Japanese Journal of Comprehensive Rehabilitation Science (2011)

Original Article

Examination of the distance measurement error and exposed dose when using a 320-row area detector CT: A comparison with videofluoroscopic examination of swallowing

Daisuke Kanamori, DDS, DMSc,[1] Hitoshi Kagaya, MD, DMSc,[2] Naoko Fujii, MD, DMSc,[3] Yoko Inamoto, SLHT, MSc,[2] Enri Nakayama, DDS,[4] Shoichi Suzuki, RT, PhD,[5] Hideki Mizutani, DDS, DMSc,[1] Sumiko Okada, SLHT, PhD,[6] Kazuhiro Katada, MD, DMSc,[3] Eiichi Saitoh, MD, DMSc[2]

[1]Department of Oral and Maxillofacial Surgery, School of Medicine, Fujita Health University, Toyoake, Aichi, Japan
[2]Department of Rehabilitation Medicine, School of Medicine, Fujita Health University, Toyoake, Aichi, Japan
[3]Department of Radiology, School of Medicine, Fujita Health University, Toyoake, Aichi, Japan
[4]Department of Dysphagia Rehabilitation, Nihon University School of Dentistry, Chiyoda-ku, Tokyo, Japan
[5]Faculty of Radiological Technology, School of Health Sciences, Fujita Health University, Toyoake, Aichi, Japan
[6]Faculty of Rehabilitation, School of Health Sciences, Fujita Health University, Toyoake, Aichi, Japan

ABSTRACT
Kanamori D, Kagaya H, Fujii N, Inamoto Y, Nakayama E, Suzuki S, Mizutani H, Okada S, Katada K, Saitoh E. Examination of the distance measurement error and exposed dose when using a 320-row area detector CT: A comparison with videofluoroscopic examination of swallowing. Jpn J Compr Rehabil Sci 2011; 2: 18-23
Purpose: The purpose of this study was to compare the distance measurement error and exposed dose in 320-row area detector computed tomography (320-ADCT) and videofluoroscopic examination of swallowing (VF).
Method: We used markers of radiopacity attached to adult skull specimens to measure the distances between various sets of 2 points. In VF, we made the corrections using the mentalis marker. In 320-ADCT, we used a distance measurement tool. After obtaining the distance measurements, we compared the errors from VF and 320-ADCT. We used a RANDO Phantom to calculate the exposed dose by using thermoluminescence dosimeter (TLD) elements.
Results: In the case of VF, the relative error associated with the actual measured values was largest (12.9%) in the area between the mentalis and the left mandibular angle. In 320-ADCT, even the measurements with the largest error had a relative error within 0.34%. In VF, the dose absorbed through the skin on the incident side was 4.8 to 12.1 times higher than the dose absorbed on the opposite side, up to a maximum of 25.30 mGy; the effective dose was 1.05 mSv. Using 320-ADCT, the maximum dose absorbed through the skin was 47.07 mGy, and the effective dose was 1.65 mSv.
Conclusion: Compared with VF, the 320-ADCT approach produces a smaller measurement error, and observation is possible from a variety of directions. However, because the exposed dose is greater, a combination of both approaches should be skillfully used to evaluate eating and swallowing functions.
Key words: Videofluoroscopic examination of swallowing, 320-ADCT, distance measurement, exposed dose

Correspondence: Daisuke Kanamori, DDS, DMSc
Department of Oral and Maxillofacial Surgery, School of Medicine, Fujita Health University, 1-98 Dengakugakubo, Kutsukake-cho, Toyoake, Aichi 470-1192, Japan
E-mail: dkanamor@fujita-hu.ac.jp
Accepted: March 24, 2011
No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

