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Reducing cone beam CT scan height as a method of radiation reduction for photorealistic three-dimensional orthognathic planning

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A B S T R A C T

Objectives: To determine the superimposition accuracy of full-face stereophotographic images with 22 cm and 13 cm cone beam computed tomography (CBCT) scans.
Material and methods: 22 cm CBCT scans and corresponding stereophotographic images (3dMD) for 30 subjects requiring orthognathic surgery were randomly selected. A 13 cm CBCT scan was generated from the 22 cm scan for each subject. All scans and images were converted into STL format. For each subject, the 22 cm and 13 cm CBCT scans were imported into CAD/CAM software and each superimposed with the corresponding 3dMD image. A one-sample *t*-test was used to test the null hypothesis that the difference in the 90th percentile of the mean absolute distance between the two 3dMD images when aligned on the 22 cm and the 13 cm CBCT scans was not clinically significant (<0.5 mm).
Results: The 90th percentile of the mean absolute distance between the two 3dMD surfaces using the 22 cm and 13 cm CBCT scans was significantly less than 0.5 mm ($p < 0.001$; 0.2 ± 0.2 mm; 95% CI, 0.16–0.30 mm).
Conclusions: There is no difference in the accuracy of superimposition of a stereophotogrammetry image with a 22 cm CBCT scan or a 13 cm CBCT scan. It should now be possible to use a 13 cm CBCT scan and a full-face stereophotogrammetry image during 3D orthognathic planning to reduce radiation exposure.

1. Introduction

Three-dimensional (3D) imaging is widely used in the management of patients with dentofacial deformities for diagnosis, treatment planning and simulation of treatment outcomes (Popat et al., 2010). Digital planning relies on the construction of a patient-specific virtual model obtained by multi-model image capture and fusion (Popat et al., 2010). The process involves superimposition and fusion of the 3D stereophotographic image of the patient with their cone beam computed tomography (CBCT) soft tissue image, creating a photorealistic virtual face. This is followed by replacement of the distorted dentition on the CBCT scan (Swennen et al., 2009). Using appropriate software, virtual surgery can then be performed and a virtual wafer and 3D soft tissue post-surgical prediction produced (Shqaidef et al., 2014; Cousley and Turner, 2014).

At present a 22 cm extended field of view (EFOV) CBCT scan forms the basis of the patient-specific virtual model as it captures the forehead and anterior cranial base with lower radiation doses and shorter scanning times compared with conventional CT scans (Sukovic, 2003). Using this scanning height, errors in stereophotographic image superimposition ranging from 0.27 mm to over 1.5 mm have been reported (Naudi et al., 2013; Xin et al., 2013). The forehead and anterior cranial base on the CBCT scan are important as they are used for superimposition, as stable structures, to assess changes following surgery (Cevidanes et al., 2010; Nada et al., 2011).

A recent study reported hard tissue superimposition on the zygomatic arch as an alternative to superimposition on the anterior cranial base (Nada et al., 2011). In the majority of patients, superimposition on the zygomatic arch requires a reduced field of view, or 13 cm height CBCT scan. This reduction in scan height may be clinically significant in terms of radiation exposure. A 22 cm CBCT scan exposes the patient to 182.1 μSv compared with 110.5 μSv for a 13 cm scan (Roberts et al., 2009). Several vital organs including the brain, eye lenses, and salivary glands are irradiated during an EFOV CBCT scan. These organs are more radiosensitive and thus carry a

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higher tissue-weighting factor (Mountford and Temperton, 1992). Under IRMER guidelines every effort should be made to reduce dose whilst maximizing clinical benefit (Ionising Radiation (Medical Exposure) Regulations 2000 (IRMER), 2012).

In order to utilize a 13 cm CBCT scan for orthognathic planning, the principles of image fusion are still applicable. The replacement of the dentition is not dependent on the scan height, as it appears on both the 22 cm and 13 cm CBCT scan. However the reduced surface area between the 13 cm CBCT and the 22 cm CBCT scan soft tissue may affect the accuracy of superimposition of the full-face stereophotographic image.

Therefore, the objective of this study was to determine the accuracy of superimposition of full-face stereophotographic images onto 13 cm and 22 cm CBCT scans. The null hypothesis was that the mean absolute distances between the 22 cm CBCT aligned full-face stereophotographic image and the 13 cm CBCT aligned full-face stereophotographic image following superimposition differed by less than 0.5 mm, as this would be considered clinically acceptable (Naudi et al., 2013).

