Original Article
บทวิทยาการ

Accuracy of linear measurements in stitched versus non-stitched cone beam CT images

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Abstract

Objective To assess the accuracy of linear measurements from stitched and non-stitched cone beam computed tomography (CBCT) images in comparison to direct measurements.

Materials and methods Ten dry human mandibles were marked with gutta-percha at reference points to obtain five vertical and five horizontal distances. CBCT using stitching and non-stitching programs were performed. All distances on CBCT images obtained using stitching and non-stitching programs were measured and compared with direct measurements. The intraclass correlation coefficients (ICCs) were calculated.

Results The intraobserver ICCs of direct measurements were 0.998 to 1.000, and those of measurements on both non-stitched and stitched CBCT images were 1.000. The intermethod ICCs between direct measurements versus non-stitched CBCT images and direct measurements versus stitched CBCT images ranged from 0.972 to 1.000 and 0.967 to 0.998, respectively. No significant differences were found between direct measurements and stitched or non-stitched CBCT images ($p > 0.05$).

Conclusion Linear measurements from stitched and non-stitched CBCT images were accurate compared with direct measurements.

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Key words*:* *cone beam computed tomography; software tools; stitched*

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Introduction

Cone beam computed tomography (CBCT) is an advanced imaging technique that demonstrates tissue in three dimensions. Early CBCT scanners for dental use were developed by Mozzo et al.[1] and Arai et al.[2] in the late 1990s. The ability of providing images in three dimensions with lower radiation exposure compared with the medical CT[3-4] offers the potential of improved diagnosis and treatment planning for a wide range of clinical applications, especially in implant dentistry.[5-7] Several studies, have reported the accuracy of linear measurements on CBCT images,[8-13] and the International Congress of Oral Implantologists has supported the use of CBCT in dental implant treatment planning particularly in regards to linear measurements, three-dimensional evaluation of alveolar ridge topography, proximity to vital anatomical structures, and fabrication of surgical guides.[14]

Currently, two types of CBCT systems are available according to the field of view (FOV). The first type is limited or regional CBCT where the size of FOV varies from 4-10 cm in diameter. The voxel size can be as small as 0.07-0.20 mm^3. Another type is full or facial CBCT where the size of FOV varies from 11-24 cm in diameter. The voxel size ranges from 0.25-0.40 mm^3. It should be noted that larger FOV results in the larger voxel size and therefore, lower resolution images.

Recently, an optional program called stitching program is available in a few CBCT systems, e.g., Kodak 9000 3D System (Carestream Health, Inc., NY, USA). This program automatically combines up to three localized volumes to construct larger images with a fixed voxel size of 0.20 mm^3. To perform imaging with this program, the radiographer selects the stitching option during acquisition setup, positions the patient, and performs up to three exposures in sequence. Then the software automatically combines the acquired volumes, and reconstructs to create one large image. However, the merged images from different volumes might affect the geometric accuracy particularly at the region near the junction between two sequences. To our knowledge, a few studies have been conducted on the accuracy of linear measurements on stitching CBCT images.[10] Another study of the stitched CBCT images found that stitching of CBCT images at different levels can provide accurate anatomical details of the oral and maxillofacial regions.[11]

The aim of the present study was to assess the accuracy of linear measurements on stitched and non-stitched CBCT images in comparison with direct measurements. Our hypothesis was that stitched and non-stitched CBCT images are sufficiently accurate and reliable to measure the vertical and horizontal distances.

Materials and methods

Phantom and imaging

This study was performed in 10 dry human mandibles. Rod shaped gutta-percha (size # 60, 1.5 x 1.5 mm) were fixated on defined anatomical points as indicated in Table 1 serving as markers for measurements on each mandible. Five vertical and five horizontal distances between defined anatomical points marked with gutta-percha were identified on each mandible (Table 2). Figures 1 and 2 showed the vertical and horizontal distances marked with gutta-percha on the mandible, respectively. Then the mandible was positioned in the Kodak 9000C 3D System (Carestream Health, Inc., NY, USA) with the occlusal plane parallel to the horizontal plane, and was scanned using stitching and non-stitching programs. The exposure factors were fixed at 70 kV and 3.2 mA. The voxel size was selected at 0.20 mm^3 both stitching and non-stitching programs for the same image resolution. Without the stitching program, each mandible was scanned three separate times for the anterior area, the right posterior area, and the left posterior area with the scan time of 10.8 s for each scan. The field of view of the images was 5 x 3.75 cm^2. With the stitching program, three continuous exposures were performed for each mandible with a total scan time of 32.4 s, and the field of view of the merged images of three areas was 9 x 3.75 cm^2.

