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A new, highly precise measurement technology for the in vitro evaluation of the accuracy of digital imaging data☆

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Objectives: Three-dimensional radiological imaging data play an increasingly role in planning, simulation, and navigation in oral and maxillofacial surgery. The aim of this study was to establish a new, highly precise, in vitro measurement technology for the evaluation of the geometric accuracy down to the micrometric range of digital imaging data.
Material and methods: A macerated human mandible was scanned optically with an industrial, non-contact, white light scanner, and a three-dimensional (3D) model was obtained, which served as a master model. The mandible was then scanned 10 times by cone beam computed tomography (CBCT), and the generated 3D surface bone model was virtually compared with the master model. To evaluate the accuracy of the CBCT scans, the standard deviation and the intraclass coefficient were determined.
Results: A total of 19 measurement points in 10 CBCT scans were investigated, and showed an average value of 0.2676 mm with a standard deviation of 0.0593 mm. The standard error of the mean was 0.0043 mm. The intraclass correlation coefficient (ICC) within the 10 CBCT scans was 0.9416.
Conclusions: This highly precise measuring technology was demonstrated to be appropriate for the evaluation of the accuracy of digital imaging data, down to the micrometric scale. This method is able to exclude human measurement errors, as the software calculates the superimposition and deviation. Thus inaccuracies caused by measurement errors can be avoided. This method provides a highly precise determination of deviations of different CBCT parameters and 3D models for surgical, navigational, and diagnostic purposes. Thus, surgical procedures and the post-operative outcomes can be precisely simulated to benefit the patient.
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1. Introduction

Three-dimensional radiological diagnosis plays an increasingly role in assessing anatomical conditions and diagnoses of pathological processes in the field of oral and maxillofacial surgery. It is increasingly used for three-dimensional (3D), virtual reality surgical planning and simulation of the post-operative outcome in

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orthognatic and craniofacial surgery (Nkenke et al., 2004). A prerequisite for accurate registration is a high geometric accuracy of the image data (Eggers et al., 2006; Xia et al., 2000a, 2000b). Computed tomography (CT) is the primarily used image modality in oral and maxillofacial surgery (Carrafiello et al., 2010). In recent years, cone beam computed tomography (CBCT) has become available as an alternative to CT for imaging in the oral and maxillofacial region, and it has also been adopted for 3D virtual reality surgical planning and simulation (Girod et al., 1995; Chen and Chen, 1999; Motohashi and Kuroda, 1999; Eggers et al., 2009). CBCT is advantageous for its low radiation exposure and can be acquired outside the environment of a conventional CT imaging suite (Broer et al., 2005; Hagtvedt et al., 2003; Ludlow et al., 2003; Ludlow and Ivanovic, 2008; Mah et al., 2003). Like CT, it allows 3D reconstruction as well as secondary reconstructions of craniofacial structures from the generated volumetric data set (Hassfeld et al., 2003). Furthermore, 3D imaging data can be used to generate medical models or surgical templates, which are increasingly used in the surgical field. These models and templates can be used for education, preoperative planning, surgical simulation, and intraoperative guidance, for example, in implant placement (McDonald et al., 2001). The use of CBCT-based models and surgical templates can provide significant benefits, including precise implant placement and reduction of risk of damaging adjacent structures.

To simulate surgical procedures and post-operative outcomes in oral and maxillofacial surgery, these medical models have to be highly precise, which requires highly accurate initial data from the 3D radiological diagnosis (Nkenke et al., 2004). This accuracy of the initial data is also prerequisite for a valid superimposition to generate 3D models or surgical templates (Nickenig and Eitner, 2010; Nickenig et al., 2015, 2010).

The aim of this study is to present and evaluate a new, highly precise, in vitro measurement technology for the evaluation of the accuracy of digital imaging data generated by CBCT down to the micrometric scale. Furthermore, this method excludes human errors, thereby avoiding measurement errors and inaccuracies.

