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Original article

Evaluating the influence of ambient light on scanning trueness, precision, and time of intra oral scanner

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ABSTRACT

Purpose: This study evaluated the influence of illuminance and color temperature of ambient light on the trueness, precision, and scanning time of a digital impression.
Methods: Master data were acquired with a high-accuracy coordinate-measuring machine. The illuminance of ambient light was set at 0 lux, 500 lux, and 2500 lux with a light-emitting diode (LED). Using a conversion filter, the color temperature was set at 3900 Kelvin (K) (yellow), 4100 K (orange), 7500 K (white), and 19,000 K (blue). There were thus a total of 12 possible lighting conditions. The reference model was scanned five times under each condition by an intraoral scanner. Trueness was calculated as the mean difference between the master data and experimental data. Precision was calculated as the mean difference between the repeated scans in each test group. Statistical analysis was performed with two-way analysis of variance (ANOVA) and post hoc Tukey's multiple comparison test. The significance level was 0.05.
Results: For trueness, the mean deviation was significantly lower at 500 lux than at 0 lux and 2500 lux. At 500 lux, the mean deviation was significantly lower at 3900 K than at other temperatures. Regardless of the color temperature, the scanning time was significantly longer at 2500 lux than at other illuminance levels.
Conclusions: The 3900 K and 500 lux condition is the most appropriate lighting condition for taking a digital impression. This condition is typical of clinical settings. High illuminance ambient light increased the scanning time.

1. Introduction

A digital impression has many benefits such as improving patient acceptance, reducing the distortion of impression materials, and three-dimensional previsualization of the preparation, and it is cost- and time-effective [1]. Moreover, a digital impression has high patient satisfaction because it does not involve noxious stimuli (e.g., suffocation hazard, gagging, and taste irritation) [2], and it reduces the clinical treatment time (e.g., retaking and curing time) [3–7].

The improved performance of intraoral scanners has led to a dramatic evolution in the accuracy of digital impressions. The accuracy of a digital impression is determined by trueness and precision [8]. Trueness is the deviation of the scanned data from the original geometry. Precision is the deviation between repeated scans of the same sample [9–11]. Some *in vitro* studies [10,11] have evaluated the trueness of digital impressions. In these studies on full arch impressions, the trueness of the digital impression was lower than that of the conventional method using polyvinyl silicone (PVS). However, other studies [12–17] have reported no significant difference in the marginal fit of crowns between crowns fabricated with a digital impression and crowns fabricated with the conventional method. Moreover, the investigators of these studies concluded that the accuracy of the marginal fit of crowns fabricated with digital impression was clinically acceptable. Some studies [10,11,16,17] have evaluated the precision of digital impressions. In *in vitro* studies [10,11] on full arch impressions, the precision of the digital impression was lower than that of the conventional method using PVS. One study [16] evaluated *in vivo*

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precision of full arch digital impressions and reported lower precision with digital impressions than with the conventional method using PVS. By contrast, no significant difference has been demonstrated between *in vivo* precision of the quadrant arch digital impression and the conventional method [17]. The accuracy of the crown and the restoration fabricated with digital impression were, therefore, clinically acceptable. However, the accuracy of the *in vivo* digital impression and full arch digital impression were inferior to that of the conventional method [10,11,17].

In recent years, some studies [5,7,18] have evaluated the efficiency of digital impressions. Efficiency was evaluated based on the operator's perception, preference, patient's perception, and operating time. The results of these studies revealed that the digital impression was a more efficient technique, compared to the conventional method. In addition, one study of hygienists reported that appropriate training could change the efficiency of taking digital impressions [19].

The accuracy of digital impression reached clinically acceptable levels with improvements in the performance of intraoral scanners; however, the accuracy of the conventional method was higher than that of digital impressions. The following factors influence the accuracy of digital impression. First, saliva has a negative effect on digital impressions because it washes out the powder used in an intraoral scanner. Moreover, a saliva film over the surface of the teeth causes the geometry of the objects in the area to be misread by the scanner [20]. Second, the scanning protocol influences a digital impression. Some studies [21] reported that an inadequate scanning protocol results in an inaccurate digital impression. Third, investigators in the engineering field have reported that ambient light affects the coordinates measured by three-dimensional scanning [22]. That study also concluded that the complete absence of ambient light was most appropriate for digitizing. However, no study has investigated the influence of ambient light on three-dimensional scanning in the dentistry field. This study aimed to evaluate the influence of illuminance and color temperature of ambient light on the trueness, precision, and scanning time of digital impressions. The illuminance is the total luminous flux (flow of light energy) incident on a surface per unit area, and the color temperature is the temperature (K) at which the color of the source would be evoked by the radiant energy of an ideal black body.

