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New approach to accuracy verification of 3D surface models: An analysis of point cloud coordinates

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ABSTRACT

Purpose: The precision of two types of surface digitization devices, i.e., a contact probe scanner and an optical scanner, and the trueness of two types of stone replicas, i.e., one without an imaging powder (SR/NP) and one with an imaging powder (SR/P), were evaluated using a computer-aided analysis.

Methods: A master die was fabricated from stainless steel. Ten impressions were taken, and ten stone replicas were prepared from Type IV stone (Fujirock EP, GC, Leuven, Belgium). The precision of two types of scanners was analyzed using the root mean square (RMS), measurement error (ME), and limits of agreement (LoA) at each coordinate. The trueness of the stone replicas was evaluated using the total deviation. A Student's *t*-test was applied to compare the discrepancies between the CAD-reference-models of the master die (m-CRM) and point clouds for the two types of stone replicas ($\alpha = .05$).

Results: The RMS values for the precision were 1.58, 1.28, and 0.98 μm along the *x*-, *y*-, and *z*-axes in the contact probe scanner and 1.97, 1.32, and 1.33 μm along the *x*-, *y*-, and *z*-axes in the optical scanner, respectively. A comparison with m-CRM revealed a trueness of 7.10 μm for SR/NP and 8.65 μm for SR/P.

Conclusions: The precision at each coordinate (*x*-, *y*-, and *z*-axes) was revealed to be higher than the one assessed in the previous method (overall offset differences). A comparison between the m-CRM and 3D surface models of the stone replicas revealed a greater dimensional change in SR/P than in SR/NP.

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1. Introduction

The fitness of a fixed dental prosthesis depends on the quality of each process applied, from taking the impression to intra-oral bonding [1]. Important factors that determine the quality of a dental prosthesis include the precision of the marginal and internal fitness. To achieve such precision, an exact duplication of the teeth is preferred [2,3].

Dental models used to create a fixed dental prosthesis are generally divided into traditional stone casts and 3D surface models using a dental CAD/CAM system. A stone cast is made from an impression, whereas a 3D surface model is obtained using an extra-oral scanner (model scanner) and an intra-oral scanner [4]. When using a scanner as a component of a dental CAD/CAM system, the accuracy and precision are important, and the data obtained should be close to the true values [2].

Industrial computer systems are being rapidly introduced into the field of dental production. In addition, a dental CAD/CAM system allows access to new standards for the production speed, precision, and detailing of the dental prostheses used. Furthermore, CAD software enables 3D analysis in the field of fitness evaluation of dental prostheses, as well as the geometrical changes made to an object with a free-form surface, such as a tooth [5–7]. Most previous studies evaluating the accuracy of 3D dental surface models have focused on analyzing all surface offset differences [2,4,8,9]. In contrast, the current study evaluated the measurement precision and accuracy of a 3D surface model in greater detail by measuring the coordinate difference of each point existing within a three-axis space, i.e., the *x*-, *y*-, and *z*-axes. The scanners recently used in dental CAD/CAM systems mostly include optical scanners. However, some optical scanners require an anti-reflection powder coating depending on the surface condition of the subject. Such powder coating can cause deformation of the scan data. Hence, the extent to which the powder coating influences the trueness of the scan data was evaluated.

A 3D surface model serves as a basis for the production of dental prostheses when using a CAD/CAM system, and the precision and accuracy play important roles in a successful prosthodontic treatment. This study consists of two parts. The first part presents a new approach for evaluating the precision of two types of surface digitization devices, i.e., a contact probe scanner and an optical scanner. The second part evaluates whether a stone replica coated with imaging powder (SR/P), as compared with the master die, or a stone replica without such a coating (SR/NP), show dimensional changes.

2. Materials and methods

To create a single master die, the maxillary central incisor of a plastic dental model (AG-3, Frasaco GmbH, Tettnang, Germany) was selected. The tooth was scanned using an optical scanner (D800, 3Shape A/S, Copenhagen, Denmark). A digitalized tooth was formed into a virtual abutment using a haptic device (Phantom Desktop, Sensable Dental, Wilmington, USA) and a CAD program. To meet the conditions of tooth reduction and form an abutment, the incisal reduction was set to 2.0 mm; the axial reduction, to a 1 mm offset; the margin, to a 1.2 mm chamfer; and the vertical angle, to 5°. To apply the milling process, the data in the virtual abutment were converted into a form suitable for use in a CAM program (PowerMILL, Delcam Plc., Birmingham, UK). The master die was made entirely of stainless steel using a CNC machine. To make a stone replica, ten vinyl-polysiloxane impressions (Deguform® Plus, DeguDent GmbH, Hanau-Wolfgang, Germany) were formed based on the master die. The impression material used was addition silicone composed of a catalyst and curing agent with a mixing ratio of 1:1. The manufacturer proposed a 7-min processing time including the mixing time, and a 30-min demolding period at 23 °C. The master die was removed from the impression after 30 min based on the product manual. Type IV dental stone (Fujirock EP, GC, Leuven, Belgium) was applied to the impression when mixed with water and powder at a ratio of 20.0 ml per 100 g, and was left to harden for an hour prior to the impression removal. Ten stone replicas were produced as a result.

2.1. *Repeated digitization of master die and stone replica for precision evaluation*

A contact probe scanner (Incise, Renishaw, Wotton-under-Edge, Gloucestershire, UK) was used for the surface digitization of the master die. A ruby ball with a diameter of 1 mm was used as the stylus tip. The scan interval was adjusted to 0.1 mm, and the scan speed was set to 5 mm/s. The master die was aligned in a position to minimize the undercut. A surface digitization of the stone replica was conducted using an optical scanner (D800, 3Shape A/S, Copenhagen, Denmark). For the stone replica and master die, 11 non-continuous scans were applied under identical conditions (Fig. 1(A)).

2.2. *Digitizing of stone replicas for trueness evaluation*

An optical scanner (D800, 3Shape A/S, Copenhagen, Denmark) was used to make the 3D surface models. Ten stone replicas with a coating of imaging powder (VITA CEREC powder scan spray, VITA, Bad Säckingen, Germany), and ten stone replicas without such a coating, were digitized (Fig. 1(B)). The VITA CEREC powder scan spray is composed of a CEREC propellant, CEREC powder, and CEREC head. The head is a tool providing a connection between the powder and propellant, and helps with spraying in regular amounts. The powder was sprayed as regularly and thinly as possible.

2.3. *Alignment*

First, to evaluate the measurement precision, the first of the 3D surface models made for the master die and the stone replica, which were obtained through repeated scans, were used as the corresponding CAD-reference models (m-CRM and s-CRM) (Fig. 2(A)). The remaining 20 3D surface models were then converted into an ASCII file in a point cloud form after the data on the bottom of the abutment margin were removed (Fig. 2(B)).

Next, to investigate the dimensional changes of the stone replicas, the data on the bottom of the abutment margin, which could affect the alignment, were removed from the 3D surface models of the stone replicas with and without the