Evaluation of the Accuracy of Distance Measurements on 3D Volume-rendered Image of Human Skull Using Multi-detector CT: Effects of Acquisition Section Thickness and Reconstruction Section Thickness

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ABSTRACT

The image quality of three-dimensional (3D) images has been widely investigated by the qualitative analysis method. A need remains for an objective and quantitative method to assess the image quality of 3D volume-rendered images. The purpose of this study was to evaluate the quantitative accuracy of distance measurements on 3D volume-rendered images of a dry human skull by using multi-detector computed tomography (MDCT). A radiologist measured five times the twenty-one direct measurement line items composed among twelve reference points on the skull surface with a digital vernier caliper. The water filled skull specimen was scanned with a MDCT according to the section thicknesses of 1.25, 2.50, 3.75, and 5.00 mm for helical (high quality; pitch 3:1) scan mode. MDCT data were reconstructed with its acquisition section thickness and with 1.25 mm section thickness for all scans. An observer also measured seven times the corresponding items on 3D volume-rendered images with measuring tools provided by volumetric analysis software. The quantitative accuracy of distance measurements on the 3D volume-rendered images was statistically evaluated (p-value < 0.05) by comparatively analyzing these measurements with the direct distance measurements. The accuracy of distance measurements on the 3D volume-rendered MDCT images acquired with 1.25, 2.50, 3,75 and 5.00 mm section thickness and reconstructed with its section thickness were 48%, 33%, 23%, and 14%, respectively. Meanwhile, there were insignificant statistical differences in accuracy of distance measurements among 3D volume-rendered images reconstructed with 1.25 mm section thickness for the each acquisition section thickness. MDCT images acquired with thick section thickness and reconstructed with thin section thickness in helical scan mode should be effectively used in medical planning of 3D volume-rendered images. The quantitative analysis of distance measurement may be a useful tool for evaluating the quantitative accuracy and the defining optimal parameters of 3D volume-rendered CT images.

Keywords: Multi-detector CT, volume-rendered images, skull specimen, scanning parameter, quantitative accuracy

1. INTRODUCTION

In recent years, the improvement of helical CT has resulted in the advent of multi-detector row CT (MDCT) equipped with multiple detector banks, which offers relatively shorter acquisition times and increased longitudinal (z-axis) resolution[1-4]. For this reason, MDCT can acquire a large quantity of cross sectional image data in relatively short scanning time, which results in improved details in 3D reconstruction and better visualization of anatomical structures. Therefore, CT image data coupled with a volume-rendering technique have increased the range of possible medical applications for detailed 3D imaging and complicated spatial information.

The potential applications for the information available from 3D volume-rendered images have been rapidly increasing in the fields of diagnosis, and surgical or radiotherapy planning[5-9]. The image quality of CT images has been evaluated quantitatively or qualitatively using appropriate phantoms or visual grading analysis. Although the image quality of 3D

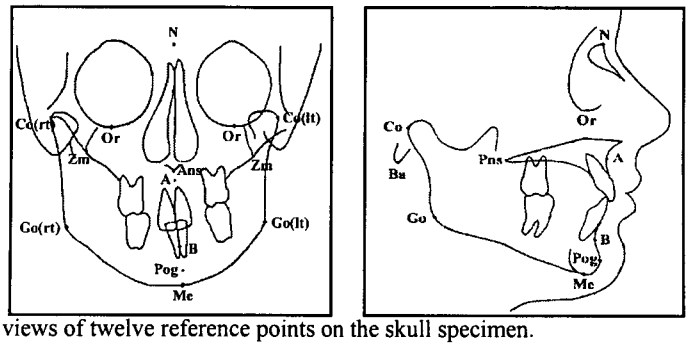


Fig 1. Front (**a**) and lateral (**b**) views of twelve reference points on the skull specimen.

images has been widely investigated by the qualitative analysis method[10-12], a need remains for an objective and quantitative method to assess the image quality of 3D volume-rendered images[13-15].

The purpose of this study was to evaluate the quantitative accuracy of distance measurements on three-dimensional (3D) volume-rendered images of a dry human skull using MDCT according to an acquisition section thickness and a reconstruction section thickness.

2. MATERIAL AND METHODS

We prepared a human dried skull specimen to evaluate the quantitative accuracy of 3D volume-rendered images. Twelve reference points, chosen for their important role on the craniofacial bone surface in plastic surgery and dentistry, were marked according to the description of reference points depicted in the Fig.1 on the skull surface based on conventional craniofacial anatomic reference points [15]. Before CT scanning, a radiologist experienced in anatomic structure measured five times repeatedly the twenty-one direct measurement line items (N-Ba, N-Me, N-Ans, Ans-Me, Ans-Pns, Co(rt)-Pog, Co(lt)-Pog, N-Go(rt), N-Go(lt), A-B, B-Me, Go(rt)-Me, Go(lt)-Me, Co(rt)-Go, Co(lt)-Go, Co(rt)-Me, Co(lt)-Me, Zm-Zm, Go-Go, Or-Or, Co-Co) composed among twelve reference points with a vernier caliper. The means of direct measurements were used as reference gold standards for evaluation of the quantitative accuracy of 3D volume-rendered CT images.

