JJOD 2221 1–6

ARTICLE IN PRESS

journal of dentistry xxx (2014) xxx–xxx

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/jden

A new method to assess the accuracy of a Cone Beam Computed Tomography scanner by using a non-contact reverse engineering technique

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ARTICLE INFO

Article history:
Received 26 October 2013
Received in revised form
28 December 2013
Accepted 30 December 2013
Available online xxx

Keywords:
Cone Beam Computed Tomography (CBCT)
Multi-Slice Computed Tomography (MSCT)
Laser scan
Virtual modelling
Benchmark free form model

ABSTRACT

Objective: Today Cone Beam Computed Tomography (CBCT) has become an important image technique for dento-maxilla facial applications. In the paper a new method to assess the geometric accuracy of these systems was proposed. It uses a free form benchmark model and a non-contact Reverse Engineering (RE) system.

Materials and methods: The test geometry chosen for this study was designed in such a way that it simulated human spongy bone, cortical bone, gingiva and teeth and it composed of removable free form parts. It was acquired with a high-resolution laser scanner (D700 Scanner – 3Shape, Denmark). The reference 3D surface models obtained with the laser scanner was compared with the 3D models that were created from a CBCT system (Scanora 3D – Soderex, Finland) and from a traditional Multi-Slice Computed Tomography (MSCT) scanner (LightSpeed VCT 64 Slice – General Electric, USA) at different reconstruction settings, using an iterative closest point algorithm (ICP) in Geomagic® software.

Results: The comparison between the different pairs of CAD models clearly shows that there is a good overlap between the models.

Significance: The results of this research show that the accuracy of CBCT 3D models is comparable to MSCT 3D models.

1. Introduction

In dentistry the use of two-dimensional (2D) imaging, conventional panoramic X-ray, introduced in the 1960s, has been dominant for many years. Numerous efforts have been made towards three-dimensional (3D) radiographic imaging and although Computed Tomography (CT) has been available, for its relatively high cost, high radiation dose, degradation of the image quality by metallic artefacts[1] and availability limited to hospitals, its application in dentistry has been relegated to investigation of neoplasia or significant developmental disturbance.

Today Cone Beam Computed Tomography technique, for its relatively low cost and low radiation dose[2–5] has created a revolution in maxilla-facial imaging, increasing dramatically the use of CT for an increasing number of dental procedures.[6]

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0300-5712/$ – see front matter © 2014 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.jdent.2013.12.018

Please cite this article in press as: Martorelli M, et al. A new method to assess the accuracy of a Cone Beam Computed Tomography scanner by using a non-contact reverse engineering technique. Journal of Dentistry (2014), http://dx.doi.org/10.1016/j.jdent.2013.12.018

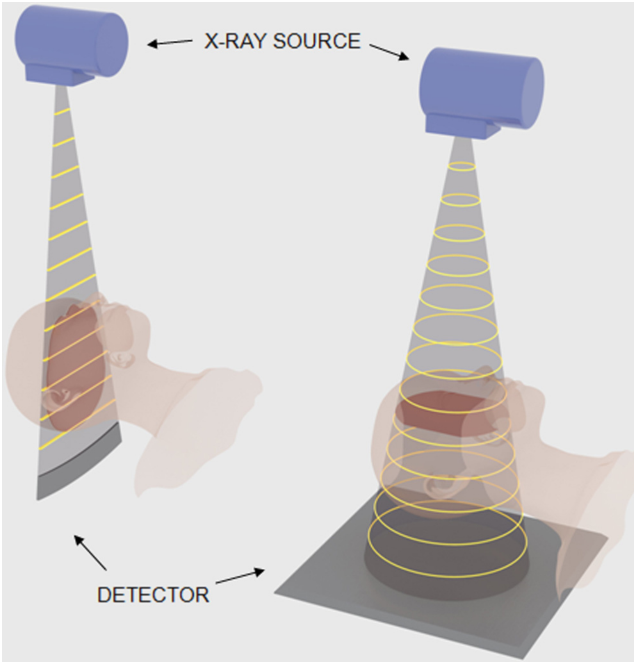

Fig. 1 – Traditional CT (on the left) and cone beam CT (on the right).