Introduction

Currently, videofluoroscopic examination of swallowing (VF) is used as the gold standard for evaluating swallowing function, but VF evaluates the three-dimensional swallowing movement in 2 dimensions, leading to a loss of information. To date, magnetic resonance imaging (MRI), computed tomography (CT), etc., have been used for three-dimensional evaluations [1-9]. However, MRI is not suitable for evaluating hard tissues such as the hyoid bone, and its temporal resolution is not satisfactory for VF. Multislice CT has become more widely adopted in recent years and can obtain high-spatial-resolution volume data with slices as thin as 0.5 mm; this enables its use in research into swallowing [2, 3]. However, previous multislice CT required a certain amount of time for data gathering in the axial direction; therefore, the time phases of the top and bottom edges of the image data were different, and quick movements like swallowing could not be captured. Furthermore, with dental cone beam CT, the scan range is limited, and even the most recent machines take nearly 10 s to acquire an image. However, with the 320-row area detector CT (hereafter referred to as the "320-ADCT"), first reported in 2008, isochronal phase imaging is possible, and this enables dynamic analysis and display of three-dimensional data through continuous or intermittent multiple scanning of the same site [10−13]. This feature of 320-ADCT makes it possible to learn the dynamics of eating and swallowing movements by visualizing the three-dimensional swallowing movement on the temporal axis.

When using VF and CT, care must be taken to avoid measurement error. Ohtsuka [14] has reported an error of about 3 mm in a distance of 40 mm on the imaging table with VF. In recent years, CT has become capable of reconstructing 0.5-mm slices with good precision. Another study has reported that distance measurement with a relative error of 0.6% was possible with CT [15]. 320-ADCT is capable of reconstruction of slices as small as 0.35 mm and appears to offer excellent spatial resolution. However, because VF and CT both use X-rays, they entail a risk of radiation damage due to X-ray exposure. The purpose of this study was to compare the measurement error and exposed dose of the 320-ADCT and VF techniques in order to provide basic data for the future use of 320-ADCT to evaluate eating and swallowing functions.

Method

Radiography Equipment

For VF, we used a digital X-ray TV system (ZEXIRA DREX-ZX80; Toshiba Medical Systems Corporation), a digital video recorder (WVD9000; SONY), and a VF-examination chair (VF-MT-1; Tomei Brace Co., Ltd.), and for CT, we used 320-ADCT (Aquilion One; Toshiba Medical Systems Corporation). The reclining chair used for CT (jointly produced by Tomei Brace Co., Ltd. and Aska Corporation) was designed such that the angle of the back of the chair and the position of the entire seat in the forward and backward directions could be adjusted, thereby allowing for accurate positioning of the facial area to the scan surface. In the support for the back of the chair, we used materials such as carbon that absorb little radiation.

1. Measurement Error

We used adult skull specimens (Kyoto Kagaku Co., Ltd.) and established markers for the submental region, left mandibular angle region, incisal margins between the mandibular central incisors, superior margin of the left articular process, anterior nasal spine, and posterior nasal spine. We used dental root canal filling material (Dentsply Gutta Percha Points; Dentsply-Sankin) as the markers. The markers were processed into a size of about 1 mm before use. The measurement sites were between the mentalis and the left mandibular angle, between the incisal edges of the mandibular incisors and the mentalis, between the left mandibular angle and the superior margin of the left articular process, and between the anterior nasal spine and the posterior nasal spine (Figure 1). The actual values of the adult skull specimens were measured between the markers by using calipers (dental calipers; YDM). We calculated the relative error from the values measured by VF and 320-ADCT (relative error = |error|/actual measured values × 100) and conducted a comparative examination.