The water filled skull specimen was scanned with a MDCT (LightSpeed Plus, GE Medical Systems, Milwaukee, WI), which is used clinically for patients in Yonsei University Medical Center (YUMC), according to the section thicknesses of 1.25, 2.50, 3.75, and 5.00 mm for helical (high quality; pitch 3:1) scan mode. Experimental acquisition parameters were tube rotation through 360^0 in one second in axial scan mode, 200 mA tube current, 120 kVp x-ray tube voltage, with 22 cm display field of view (DFOV), gantry angle of 0 degrees, 512 x 512 matrix. MDCT data were reconstructed with its acquisition section thickness and with 1.25 mm section thickness for all scans.

Acquisition and reconstruction section thickness, total scanning time and number of reconstructed slices were recorded as shown in Table 1. 3D volume rendering from the tomographic data were performed and distance measurements were made on a monitor with a PC based volumetric analysis tool, Vworks^{TM} 4.0 (CyberMed Inc., Seoul, Korea). After monitor display of the tomographic images as 3D volume-rendered images in head protocol, an observer blind to the anatomic structure also measured seven times repeatedly the corresponding items with measuring tools provided by volumetric analysis software.

The quantitative accuracy of distance measurements on the 3D volume-rendered images was statistically evaluated by comparatively analyzing these measurements with the direct distance measurements.

Table 1. MDCT imaging parameters for the skull specimen in the helical scan mode of high quality, pitch of 3:1

Acquisition Section Thickness (mm)	Reconstruction Section Thickness (mm)	Scan Time (Seconds)	Table Speed (mm per rotation)	Number of Reconstructed Slices
1.25	1.25	55.1	3.75	161
2.50	1.25	28.5	7.50	81
2.50	2.50	28.5	7.50	161
3.75	1.25	19.5	11.25	54
3.75	3.75	19.5	11.25	161
5.00	1.25	15.1	15.00	41
5.00	5.00	15.1	15.00	161

3. RESULTS

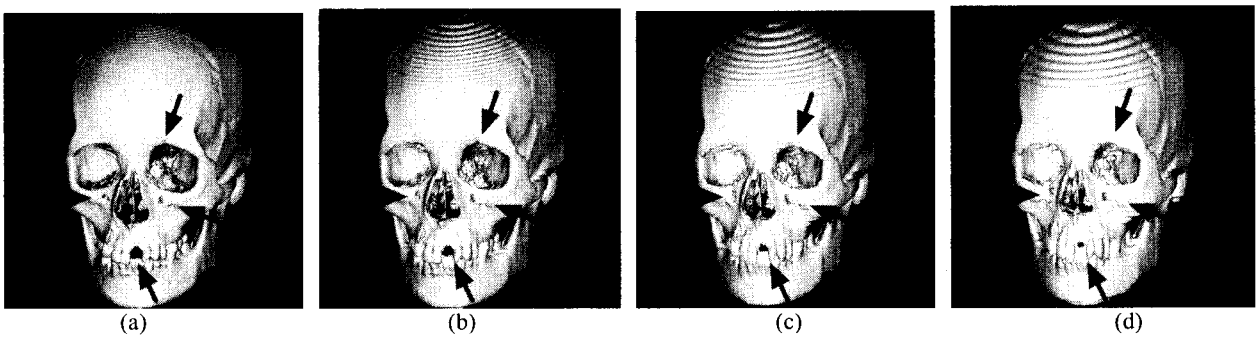
A radiologist measured the direct distances of twenty-one lines between twelve selected reference points five times per each item with an accuracy of 0.01 mm. The standard deviation of the direct measurements ranged from 0.07 mm to

0.38 mm, indicating the high level of consistency in the direct measurements. Therefore, the direct distance measurements were used as gold standards for quantitative analysis of the distance measurements on the 3D volume-rendered images.