Table 1 List of defined anatomical points for fixing gutta-percha

	Anatomical points
1	The superior border of the right and left mental foramen
2	The buccal alveolar crest perpendicular to the superior border of the right and left mental foramen
3	The inferior border of the mandible perpendicular to the distobuccal alveolar crest of the right and left first molar teeth
4	The distobuccal alveolar crest of the right and left first molar teeth perpendicular to the inferior border of the mandible
5	The superior border of the lingual foramen
6	The lingual alveolar crest perpendicular to the superior border of the lingual foramen
7	The lingual surface teeth on the same level with to the superior border of the right and left mental foramen
8	The distolingual alveolar crest of the right and left first molar teeth on the same level with the distobuccal alveolar crest of the of same tooth
9	The labial surface on the same level with the superior border of the lingual foramen

Table 2 List of the linear distances selected for the study

Plane of the distance		Definition of the distance
Vertical	1	From the buccal alveolar crest perpendicular to the superior border of the right mental foramen
	2	From the distobuccal alveolar crest of the right first molar tooth perpendicular to the inferior border of the mandible
	3	From the buccal alveolar crest perpendicular to the superior border of the left mental foramen
	4	From the distobuccal alveolar crest of the left first molar tooth perpendicular to the inferior border of the mandible
	5	From the lingual alveolar crest perpendicular to the superior border of the lingual foramen
Horizontal	1	From the superior border of the mental foramen on the right side to the perpendicular point at the lingual surface
	2	From the distobuccal alveolar crest of the right first molar tooth perpendicular to the distolingual alveolar crest of the same tooth
	3	From the superior border of the mental foramen on the left side to the perpendicular point at the lingual surface
	4	From the distobuccal alveolar crest of the left first molar tooth perpendicular to the distolingual alveolar crest of the same tooth
	5	From the superior border of the lingual foramen to the perpendicular point at the labial surface

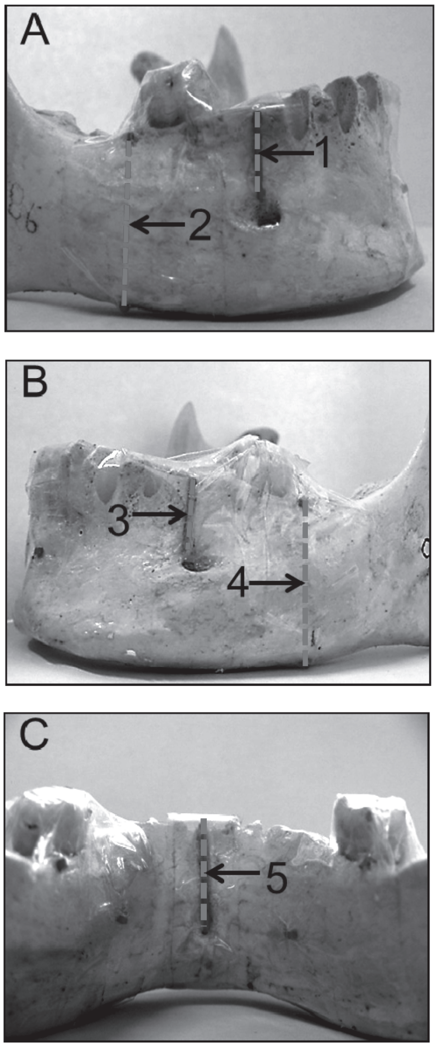

Figure 1 Vertical distances marked with gutta-percha of a dry mandible on A. the right side; B. the left side; and C. the anterior region.