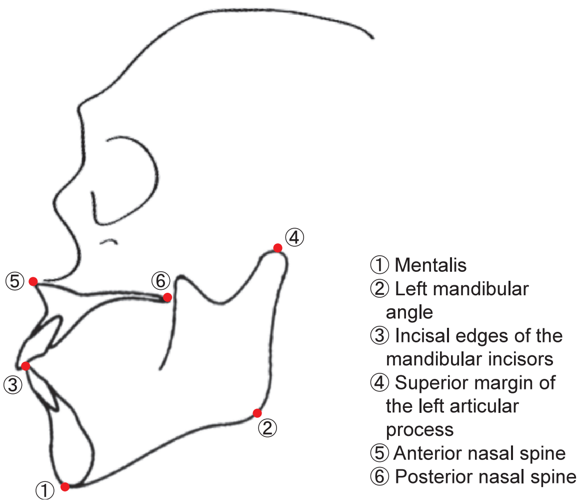


Figure 1. Marker positions

a. VF

We placed the adult skull specimen on the headrest of the VF-examination chair and acquired an image in the lateral view in which the correction markers with a diameter of 10 mm were attached to the anterior portion of the mentalis. The distance from the tube to the bed was 140 cm, the tube voltage was 75 kV, and tube current was 1.2 mA. After the VF, we produced the images using a personal computer (VAIO VGNSZ95; Windows Vista Ultimate SP2, SONY) and a video-editing software (Adobe Premier Elements 4; Adobe).

We corrected the distance from the correction markers and used an image-processing software (ImageJ; US National Institutes of Health) to measure the distances between the markers.

b. 320-ADCT

We placed the same adult skull specimen used for VF on the CT bed and performed the scan at a tube voltage of 120 kV and tube current of 60 mA. We used the workstation Ziosoft M900 Quadra accompanying the Toshiba Aquilion One and used the three-dimensional images producing using the multi-planar reconstruction (MPR) and volume rendering (VR) methods to produce and measure the images from the obtained data. For distance measurement, we used the accompanying distance measurement tool.

2. Exposed Dose

The dose measurements for VF and 320-ADCT were made with the thermoluminescence dosimeter (TLD) method (TLD elements: MSO-S; TLD reader: Tmodel 3000, manufactured by Kyokko Co., Ltd.) by using a humanoid phantom (Alderson; RANDO). The TLD method is a dose-measurement method that measures the emitted fluorescence when a crystalline substance that has been exposed to radiation is heated. This method is often used to evaluate occupational exposure to radiation, monitor environmental radiation, and measure the exposed dose when medical radiation is delivered [14, 16, 17].

a. Dose Measurement during VF Imaging

We inserted 186 TLD elements from the head to the gonad area of the humanoid phantom (Figure 2, the area within the red-bordered rectangle). We included 2 TLD elements (one on the left and the other on the right) in each set of elements for measuring the skin dose and built a total of 39 sets on the surface. We placed them below both the eyes, both the ears, and the front, back, left, and right sides of the neck, chest, and gonads. We placed the phantom in a reclining position at an angle of 45° on the VF-examination chair and took it from the sides and front. This study is based on five minutes, the standard for VF [16], and we carried out the radiography for a total of five minutes. The radiographic conditions are shown in Table 1. The radiographic examination of the sides was conducted at a tube voltage of 75 kV and a tube current of 1.2 mA, and the left side was exposed to the X-rays. After X-ray exposure, we determined the amount of fluorescence of the TLD elements by using the TLD reader.

Figure 2. RANDO Phantom
The inside of the red line is a TLD elements installation area.

Table 1. Exposure parameters for VF

	Tube voltage (kV)	Tube current (mA)	Exposure time (min)
Lateral view	75	1.2	4.2
Anteroposterior view	120	1.2	0.8

b. Dose Measurement during 320-ADCT Imaging

We placed the TLD elements in the same positions used for VF and set up the humanoid phantom in the same position used for the actual CT scan. In other words, we took care to minimize exposure to the crystalline lens by making the angle of elevation 45° and tilting the gantry at an angle of 22° toward the head. The radiographic conditions are shown in Table 2. For this scan, we used a tube voltage of 120 kV and a tube current of 60 mA and performed a dynamic volume scan for a period of 3.15 s. After X-ray exposure, we determined the amount of fluorescence of the TLD elements by using the TLD reader.