Visual inspections indicated that the image quality of 3D volume-rendered MDCT images was gradually degraded with increasing acquisition slice thickness (Fig. 2). Distances on the 3D volume rendered images were measured with an accuracy of within 1 mm for 1.25 mm and 2.50 mm slice thickness and within 2 mm for 3.75 and 5.00 mm slice thickness. Statistical evaluation of the distance measurements of 3D volume-rendered images was performed with the data of the direct distance measurements by using two-way ANOVA and Tukey's studentized range test for the twenty-one items. In this study, a probability value less than 0.05 was considered to be statistically significant. The accuracy of distance measurements on the 3D volume-rendered MDCT images acquired and reconstructed with 1.25, 2.50, 3,75 and 5.00 mm section thickness were 48%, 33%, 23%, and 14%, respectively. Meanwhile, there were insignificant statistical differences (p-value < 0.05) in accuracy of distance measurements among 3D volume-rendered images reconstructed with 1.25 mm section thickness for the each acquisition section thickness (Fig. 3).

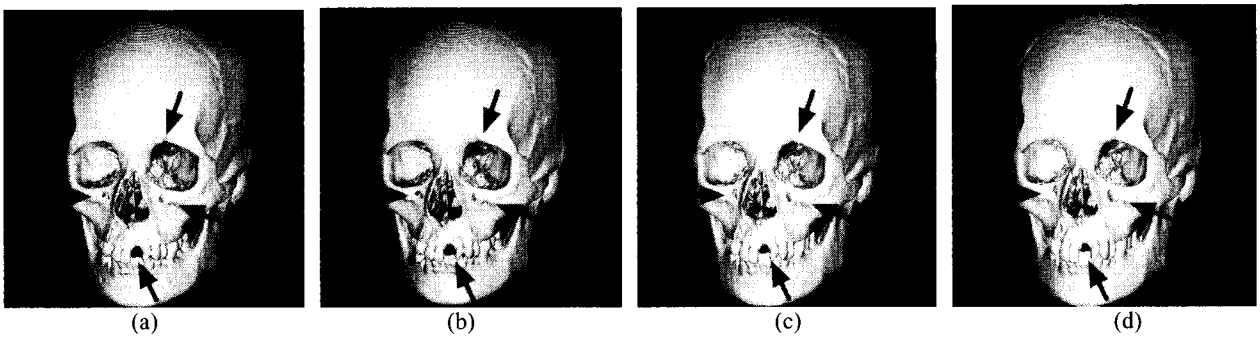
4. CONCLUSION

We performed quantitative analysis of the measurement accuracy of 3D volume-rendered images, acquired according to various scanning parameters, by comparing the measured distances between direct measurements on the skull and 3D measurements on a monitor. We defined the means of direct measurements on skull surface, which were conducted by a



(a) (b) (c) (d)

Fig. 2. The frontal views of 3D volume-rendered MDCT images of the skull specimen reconstructed with the acquisition section thickness for the each scan. (a): acquired with 1.25 mm and reconstructed with 1.25 mm section thickness. (b): acquired with 2.50 mm and reconstructed with 2.50 mm section thickness. (c): acquired with 3.75 mm and reconstructed with 3.75 mm section thickness. (d): acquired with 5.00 mm and reconstructed with 5.00 mm section thickness. (Arrows indicate defects on the 3D volume-rendered images.)



(a) (b) (c) (d)

Fig. 3. The frontal views of 3D volume-rendered MDCT images of the skull specimen reconstructed with 1.25 mm section thickness for the each scan. **A**: acquired with 1.25 mm and reconstructed with 1.25 mm section thickness. **B**: acquired with 2.50 mm and reconstructed with 1.25 mm section thickness. **C**: acquired with 3.75 mm and reconstructed with 1.25 mm section thickness. **D**: acquired with 5.00 mm and reconstructed with 1.25 mm section thickness. (Arrows indicate defects on the 3D volume-rendered images.)

radiologist experienced in anatomic structures, as the reference gold standard. As one method of quantitative analysis of the3D volume-rendered images, we carried out a statistical analysis by evaluating the quantitative accuracies of distances measured on a monitor compared with the directly measured distances.

The results of direct distance measurement on the 3D volume rendered images for various section thicknesses may be effectively used to predict the inaccuracy of distance measurements on the study of 3D volume rendered images. In

general, the image quality of MDCT's 2D tomographic images was evaluated by visual observation analysis to be equal or better in axial scan mode than in helical scan mode[10]. However, the results of quantitative analysis of the 3D volume-rendered images revealed that accuracy of distance measurements was not significantly different among the three scan modes for each slice thickness[15]. MDCT images acquired with thick section thickness and reconstructed with thin section thickness in helical scan mode should be effectively used in medical planning of 3D volume-rendered images. The quantitative analysis of distance measurement may be a useful tool for evaluating the quantitative accuracy and the defining optimal parameters of 3D volume-rendered CT images.

ACKNOWLEDGEMENT

This research was supported in part, by BK21 project for Medical Sciences, and by the Research Institute of Radiological Science, Yonsei University, Seoul 120-752, Korea.

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