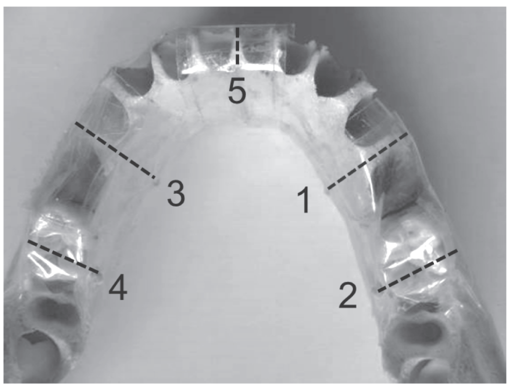

Figure 2 Top view of a mandible shows the horizontal distances marked with gutta-percha.

Image analysis

The data in DICOM format were transferred to a personal computer. Image analysis was performed using the linear measurement tool of the image processing software provided by the manufacturer called Kodak Dental Imaging Software (KDIS, Carestream Dental, NY, USA) version 6.12.17 and 3D imaging version 2.4. All distances were measured on cross-sectional CBCT images (Figure 3). Direct measurements by a digital caliper (Mitutoyo Absolute Digimatic Caliper, Mitutoyo Corporation, Kanagawa, Japan) with 0.01 mm resolution and ± 0.02 mm accuracy served as the gold standard. All distances were measured three times on three different days and taken note into the separate sheet. The means and standard deviations (SD) of vertical and horizontal distances from direct measurements, non-stitched and stitched CBCT images in each mandible were calculated using Microsoft Excel. The errors of distances measured on non-stitched and stitched CBCT images compared with direct measurements in each mandible were also calculated using the following equations:

$$E = D - NS \quad \text{or} \quad E = D - S$$

where E was the error of the measured distance; D was the distance measured by direct measurements; NS was the distance measured on non-stitched CBCT images; and S was the distance measured on stitched CBCT images.

Statistical analysis

Intraclass correlation coefficients (ICCs) to evaluate intraobserver reliability and the accuracy of linear measurements between direct measurements and non-stitched CBCT images and between direct measurements and stitched CBCT images were calculated using SPSS for Windows (version 16.0, SPSS Inc., Chicago, IL), and *p* less than 0.05 was considered to indicate significant.

Results

The overall mean absolute differences between direct measurements and non-stitched CBCT measurements for vertical and horizontal distances were 0.24 ± 0.21 mm and 0.34 ± 0.25 mm, respectively. The mean absolute differences between direct measurements and stitched CBCT measurements for vertical and horizontal distances were 0.27 ± 0.24 mm and 0.34 ± 0.27 mm, respectively.

The errors of distances measured on non-stitched and stitched CBCT images compared with direct measurements in each mandible were shown in Table 3 and 4, respectively.

Plots of the ranked measurement differences to depict the range of each value were shown in Figure 4. Most of the errors between direct measurements and non-stitched CBCT images and between direct measurements and stitched CBCT images were positive values and less than 1 mm.

The ICCs of intraobserver reliability were 0.998 to 1.000 in direct measurements. All ICCs of both non-stitched CBCT images and stitched CBCT images were 1.000 indicating strong agreement between duplicated measurements made by a single observer.

The ICCs of intermethod reliability ranged from 0.972 to 1.000 in direct measurements versus non-stitched CBCT images and 0.967 to 0.998 in direct measurements versus stitched CBCT images. These results showed that measurements on non-stitched CBCT images were slightly more accurate than stitched CBCT images. However, no significant differences were found between direct measurements and stitched CBCT images or non-stitched CBCT images ($p > 0.05$).

Table 3 Errors of each distance between direct measurements and non-stitched CBCT measurements in each mandible

Distance (mm)		Mandible No. 1	2	3	4	5	6	7	8	9	10	Mean absolute difference	± SD
Vertical	1	−0.30	0.07	0.11	0.14	0.03	0.35	0.24	0.07	0.08	−0.03	0.14	0.11
	2	0.29	0.16	0.31	0.97	0.22	0.94	−0.02	0.77	0.14	0.05	0.39	0.36
	3	0.05	−0.05	0.07	−0.25	−0.54	0.14	−0.01	0.00	−0.10	0.04	0.13	0.16
	4	−0.03	0.12	0.56	0.38	0.14	0.35	0.98	0.40	0.30	−0.10	0.34	0.28
	5	0.22	0.09	0.30	0.10	0.34	0.18	0.08	0.22	0.36	0.27	0.22	0.10
Horizontal	1	0.50	0.00	0.26	0.51	0.62	0.41	0.31	0.02	0.46	1.11	0.42	0.32
	2	−0.47	0.05	0.06	−0.30	−1.18	0.16	−0.07	−0.13	0.00	0.17	0.26	0.35
	3	0.24	0.04	0.12	1.19	0.45	0.33	0.23	0.45	0.55	0.86	0.45	0.35
	4	−0.66	0.10	0.64	0.42	−0.03	−0.23	0.26	0.09	0.18	0.23	0.26	0.22
	5	0.06	0.08	−0.22	0.19	−0.67	−1.05	0.32	−0.44	0.04	−0.07	0.31	0.33

