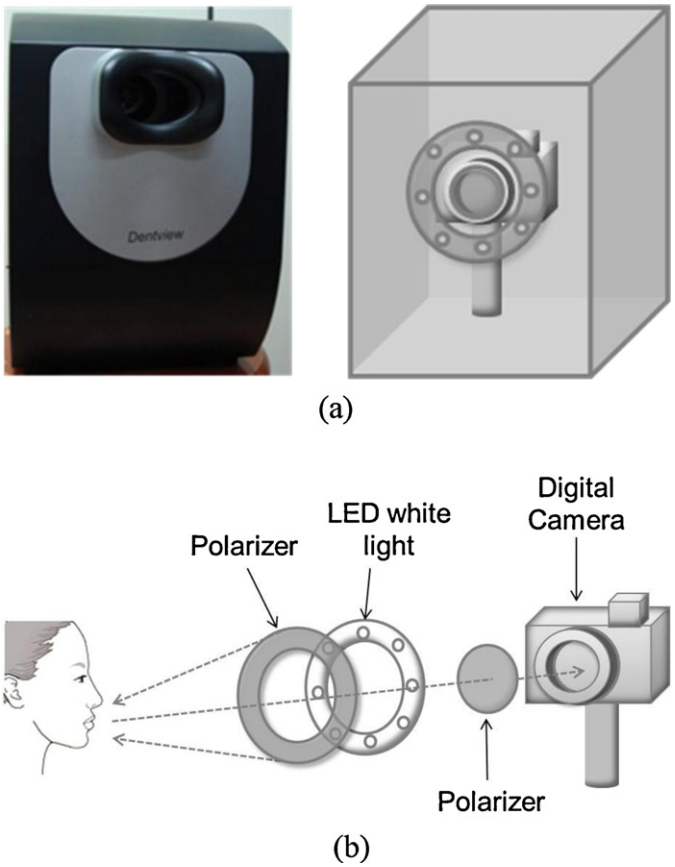

Fig. 1 – (a) Polarization dental imaging modality (PDIM) and (b) its schematic diagram. The PDIM consists of a digital color camera and 2 linear polarizers mounted at perpendicular to each other.