2. Materials and methods

2.1. Master data

A mandibular dentulous model (500H-1; Nissin Dental Products, Inc., Kyoto, Japan), which contains the first and second premolars and the first and second molars, was prepared as the reference model. The master data were constructed with the scanned first premolar to second molar on the reference dentulous model by using a high-accuracy noncontact three-dimensional coordinate measuring machine (Infinite Focus G5; Alicona Imaging, Graz, Austria). The scanner delivered high accuracy with a precision of $1.6 \pm 0.6\,\mu m$ and a trueness of $5.3 \pm 1.1\,\mu m$ [10,11]. The surface of the reference models were uniformly sprayed with titanium dioxide powders (High-Resolution Scanning Spray; 3M St. Paul, MN, USA) for constant reflectivity before scanning. The scanning order was (1) the scanned occlusal surface with the reference model placed horizontally to the platform and (2) the scanned buccal surface and lingual surface with the position of the reference model rotated approximately 10–20° to the platform. The experiment room temperature was kept at $22 \pm 1\,°C$. Data from these three scans were superimposed with a best-fit algorithm and converted to one data value.

2.2. Experimental data of the intraoral scanner

The experimental data were taken by an intraoral scanner (True Definition; 3M). The accuracy of the intra oral scanner was investigated *in vivo* in previous studies, showing the precision of the quadrant arch was $21.7 \pm 7.4\,\mu m$ [16]. To block environmental light, all experiments were conducted in a darkroom. The temperature of this room was kept at $20 \pm 1\,°C$. The influence of two parameters of ambient light was evaluated: illuminance (lux) and color temperature (Kelvin [K]). The illuminance of ambient light was set with a white LED light (SpotAce; Hayashi Watch-works, Tokyo, Japan). The illuminance was set at 0 lux, 500 lux, and 2500 lux using an illuminometer (510 Lux Meter; Yokogawa, Tokyo, Japan). The color temperature of ambient light was adjusted using a conversion filter (Color conversion filter, Hayashi Watch-works). The color tones of the conversion filter are shown in Fig. 1. The tones used were yellow (3900 K), orange (4100 K), white (7500 K), and blue (19,000 K). Thus, the experiment was conducted under 12 conditions of ambient light, which involved all combinations of the three illuminance and four color temperature conditions. The experimental data were taken by scanning the first premolar to second molar on the reference dentulous model. To ensure accuracy of the scanner and to generate the necessary stochastic pattern per the scanning sprayer guidelines, the reference model was lightly coated with a titanium dioxide powder (High-Resolution Scanning Spray; 3M). The scanning protocol was divided into three steps. The first step involved scanning the occlusal surface by moving the reference model. The second step involved scanning the buccal surface by inclining the scanner wand toward the buccal surface while moving the reference model. The third step involved scanning the lingual surface by inclining the scanner wand toward the lingual surface and scanning the lingual surface. The experimental data were taken five times for each test group. The scanner wand was fixed while scanning the model (Fig. 2). The experimental data were converted to stereolithography (STL) data. The gum parts were thereafter trimmed using computer-aided design (CAD) software (Geomagic Freeform; 3D Systems, Rock Hill, SC, USA).

2.3. Trueness, precision, and scanning time

To assess trueness, the experimental data were superimposed on the master data with a best-fit algorithm ($n = 5$). Deviation analysis was performed using CAD software (CATIA V5; Dassault Systemes, Vélizy-Villacoublay, France). The distance between the corresponding points of two data values were calculated, and color maps indicate the deviation patterns that were made using deviation analysis (Fig. 3). The calculated distances of the two data values were exported as text files. The mean deviation of the aligned data was determined by calculating the average of the 10th and 90th percentiles of the measured distances, using the following equation: average = (90th percentile − 10th percentile)/2. To assess precision, two sets of experimental data values, derived from the five sets in each test group, were superimposed using the best-fit algorithm. Deviation analysis was performed, and color maps were made using CAD software (CATIA V5; Dassault Systems). The deviation analysis was performed for all combinations of the experimental data into each test group ($n = 10$). The scanning time was defined as the time that elapsed from scanning the first premolar to the completion of all scanning processes.

2.4. Statistical analysis

This study focused on two factors: illuminance (0 lux, 500 lux, and 2500 lux) and color temperature (3900 K, 4100 K, 7500 K, and 19,000 K). Normality testing for illuminance and color temperature

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