Table 4 Errors of each distance between direct measurements and stitched CBCT measurements in each mandible

Distance (mm)		Mandible No.										Mean absolute difference	±SD
		1	2	3	4	5	6	7	8	9	10		
Vertical	1	−0.40	0.04	0.07	0.00	−0.33	0.35	0.34	0.21	0.04	0.04	0.17	0.15
	2	0.52	0.13	0.34	0.80	0.16	0.74	−0.12	0.73	0.34	0.09	0.40	0.28
	3	0.01	−0.01	0.01	−0.52	−0.91	0.04	0.19	0.00	−0.10	0.04	0.19	0.30
	4	0.00	0.25	0.56	0.28	0.01	0.48	1.05	0.27	0.34	0.07	0.33	0.31
	5	0.18	0.06	0.20	0.57	0.50	−0.02	−0.26	0.18	0.40	0.30	0.27	0.18
Horizontal	1	0.40	−0.06	0.23	0.15	0.82	0.31	0.21	0.05	0.60	0.87	0.37	0.30
	2	−0.23	0.02	0.00	−0.50	−1.22	0.30	0.13	−0.30	0.00	0.14	0.28	0.37
	3	0.14	−0.13	0.02	1.02	0.58	0.40	0.03	0.00	0.35	0.82	0.41	0.34
	4	−0.76	0.13	0.57	0.32	−0.30	−0.33	0.33	0.16	−0.02	0.17	0.31	0.22
	5	0.26	−0.09	−0.15	0.12	−0.84	−1.08	0.32	−0.47	0.01	0.06	0.34	0.36

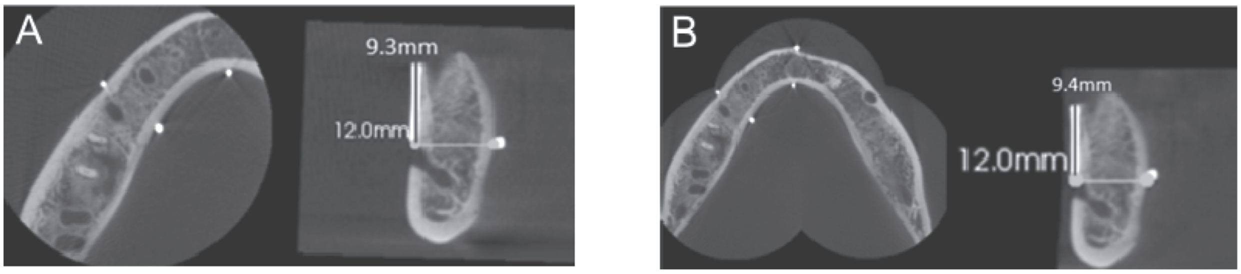

Figure 3 A. Non-stitched axial CBCT image (left) and cross-sectional CBCT image (right) at the premolar area. B. Stitched axial CBCT image (left) and cross-sectional CBCT image (right). Vertical measurement, from the buccal alveolar crest perpendicular to superior border of the left mental foramen, and horizontal measurement, from the superior border of the mental foramen on the left side to the perpendicular point at the lingual surface are illustrated.

