ORIGINAL ARTICLE

Patients' Radiation Dose During Videofluoroscopic Swallowing Studies According to Underlying Characteristics

Hong Min Kim · Kyoung Hyo Choi · Tae Woo Kim

Abstract The videofluoroscopy swallowing study (VFSS) is regarded as the gold standard in diagnosing and assessing swallowing disorders. The goal of this study was to evaluate patients' radiation dose during a VFSS and to determine the influence of patients' underlying characteristics on radiation exposure risk. A total of 295 patients who underwent VFSS were included in this study. The fluoroscopy machine was equipped with a dose area product (DAP). The mean screening time was 4.82 ± 1.80 min and the mean DAP was 9.62 ± 5.01 Gy cm^2. The mean effective dose was 1.23 ± 0.64 mSv. Screening time and DAP had a positive correlation ($r = 0.76$, $P < 0.0001$). The cerebrovascular accident (CVA) group showed higher screening time and DAP than the nasopharyngeal cancer (NPC) group with statistical significance. Patients' BMI and DAP had a positive correlation ($r = 0.28$, $P < 0.0001$), and height, weight, and body surface area (BSA) also showed positive correlations with DAP. Radiation dose during VFSS is much lower than that of a routine chest CT, and it would take more than 40 VFSSs annually to exceed the annual radiation exposure dose limit according to the mean effective radiation exposure dose of this study. As it is difficult to exceed the annual dose limit, we assume that VFSS is relatively safe in terms of its radiation exposure risk.

The videofluoroscopy swallowing study (VFSS) is regarded as the gold standard for diagnosing and assessing swallowing disorders. However, there are only a few studies that have quantified the patients' radiation exposure dose during VFSS [1–3].

According to the As Low As Reasonably Achievable (ALARA) principle, examiners must closely monitor and minimize radiation exposure doses to patients [4]. Exposure to ionizing radiation has deterministic and stochastic effects. Deterministic effects occur above a threshold that is associated with cell killing. Stochastic (nondeterministic) effects, such as mutation, have no threshold and can result in cancer and hereditary effects.

Air kerma (AK) indexes the amount of radiation at a point in space and assesses the hazard at that specific location. AK multiplied by the cross-sectional area of the X-ray beam at the point of measurement is the dose area product (DAP), which is expressed as Gy cm^2. The DAP value acts as a powerful tool for the dose assessment for simple fluoroscopic examinations [5].

There are some studies that have evaluated the patients' radiation exposure doses during VFSS. Chau et al. [6] recently reported that the mean DAP during VFSS was 2.42 ± 2.04 Gy cm^2 for an effective dose of 0.31 ± 0.26 mSv, and that cerebrovascular accident (CVA) patients showed significantly higher DAP values than nasopharyngeal cancer (NPC) patients.

Recording systems in fluoroscopy require automatic exposure control for optimal image quality. Automatic brightness control maintains intensifier exposure rates on the basis of subject thickness by adjusting various

H. M. Kim · K. H. Choi (✉)
Department of Rehabilitation Medicine, Asan Medical Center, University of Ulsan College of Medicine, 388-1, Pungnap-2 Dong, Songpa-Gu, Seoul, Korea
e-mail: khchoi@amc.seoul.kr

T. W. Kim
Department of Rehabilitation Medicine, Gangneung Doing-in Hospital, Gangneung, Korea

technique factors [7]. However, there are few studies that consider the correlation between the patient body size and the radiation exposure dose during VFSS.

The goals of this study were to evaluate the patients' radiation dose during VFSS and to determine the influence of a patient's underlying characteristics, including body size, on the radiation dose for evaluating the associated risk.

Methods

Participants

A total of 295 VFSS examinations were performed in Asan Medical Center in Korea from November 2010 to January 2011. There were 271 adults and 24 children. The patients' underlying pathologies included stroke, brain tumor, traumatic brain injury, other neurologic impairment, parkinsonism, head and neck cancer, and cardiopulmonary problems. Patients who were unable to continue with the study for any reason were excluded.