The possibility to have 3D models is very useful in dentistry to perform, by using CAD (Computer Aided Design) – FEA (Finite Element Analysis) – RP (Rapid Prototyping) techniques, different virtual and physical simulations using them,[7–13] for example for analyzing their mechanical behaviour with different loading conditions or for a pre-operative surgical planning.[14–16]

With CBCT, unlike the traditional CT that uses a linear detector and a fan shaped X-ray beam, a large detector and a cone shaped X-ray beam are used (Fig. 1) and data are gathered in a single pass. The X-ray source and detector rotate around a rotation fulcrum fixed within the centre of the region of interest. During the rotation, multiple (from 150 to more than 600) sequential planar projection images of the field of view (FOV) are acquired in a complete, or sometimes partial, arc. This makes the CBCT a smaller unit that provides more rapid acquisition of a data set of the entire field of view (FOV).

This procedure varies from the traditional CT, which uses a fan-shaped X-ray beam in a helical progression to acquire individual image slices of the FOV and then stacks the slices to obtain a 3D representation. Each slice requires a separate scan and separate 2D reconstruction. The value of the slices spacing influences the accuracy of the 3D model.[16]

CBCT initially developed for angiography[18] was immediately used specifically for use in maxillofacial area.[19–21] More recent medical applications have included it for radiotherapy[22] and mammography.[23]

The accuracy of 3D models from CBCT has not yet been thoroughly evaluated. The quality of these models is largely dependent on the scanner type, scanning parameters and reconstruction settings.[24]

Aim of this study is to assess the accuracy of 3D surface models with a new approach, using a high resolution laser scanner and a benchmark physical model composed of removable free form parts of different materials to simulate human spongy bone, cortical bone, gingiva and teeth.

2. Materials and methods

For this study a benchmark physical model was designed so that:

- It was a free form object.
- It was composed of removable free form parts for the RE acquisition.
- Its parts were of different materials to simulate human spongy bone, cortical bone, gingiva and teeth for the CT exams.

In Fig. 2 the test geometry designed with these requirements is shown. A set of 6 real human teeth – 11, 21, 22, 23, 24, 25 – were used. The spongy bone, the cortical bone and the gingiva were obtained using acrylic resin with different % of barium, 10%, 20% and 0%, respectively, to simulate as they usually appear, in grey scale, in a CT image[25–27] (Fig. 3).

These free form removable parts were acquired, with and without the gingiva, to get the reference 3D surface models (of the gingiva and the cortical bone), using a high resolution Laser Scanner, D700 Scanner – 3Shape, Denmark (Fig. 4). The accuracy of this system is of ±20 μm, an order of magnitude higher than traditional CT.

These reference 3D models were then compared in Geomagic® software, using an iterative closest point algorithm (ICP)[28,29] to minimize the difference between the models points, with the 3D models created from a CBCT system (Scanora 3D – Soderex, Finland) using the manufacturer's recommended voxel size and with those created from a traditional MSCT scanner (LightSpeed VCT 64 Slice – General Electric, USA) using 4 different reconstruction settings for the voxel sizes, as shown in Table 1.

In Fig. 5 a test geometry CT image is shown. Clearly it is possible to note in it spongy bone, cortical bone, gingiva and teeth as they usually appear, in grey scale, in a CT image for a patient.

3. Results

The 3D CAD models of the benchmark physical model, with and without gingiva, obtained from the laser scanner (named LS models) were considered as the reference 3D models. They were compared, using Geomagic® software (by 3D Systems, USA), with the 3D CAD models obtained from CBCT and MSCT, for a total of 10 comparisons.

Fig. 6 depicts, by means of a coloured map, the deviation check between the 3D CAD reference models (LS models) and the CAD models obtained from CBCT (Fig. 6a and b) and from MSCT (Fig. 6c and d) using the manufacturer's recommended voxel size. The statistical parameters of all 10 comparison are summarized in Table 2.

The values of the standard deviations in the comparisons of the 10 different pairs of CAD models, clearly show that there is a good overlap between the models.

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