2. Material and methods

2.1. Cadaveric specimen

A macerated human mandible that was provided by the Institute of Anatomy (Department I, Friedrich-Alexander-University of Erlangen–Nuremberg) served as a master model. The mandible was prepared with self-sticking standardized reference points (GOM mbh, Braunschweig, Germany) (Fig. 1) (Nokar et al., 2011). These points consist of a central white circle (diameter 0.8 mm) that is surrounded by a black circle (diameter 2.5 mm). Subsequently, the surface was sprayed with rutile (Rutile Titanium White; GOM mbh, Braunschweig, Germany), which was mixed with 95% ethanol by using an air-brush gun. The reference points were protected by a silicone cover, which was removed after the spraying.

Fig. 1. Macerated human mandible prepared for scan. Standardized reference points are used to align the generated master model data in the three-dimensional space.

2.2. Master model acquisition

The mandible was scanned optically with an industrial, noncontact, white light scanner (Atos SO II, GOM mbh Braunschweig, Germany) (Holst et al., 2012, 2011). A measuring volume of

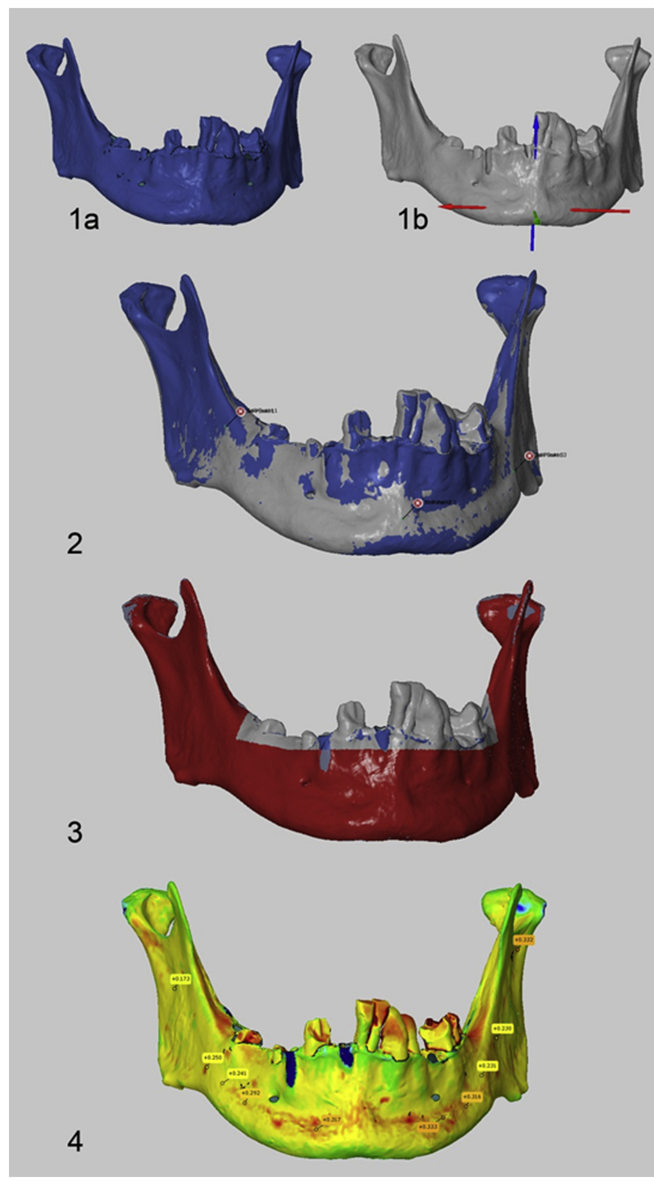

Fig. 2. Different stages of the deviation analysis are as follows: **Stage 1a**: The STL file of the optically scanned macerated mandible was set as an index value (Atos SO II, GOM mbh, Braunschweig, Germany). **Stage 1b**: The CBCT scan data were exported as DICOM, converted into STL file format, imported, and set as actual value. **Stage 2**: A rough alignment was performed by selecting three anatomical points manually. **Stage 3**: A specific area for the best fit software function was selected, and a precise alignment was performed. **Stage 4**: A false colour image was generated, and 19 measurement points (10 vestibular site, 9 lingual site) were determined; the deviation was displayed in millimetres.

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