X-ray Facilities

All VFSSs were performed using the EasyDiagnost Eleva® (Philips, Amsterdam, Netherlands) (Fig. 1). In this machine there is no specific program for VFSS. However, the barium swallowing study is similar to VFSS so we used barium swallowing study program. Exposure factors were adjusted by automatic fluoroscopic control throughout the procedure. The radiology technicians performed the regular calibration and quality assurance checks.

Fig. 1 EasyDiagnost Eleva® (Philips, Amsterdam, Netherlands)

Videofluoroscopic Technique

The VFSS was performed by three physicians and two radiology technicians. The patients' were positioned either sitting on a chair or lying on a bed, depending on their physical condition, and they were screened in the lateral and anteroposterior (AP) positions.

One physician gave the barium-mixed swallowing materials to the patients, and the other physicians interpreted the patients' swallowing function via the video while they swallowed the food materials. The study was started in lateral projection with the patient either in an upright sitting position or lying on a bed. Patients were given 2 and 5 ml of thick barium fluid mixture via a syringe, followed by 2 spoons of pureed diet, mechanically altered diet, and regular texture food each. For the last step, 2- and 5-ml boluses of thin barium fluid mixture were given via syringe and twice by cup. After that, AP projection was done while giving 2 ml of thin fluid mixture via syringe. Oral and pharyngeal phases were evaluated in all patients; however, the esophageal phase was evaluated only in patients with symptoms related to gastroesophageal reflux, a history of esophageal surgery, or other esophageal problems. When the physicians decided that therapeutic strategies were needed, patients were given an additional diet with altered position or maneuvering according to the physicians' decision. All examinations were recorded as files in the database of Asan Medical Center.

Dose Assessment

The fluoroscopy machines was equipped with a DAP meter. VacuDAP® (VacuTec, Dresden, Germany) (Fig. 2), which provides screening times and DAP, was used to estimate DAP.

The effective dose was calculated from the DAP for each patient using the conversion coefficient published by the National Radiological Protection Board (NRPB-R262). This conversion factor was used for lateral throat projection, which included the thyroid, upper esophagus, and top most part of the lung.

Statistical Analysis

Statistical analysis was carried out using SPSS ver. 16.0 (SPSS, Inc., Chicago, IL). A Pearson correlation coefficient was calculated for simple linear regression analysis; $P < 0.05$ was considered significant. The Kruskal–Wallis test was used for comparing the screening time, DAP, and DAP/screening time between the CVA, NPC, and cardiopulmonary disease (CPD) groups. The Bonferroni adjusted Mann–Whitney U test was used after the significant Kruskal–Wallis test to determine which groups differ from

Fig. 2 VacuDAP® (VacuTec, Dresden, Germany). r = Pearson's correlation coefficient; * $P < 0.05$

each other. Statistical significance was set at $P < 0.05$ for analysis and at $P < 0.017$ for the Bonferroni adjusted Mann–Whitney U test.

Results

In this study, a total of 295 patients who underwent VFSS exams were enrolled. Of these, 133 patients had a central nervous system (CNS) lesion, 87 had NPC, 37 had cardiopulmonary disease (CPD), 15 were pediatric patients, and 52 had other diseases (Table 1). The mean screening time was 3.32 ± 1.32 min and the mean DAP was 9.62 ± 5.01 (range = 7.49–24.96) Gy cm². In the adult group ($n = 271$), the mean screening time was 3.37 ± 1.32 min and the mean DAP was 9.94 ± 4.93. In the pediatric group ($n = 24$), the mean screening time was

Table 1 Characteristics of subjects

Characteristics		Value	(%)
Gender	Male	212	(71.1)
	Female	83	(28.9)
Type of lesion	Central nervous system (CNS) lesion	133	(45.1)
	Cerebrovascular accident (CVA)	91	(30.8)
	Brain tumor	16	(5.4)
	Traumatic brain injury	3	(0.1)
	Parkinsonism	13	(4.4)
	Other	10	(3.4)
	Nasopharyngeal cancer (NPC)	87	(29.5)
	Cardiopulmonary disease (CPD)	37	(12.5)
	Pediatric	15	(5.0)
	Others	52	(17.6)
Total		295	(100.0)

Table 2 Radiation dose and screening time

	DAP (Gy cm²)	Screening time (min)
Adult	9.94 ± 4.93	3.37 ± 1.32
CNS	10.80 ± 5.42	3.62 ± 1.44
NPC	8.69 ± 3.42	3.07 ± 1.12
CPD	10.32 ± 4.87	3.12 ± 0.98
Pediatric	3.71 ± 2.06	2.42 ± 1.00
All cases	9.62 ± 5.01	3.32 ± 1.32

Values are mean $\pm$ SD

2.42 ± 1.00 min and the mean DAP was 3.91 ± 2.06 (Table 2).