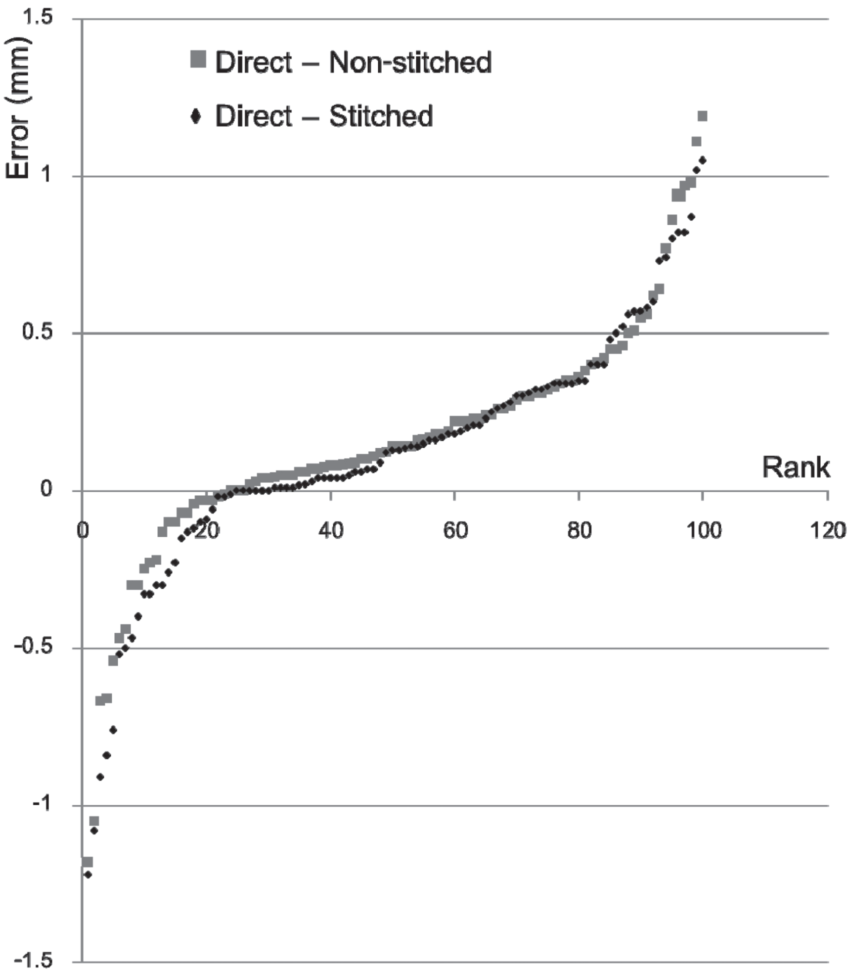

Figure 4 Plots of the ranked measurement differences between CBCT images and direct measurements.

Discussion

CBCT has become an important imaging method to evaluate oral and maxillofacial structures. The accuracy of linear measurements on CBCT images, necessary for treatment in this region particularly for implant placement, has been documented in previous studies.[8-13] The stitching program is a software tool to combine continuous sequences into a large volume. However, the accuracy of the stitched images has not been guaranteed. The present study evaluated the vertical and horizontal measurements at different positions of the mandible on stitched and non-stitched CBCT images compared with direct measurements. The results show that linear measurements on both CBCT images were highly accurate without significant difference when compared with direct measurements. However, only measurements for vertical distances on non-stitched CBCT images were slightly more accurate than those on stitched CBCT images.

The accuracy of linear measurements on stitched CBCT images in this study is in agreement with a previous report by Kopp and Ottl[10] who evaluated the dimensional stability in Kodak 9000 3D CBCT system with stitching software, and concluded that linear measurements from stitching software were accurate even when rotating the mandible in x axis or y axis.

Most distances measured from direct measurements were longer than those measured on CBCT images. The slight underestimation on CBCT images might be because measurements on CBCT images were made in truly cross-sectional areas, whereas direct measurements were performed in the mandibles with some convex surfaces. These results are in accordance with previous study by Lascala et al.[8] showed that the real distances measured on dry skulls were always longer than those obtained from the CBCT images. However, the differences between the CBCT and real measurements were only statistically significant for measurements of the skull base. Another study by Moshfeghi et al.[15] evaluated the accuracy of the linear measurement of CBCT (Newtom VG) in the axial and coronal planes. They also found that the CBCT measurements were slightly underestimated (but not statistically significant), except for the axial high resolution.

In an unpublished study, Egbert NL[16] evaluated dimensional accuracy and reliability of stitched CBCT images by the Kodak 9000D (Carestream Health Inc, Kodak Dental Systems, Marne-la-Vallee, France), and found that the stitched CBCT images appeared accurate and reliable for diagnostic purposes. He suggested that proven accuracy of stitched CBCT data sets may allow image-guided implant surgical stents to be fabricated from such data sets.