2. Material and methods

Ethical approval was granted by the Institutional Review Board (IRB) of The University of Hong Kong and Hospital Authority Hong Kong, West Cluster (Protocol reference no: UW14-115) to access pre-existing data for this retrospective study. The 22 cm extended field of view CBCT scans (i-CAT Imaging System, Imaging Sciences International Inc, Hatfield, PA, USA) and the corresponding stereophotographic image (3dMD, Atlanta, USA) for 30 patients requiring orthognathic surgery were randomly selected. These images were obtained as part of the routine three-dimensional (3D) orthognathic planning protocol.

2.1. Sample size calculation

Based on a previous study (Naudi et al., 2013), the standard deviation of the mean absolute distance between the surfaces of CBCT superimposition and 3D stereophotogrammetry could be as high as ±0.84 mm. Assuming a power of 80%, an alpha value of 0.05, and a clinically significant difference of 0.5 mm, a minimum of 25 individuals were required.

2.2. Inclusion criteria

To enable accurate superimposition and analysis, only patients with complete 3D images; 22 cm CBCT scans and 3dMD images taken pre-surgery were included. For male subjects, only patients with no facial hair were included. All subjects were non-syndromic.

2.3. Exclusion criteria

Patients with incomplete scan data, syndromic patients, and males with facial hair were excluded from this study.

2.4. Image acquisition

For each patient a CBCT scan and the corresponding 3dMD image were retrieved. The CBCT scans were acquired using the i-CAT Imaging System with an EFOV option, producing a 22 cm × 16 cm and 0.4 mm voxel size scan. A 3D photograph was taken using the 3dMD face stereophotogrammetric system. Prior to image capture, patients were instructed to sit comfortably and remain still with the soft tissues in repose. To prevent any facial soft tissue distortion, no head rests or chin cups were used during the scans.

2.5. Data processing

2.5.1. Simulation of 13 cm CBCT scan from 22 cm CBCT scan

A standard 22 cm EFOV CBCT scan consisted of 549 multi-file format DICOM files, whilst a standard 13 cm CBCT scan contained 324 DICOM files. Therefore by deleting the first 225 DICOM files from a 22 cm EFOV CBCT scan it was possible to simulate the output of a 13 cm scan without taking a further scan. Hence, for each patient, a full 22 cm CBCT scan and simulated 13 cm scan were produced in DICOM format. For each patient the two DICOM file datasets were saved as two separate files.

2.5.2. Conversion of CBCT and 3dMD images into a common format

For superimposition the CBCT image (DICOM files) and the 3dMD image (OBJ files) required conversion to a common format. Using Maxilim software (Medicim, Mechelen, Belgium) the 22 cm and 13 cm CBCT scans for each patient were imported and surface models were produced using the default HU (Hounsfield unit) for skin. Each of the 22 cm and 13 cm CBCT soft tissue scans were exported as STL files and saved. Using VRMesh software (VirtualGrid, Bellevue, WA) the 3dMD images in OBJ format were imported and saved as STL files.

2.6. Image superimposition

2.6.1. Initial alignment and image preparation

For each patient the 22 cm, 13 cm CBCT and 3dMD images, all in STL format were imported into VRMesh software (Fig. 1). As the 13 cm CBCT scan was generated from the 22 cm CBCT scan, both images were automatically loaded in the same location in 3D space. The 3dMD image was imported at a different location in 3D space. To group all the images together, the 3dMD image (source) was aligned manually onto the CBCT images (target). Following initial alignment the extraneous data superior to the hairline, inferior to the lower border of the mandible, lateral to the preauricular areas, eyes, eye brows and lips were deleted. The 3dMD image was then moved away (translated) from the CBCT images; all three trimmed images (masks) were individually saved ready for the experimental study.

2.6.2. Accuracy of superimposition of the 3dMD image on 22 cm CBCT and 13 cm CBCT images

For each patient the 22 cm CBCT image together with the corresponding 3dMD image were imported into VRMesh software. Three landmarks, soft tissue nasion and right and left alar bases were identified on both images. Using rigid registration, allowing translation and rotation only, the 3dMD image (source) was superimposed onto the 22 cm CBCT image (target); the superimposition was further refined by using the iterative closest point (ICP) algorithm. The 3dMD image was then saved in the new position in VRML (virtual reality modelling language) format (22 cm CBCT-aligned). The 13 cm CBCT scan for the same patient was then imported into VRMesh software; since it had been generated from the 22 cm image it was in exactly the same 3D space as the 22 cm scan. The 3dMD image was superimposed onto the 13 cm CBCT scan using the same procedure and exported in VRML format (13 cm CBCT-aligned).

2.7. Analysis

2.7.1. Full-face

The root mean square (RMS) value of the distance between the 22 cm CBCT and 3dMD surface was calculated for all patients using Excel (Microsoft software). Using in-house developed software the 90th percentile of the mean absolute distances between the 22 cm