c. Method of Calculating the Measurement Results

1) Method of Calculating the Absorbed Dose

The absorbed dose that forms the basis of X-ray

Table 2. Exposure parameters for 320-ADCT

	Locations selected for CT scan	CT scan
Scan mode	Volume	Dynamic Volume
Tube voltage (kV)	120	120
Tube current (mA)	10	60
Gantry revolution time (s/rot)	0.35	0.35 (3.15)
Detector configuration (mm)	160	160
Pitch	1	1
FOV (mm)	240 (s)	240 (s)
CTDI vol (mGy)	0.4	21.7
CTDI vol.e (mGy)	0.6	34.7
DLP.e (mGy・cm)	10.3	554.9

exposure is expressed by the TLD-read value × the TLD calibration constant × the correction factor for soft tissue (in other words, the mass attenuation coefficient of the soft tissue/the mass attenuation coefficient of air). We used the average value of the left and right markers for the TLD-read value of the skin. For the TLD calibration constant, we used an ionization chamber calibrated to national standards, performed the calculation using the exchanged calibration method, and used the values calibrated for each marker. We set the correction factor for the soft tissue to 1.074 for regions up to the lung (planes 12−28), and considering the other areas to be soft tissue, set the factor to 1.07 for those areas.

2) Method of Calculating the Effective Dose

The effective dose is expressed as Σ (the absorbed dose × the radiation weighting factor × the tissue weighting factor). We set the radiation weighting factor to 1.0 and obtained the tissue weighting factors from the 2007 Recommendations of the International Commission on Radiological Protection (ICRP) [18]. The tissue weighting factors were as follows: 0.01 for bone surface, brain, salivary glands, and skin; 0.04 for the bladder, liver, esophagus, and thyroid; 0.08 for the gonads; and 0.12 for the pelvis, colon, lung, stomach, breast, and other organs. For the skin, we calculated the tissue weighting factor for 3 areas that are most commonly examined—the face, the neck and chest regions, and the gonads. We used the calculated values to perform a comparison of the absorbed doses and effective doses in VF and 320-ADCT.

Table 3. Absorbed dose on the skin surface during VF

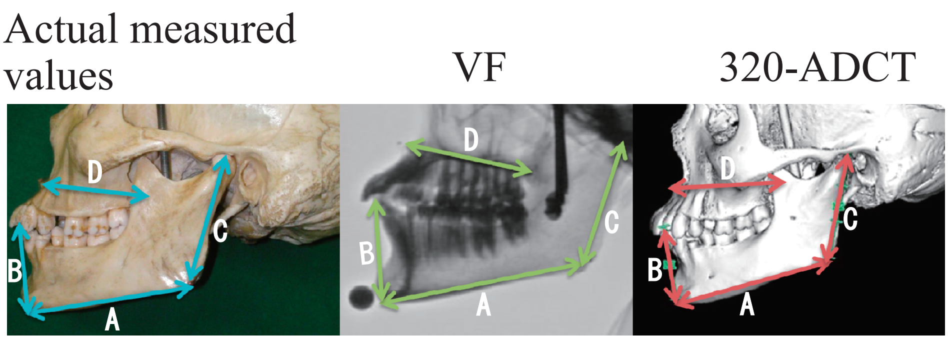
Region	Right	Left	Front	Back
Below both eyes	3.32	23.71		
Below both ears	3.91	25.30		
Upper neck	5.13	24.77	19.85	10.51
Middle neck	4.06	21.25	19.52	10.28
Lower neck	1.55	18.79	18.33	1.37
Thyroid	14.22	21.15		0.57
Chest 1	0.22	0.45	3.10	0.18
Chest 2	0.22	0.30	4.12	0.18
Chest 3	0.24	0.25	5.79	0.13
Chest 4	0.18	0.30	5.72	0.13
Gonad	0.01	0.02	0.03	0.01