According to a previous study of measurement accuracy using CBCT, a 0.07 mm and 0.27 mm average deviation from true values in the horizontal and vertical distances were considered to be statistically significant.[17] In the present study, errors of only vertical measurements on non-stitched CBCT images compared with direct measurements were less than 0.27 mm.

The ICCs on non-stitched, stitched CBCT images, and direct measurements of vertical distances were slightly higher than those of horizontal distances. This indicated that the measurements in vertical orientation were more accurate than those in horizontal orientation. However, the differences were not significant.

According to the present results, stitched CBCT images yielded accurate measurements. This technique might be applied for patients with multiple edentulous areas who require more than one single exposure for implant planning because it might be more convenient to evaluate bone height and width in one combined image than multiple single volumes. Regarding the radiation effective dose, one shot of the stitching program yields the same dose as one shot of the non-stitching program. Thus, taking three shots including the anterior region, right and left sides of the mandible yields the same dose as taking three areas separately with non-stitching program. However, the stitching program requires longer imaging time, which can lead to blurred artifacts from patient's movement during the imaging procedure.

Conclusion

Linear measurements from non-stitched and stitched CBCT images using Kodak 9000C 3D CBCT system were accurate compared with direct measurements. With the stitching program, measurements of multiple areas can be carried out in a single combined image. Therefore, it provides a useful tool for image evaluation in patient requiring multiple implant placements.

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ความแม่นของการวัดเชิงเส้นระหว่างการใช้โปรแกรมการเย็บกับไม่ใช้ในภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบลำรังสีรูปกรวย

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บทคัดย่อ

วัตถุประสงค์ เพื่อประเมินความแม่นของการวัดเชิงเส้นระหว่างการใช้โปรแกรมการเย็บกับไม่ใช้ในภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบลำรังสีรูปกรวยเมื่อเปรียบเทียบกับการวัดโดยตรง

วัสดุและวิธีการ ทำในกระดูกขากรรไกรล่างจำนวน 10 ชิ้น โดยแต่ละชิ้นจะกำหนดจุดที่กระดูกตามตำแหน่งอ้างอิง จะได้ระยะแนวตั้งและแนวนอนทั้งหมด 10 ระยะ โดยใช้วัสดุอุดคลองรากฟัน ใช้ digital caliper วัดโดยตรงที่กระดูก ซึ่งเป็น gold standard วัด 3 ครั้ง คนละวันกัน แล้วหาค่าเฉลี่ย นำกระดูกขากรรไกรล่างไปถ่ายภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบลำรังสีรูปกรวย โดยใช้โปรแกรมการเย็บกับไม่ใช้โปรแกรมการเย็บ แล้ววัดระยะเดียวกันในภาพรังสี แต่ละระยะวัด 3 ครั้ง คนละวันกัน แล้วหาค่าเฉลี่ย จากนั้นจึงวิเคราะห์ผลที่ได้จากการวัด

ผลการศึกษา การวัดที่กระดูกโดยตรงมีค่า intraclass correlation coefficients เป็น 0.998 ถึง 1.000 การวัดในภาพรังสีโดยใช้โปรแกรมการเย็บกับไม่ใช้มีค่า intraclass correlation coefficients เท่ากับ 1.000 แสดงถึงการวัดที่มีความแม่นยำอย่างมากในผู้วัดคนเดียวกัน เมื่อเปรียบเทียบการวัดโดยตรงกับการวัดในภาพรังสีโดยไม่ใช้โปรแกรมการเย็บ พบว่าค่า intraclass correlation coefficients เท่ากับ 0.972 ถึง 1.000 และเมื่อเปรียบเทียบการวัดโดยตรงกับการวัดในภาพรังสีโดยใช้โปรแกรมการเย็บ พบว่าค่า intraclass correlation coefficients เท่ากับ 0.967 ถึง 0.998

สรุป ไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติระหว่างการวัดโดยตรงและการวัดในภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบลำรังสีรูปกรวย โดยใช้โปรแกรมการเย็บกับไม่ใช้ ($p > 0.05$)

(ว ทันต จุฬาฯ 2558;38:93-104)

คำสำคัญ: *ภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบลำรังสีรูปกรวย; เครื่องมือซอฟต์แวร์; โปรแกรมการเย็บ*

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