Screening Time and DAP

Screening time and DAP had a positive correlation, with a Pearson's correlation coefficient (r) of 0.76 and $P < 0.0001$ (Fig. 3). This result suggests that the screening time and DAP have a significant linear correlation; this correlation is the same as the results of previous studies.

Effective Dose Assessment

The mean effective dose for the procedure was 1.23 ± 0.64 (range = 0.09–3.20) mSv, using the conversion coefficient published as NRPB-R262, and the mean effective dose for the adults was 1.27 ± 0.63 mSv. In the pediatric group, the mean effective dose was 0.48 ± 0.26 mSv.
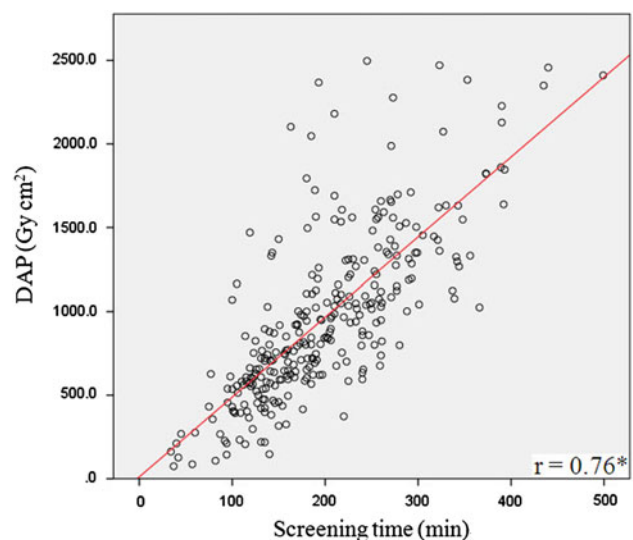

Fig. 3 Correlation between screening time and DAP. r = Pearson's correlation coefficient; * $P < 0.05$

CVA Group vs. NPC Group vs. CPD Group

There was significant difference in the screening time and the DAP ($P < 0.05$) among the three groups, but there was no statistical significance seen for the DAP/screening time (Fig. 4). The CVA group had a higher screening time and DAP ($P = 0.008$ at screening time, $P = 0.001$ at DAP) compared with those of the NPC group; there was no significant difference in these values between the CVA and CPD groups and between the NPC and CPD groups.

Gender, Age, and DAP

There was no significant correlation between patient gender and DAP ($r = -0.006$, $P = 0.92$), and there was no significant difference in DAP between male and female patients. ($P = 0.750$).

Correlation Between Patient Body Size and DAP

The patients' BMI and DAP had a positive correlation, with a Pearson's correlation coefficient (r) of 0.28 and $P < 0.0001$. The height, weight, and body surface area (BSA) also showed a positive correlation with DAP ($r = 0.35$, 0.36, 0.36, respectively; $P < 0.0001$). Upon analysis, it was found that those body size parameters (i.e., height, weight, BMI, BSA) had a positive correlation with DAP/screening time ($r = 0.37$, 0.44, 0.36, 0.42, respectively) (Table 3), and there was a stronger correlation with the DAP/screening time than with DAP (Fig. 5).

Discussion

Our study is the first report on the effect of patient body size on radiation exposure during VFSS. Moreover, this is the first study to report the patient radiation exposure dose in a large group of patients who underwent VFSS in Korea.