mGy

Table 4. Absorbed dose on the skin surface during 320-ADCT

Region	Right	Left	Front	Back
Below both eyes	26.74	32.78		
Below both ears		39.83		
Upper neck	41.65	41.16	44.77	30.66
Middle neck	34.66	35.16	47.07	26.44
Lower neck	21.11	26.70		24.96
Thyroid	8.02	9.00		15.18
Chest 1	0.62	0.72	0.93	1.05
Chest 2	0.52	0.62	0.80	0.66
Chest 3	0.46	0.48	0.62	0.38
Chest 4	0.31	0.44	0.43	0.31
Gonad	0.03	0.04	0.03	0.03

mGy



	A	B	C	D
Relative error (%)	Mentalis-left mandibular angle	Incisal edges of the mandibular incisors-mentalis	Left mandibular angle-superior margin of the left articular process	Anterior nasal spine-posterior nasal spine
VF	12.9	0.24	8.14	0.96
320-ADCT	0.33	0.24	0.34	0.19

Figure 3. Measurement error of the distances between 2 points
Midline structures show relatively good results.

Results

1. Results of the Measurements of the Distances between 2 Points

Figure 3 shows the measurement sites and the results for each site. In the case of VF, the relative error associated with the actual measured values was largest (12.9%) in the area between the mentalis and the left mandibular angle. In the case of 320-ADCT, the error was largest (0.34%) in the area between the left mandibular angle and the superior margin of the left articular process.

2. Results of the Measurements of the Exposed Doses

The results for the absorbed dose and the effective dose during the VF are shown in Table 3. The maximum absorbed dose using VF was 25.30 mGy at the site of the skin that corresponds to the left parotid region (incident side), and it was 3.91 mGy on the opposite side. In the front, it was highest (19.85 mGy) at the skin on the neck region. The effective dose of VF was 1.05 mSv.

The results for the absorbed dose and effective dose during the 320-ADCT are shown in Table 4. The maximum absorbed dose using 320-ADCT was 47.07 mGy at the site of the skin that corresponds to inside the neck region. The dose was 34.66 mGy on the right side and 35.16 mGy on the left side. The effective dose of 320-ADCT was 1.65 mSv.

Discussion

In motion analyses using VF, the general approach is to examine the distance and speed of movement by using correction markers attached to the neck region and mentalis for correcting the magnification ratio [19]. The results of this study showed that the relative errors for sites passing through the midline, such as from the incisal edges of the mandibular incisors to the mentalis or from the anterior nasal spine to the posterior nasal spine, were within 1% for both VF and 320-ADCT; these are considered good results. The relative error in VF was 12.9% from the mentalis to the left mandibular angle and 8.14% from the left mandibular angle to the superior margin of the left articular process. We concluded that the major factors explaining this finding were as follows: (1) the distance of the measurement sites from the radiography table were different from the correction markers, causing a change in the magnification ratio; (2) the magnification ratio increased as we moved from the center of the image to its periphery; and (3) a three-dimensional body was being represented in 2 dimensions, and hence, if the phantom was placed in an inclined position with respect to the radiography table, the measurement could not be made accurately. On the basis of these results, we concluded that using the VF lateral view to examine the positional relationships of the alimentary bolus, which passes through the midline when swallowing, to the hyoid bone and the larynx presents no problem in terms of precision. The maximum error with 320-ADCT was 0.34%, which was smaller than the relative error of 0.6% for CT measurements obtained using a dry skull in a study by Ludlow et al. [15]. The reasons why the error was small could be that (1) the smallest unit for data acquisition with 320-ADCT (i.e., the voxel) is isotropic, and hence, 320-ADCT has high spatial resolution and (2) it is possible to measure the distance directly from the three-dimensional data.