Table 3 Correlation between body size and radiation exposure dose

	DAP	DAP/screening time
Height	0.35*	0.37*
Weight	0.36*	0.44*
BMI	0.28*	0.36*
BSA	0.36*	0.42*

Values are Pearson's correlation coefficient (r)

* $P < 0.05$

Compared to previous studies in other countries, the mean DAP and the mean screening time of this study are higher. In particular, comparing our study to that of Chau et al. [6], which is the largest study on radiation exposure dose during VFSS, our mean screening time was 1.14 times higher and the DAP was 3.98 times higher. These results show that the screening time did not differ substantially between the studies but that our DAP was much higher. We believe the reasons for these results are as follows: First, the fluoroscopy machine used in our study was different from that used in previous studies. The study of Chau et al. used the model AXIOM Iconos R200 (Siemens, Germany), and other studies used different equipment [6]. In this study, we used the EasyDiagnost Eleva® (Philips, Amsterdam, Netherlands). The setting and the performance of the machines could differ according to the products and the manufacturing companies. Second, the different body sizes could be a factor which contributing to our results. However, as there is no information regarding patient body size in the previous studies, it is difficult to prove this assumption.

The recommended radiation exposure dose limit for adults is 3,000 millirem (mrem) to any tissue during a 13-week period and 5,000 mrem (=50 mSv) annually, according to the NIH radiation safety guideline. In our study, the mean effective dose was 0.09–3.20 (mean = 1.23 ± 0.64) mSv. With this mean effective dose, more than 40 VFSSs annually would be needed to exceed the

Fig. 4 DAP and screening time among groups (CNS vs. NPC vs. CPD). * $P < 0.017$ by the Mann–Whitney U test with Bonferroni correction after the Kruskal–Wallis test
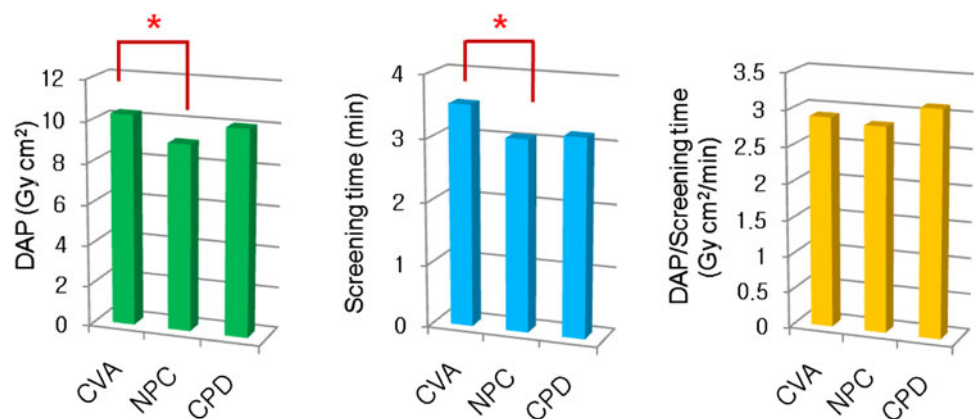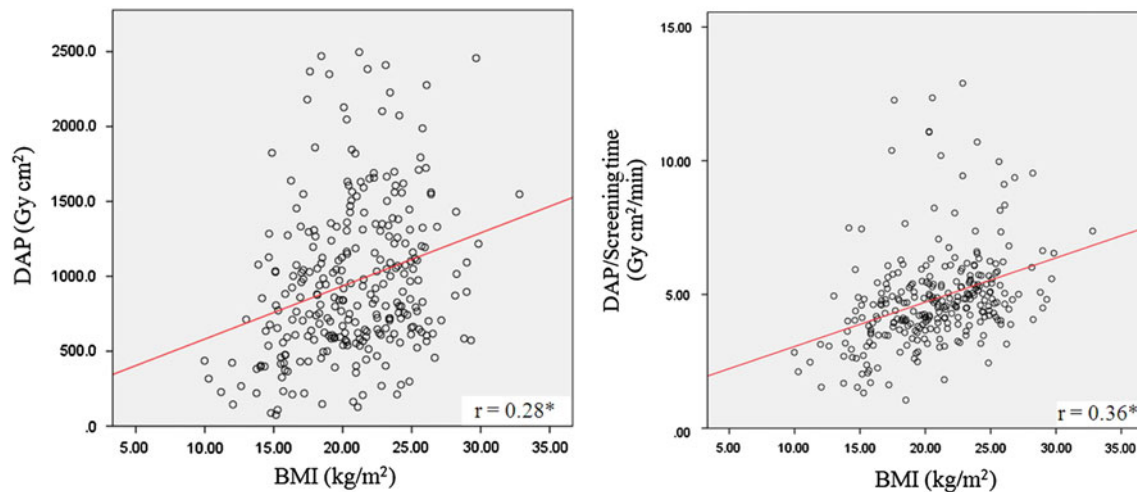
Fig. 5 Correlation between BMI and DAP. r = Pearson's correlation coefficient; $* P < 0.05$