In VF, the exposed dose absorbed through the skin was a maximum of 25.30 mGy, which was smaller than 2,000 mGy—the threshold value for the deterministic effect of early transient skin erythema; the effective dose of VF was 1.05 mSv. Many studies have reported the exposure of VF [14, 16, 20−23]. Wright et al. [21] concluded that it was on average 0.4 mSv for 23 patients with an average examination time of 286 s, which was equivalent to the dose of 10 plain radiographs of the chest region (a single exposure is 0.04 mSv). The effective doses reported in this study are higher than those reported in earlier studies. One reason for the higher effective doses is that in the previous academic studies, only the neck region was radiographically examined in the frontal view, and no radiographic examination of the esophagus aimed at diagnosing the passage of the alimentary bolus was done. It is necessary to use better imaging conditions in imaging radiography for the diagnosis of the esophagus, so it can be concluded that this is why the doses in this study were higher than the past reports of doses.

The dose absorbed through the skin in 320-ADCT was a maximum of 47.07 mGy, which is a smaller exposure than 2,000 mGy—the threshold value for the deterministic effect of early transient skin erythema. In the crystalline lens area (under the eyes), it was 26.74 mGy on the right side and 32.78 mGy on the left side, which was below the threshold value for mild turbidity (1-2 Gy) and for cataract (5 Gy). The effective dose of 320-ADCT (1.65 mSv) was smaller than that of a neck region CT examination (2.8 mSv). Although this dose is considered a comparatively low dose [24], it was about 1.6 times the effective dose of VF. The measurement errors and exposed doses were not identical because of differences in the measurement sites, apparatus used, radiographic method, etc., but this study can be considered as providing important basic data for the future clinical application of 320-ADCT.

VF has a smaller exposed dose than 320-ADCT, and hence, it is useful for examinations in which radiography has to be performed over a long time, e.g., examination of mastication. Furthermore, its error is comparatively small as long as it is limited to the measurement of parallel midline structures on the radiography table. In contrast, more accurate distance measurements of a variety of sites are possible with 320-ADCT than with VF. However, the amount of exposure is greater for a single 320-ADCT than for VF; hence, the number of 320-ADCT scans should be kept to a minimum. Therefore, we believe that 320-ADCT is not an examination that can replace VF; instead, it should used to gain a more detailed understanding of the disease state by using three-dimensional observations from multiple directions. This is something that cannot be achieved using VF and that should be utilized in training and treatment. Both these approaches should be used skillfully and in combination to evaluate eating and swallowing functions.

Acknowledgments

The authors thank the radiologic technologists at the Fujita Health University Hospital, for their invaluable assistance with the study.

References

1. Kitano H, Asada Y, Hayashi K, Inoue H, Kitajima K. The evaluation of dysphagia following radical surgery for oral and pharyngeal carcinomas by cine-magnetic resonance imaging (cine-MRI). Dysphagia 2002; 17: 187−91.
2. Takehara I, Sugimoto A, Kamikubo T, Fujitani J, Miyano S, Ikai T,et al. A new experiment in evaluation for swallowing movement by helical CT. Jpn J Dysphagia Rehabil 2002; 6: 128−32. Japanese.
3. Takehara I, Chu J. Pharynx and oesophagus evaluation during the swallow using helical computerized tomography. Disabil Rehabil 2004; 26: 733−8.
4. Hartl DM, Kolb F, Bretagne E, Marandas P, Sigal R. Cine magnetic resonance imaging with single-shot fast spin echo for evaluation of dysphagia and aspiration. Dysphagia 2006; 21: 156−62.
5. Karacay S, Akin E, Sayin MO, Bulakbasi N. Real time balanced turbo field echo Cine-MRI in the analysis of deglutition events and transit times. J Oral Rehabil 2006; 33: 646−53.
6. Akin E, Sayin MO, Karacay S, Bulakbasi N. Real-time balanced turbo field echo cine-magnetic resonance imaging evaluation of tongue movements during deglutition in subjects with anterior open bite. Am J Orthod Dentofacial Orthop 2006; 129: 24−8.
7. Sutthiprapaporn P, Tanimoto K, Ohtsuka M, Nagasaki T, Konishi M, Iida Y,et al. Improved inspection of the lateral pharyngeal recess using cone-beam computed tomography in the upright position. Oral Radiol 2008; 24: 71−5.
8. Yamashina A, Tanimoto K, Ohtsuka M, Nagasaki T, Sutthiprapaporn P, Iida Y,et al. A morphological comparison of the piriform sinuses in head-on and head-rotated views of seated subjects using cone-beam computed tomography. Oral Radiol 2008; 24: 64−70.
9. Breyer T, Echternach M, Arndt S, Richter B, Speck O, Schumacher M, et al. Dynamic magnetic resonance imaging of swallowing and laryngeal motion using parallel imaging at 3 T. Magn Reson Imaging 2009; 27: 48−54.
10. Rybicki FJ, Otero HJ, Steigner ML, Vorobiof G, Nallamshetty L, Mitsouras D, et al. Initial evaluation of coronary images from 320-detector row computed tomography. Int J Cardiovasc Imaging 2008; 24: 535−46.
11. Fujii N, Inamoto Y, Saitoh E, Baba M, Okada S, Yoshioka S, et al. Evaluation of Swallowing Using 320-Detector-Row Multislice CT. Part I: Single-and Multiphase Volume Scanning for Three-dimensional Morphological and Kinematic Analysis. Dysphagia 2010 Jan 20. Epub ahead of Print.
12. Inamoto Y, Fujii N, Saitoh E, Baba M, Okada S, Katada K, et al. Evaluation of Swallowing Using 320-detector-row Multislice CT. Part II: Kinematic Analysis of Laryngeal Closure during Normal Swallowing. Dysphagia 2010 Mar 5. Epub ahead of Print.
13. Klingebiel R, Siebert E, Diekmann S, Wiener E, Masuhr F, Wagner M, et al. 4-D Imaging in cerebrovascular disorders by using 320-slice CT: feasibility and preliminary clinical experi- ence. Acad Radiol. 2009; 16: 123−9.
14. Ohtsuka M. Reduction of Patient Dose and Improvement of Measurement Accuracy in Radiographic Swallowing Studies. Dent Radiol 2004; 44: 1−15. Japanese.
15. Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007; 103: 534−42.
16. Hasegawa J, Sunayasiki T, Takeuchi K. Estimation of Radiation Exposure Doses to Examiner from the Videofluoroscopic Examination of Swallowing. Jpn J Dysphagia Rehabil 2007; 11: 33−41. Japanese.
17. Syoichi S, Kobayasi M. Dose Estimation of Head CT Examination by Volume Scanning of 320 Area Detector Row CT. Jpn J Radiol Technol 2009; 65: 1127−34. Japanese.
18. International Commission on Radiological Protection. 2007 recommendations of the International Commission on Radiological Protection. Ann ICRP 2007; 37: publication no. 103
19. Kanamori D, Kagaya H, Yokoyama M, Saitoh E, Ozaki K, Okada S, et al. Trajectory of the Hyoid Bone during Isolated Pharyngeal Swallow. Jpn J Dysphagia Rehabil 2009; 13:192−6. Japanese.
20. Beck TJ, Gayler BW. Image quality and radiation levels in videofluoroscopy for swallowing studies: a review. Dysphagia 1990; 5: 118−28.
21. Wright RER, Boyd CS, Workman A. Radiation doses to patients during pharyngeal videofluoroscopy. Dysphagia 1998; 13: 113−5.
22. Crawley MT, Savage P, Oakley F. Patient and operator dose during fluoroscopic examination of swallow mechanism. Br J Radiol 2004; 77: 654−6.
23. Zammit-Maempel I, Chapple CL, Leslie P. Radiation dose in videofluoroscopic swallow studies. Dysphagia 2007; 22: 13−5.
24. Cohnen M, Poll LW, Puettmann C, Ewen K, Saleh A, Mödder U. Effective doses in standard protocols for multi-slice CT scanning. Eur Radiol 2003; 13: 1148−53.