annual radiation exposure limit of NIH guideline. At the maximum radiation exposure dose of this study, approximately more than 15 VFSSs annually would be needed to exceed the annual radiation exposure dose limit. It is rare that a patient receives VFSSs for more than 15 times each year, as well as 40 times a year. Therefore, it is difficult to exceed the annual radiation dose limit by undergoing only VFSSs. In addition, the radiation dose during VFSS in our study was much lower than that of a routine chest CT performed in previous studies (mean effective dose = 5–12 mSv) [8, 9].

It is difficult to estimate the possible number of VFSSs that a patient can undergo annually because a patient can undergo other radiological studies or use radioactive drugs. According to the ALARA principle, it is preferable to minimize the patient's radiation exposure dose [2]. Therefore, minimizing the screening time is important for reducing patient risk from radiation exposure.

In this study, there was a significant difference in the screening time and the DAP between the CVA group and the NPC group. The CVA group showed a higher screening time and a higher DAP than the NPC group; however, there was no significant difference in the DAP/screening time in both groups. These results indicate that the radiation exposure risk of the CVA group was higher than that of the NPC group due to the longer screening time. CVA patients have many problems such as cognitive impairment, aphasia, and apraxia, which can elongate the screening time [10–12]. It is important to reduce the screening time in CVA patients so as to reduce the radiation exposure risk. However, patients should not be made to swallow food materials faster in order to reduce the screening time because this could change the result of the study and also increase a patient's aspiration risk.

This is the first study to analyze the correlation between patient body size and radiation exposure dose during VFSS. However, there are a few other studies that relate this correlation during other radiological procedures. Kuon et al. [13] found that the patient radiation dose while undergoing invasive cardiac procedures had a positive correlation with BMI and BSA. Ector et al. [14] stated that obese patients receive more than twice the effective radiation dose of normal-weight patients during AF ablation procedures.

In our study, all the parameters of patient body size, i.e., BMI, weight, height, and BSA, showed a correlation with DAP and the DAP/screening time. The DAP/screening time had a stronger correlation with all body size parameters than did DAP. This result indicates that not only obesity but other body size parameters, such as height or BSA, also can affect the radiation exposure dose due to the larger irradiated field.

Study Limitation

We did not evaluate other patient characteristics that could influence the results, such as cognitive function or the severity of dysphagia. Patient age and sex also were not associated with radiation dose in this study. Further studies with a larger sample population and that consider other risk factors will be needed in order to evaluate the influence of these factors on the radiation exposure risk. We could not evaluate all patients with the same trials of diets because some patients received additional diets for evaluating esophageal phase or assessing the effect of therapeutic strategies. This could have changed the screening time. We also did not evaluate the annual number or the annual total radiation dose of VFSSs. Further study will be needed to

more accurately evaluate the annual radiation risk caused by VFSSs.

Conclusion

As it is possible for patients with a lager body size as well as CVA patients to be exposed to a higher radiation dose during VFSS, it is necessary to monitor the screening time during VFSS when evaluating obese patients or CVA patients according to ALARA principle. However, the radiation dose during VFSS is lower than that of other radiological studies such as the chest CT, and it is difficult to exceed the annual dose limit by undergoing only VFSSs. Therefore, we assume that VFSS is relatively safe in terms of its radiation exposure risk.

References

1. Wright RE, Boyd CS, Workman A. Radiation doses to patients during pharyngeal videofluoroscopy. Dysphagia. 1998;13:113–5.
2. Martin-Harris B, Logemann JA, McMahon S, Schleicher M, Sandidge J. Clinical utility of the modified barium swallow. Dysphagia. 2000;15:136–41.
3. Logemann JA. Role of the modified barium swallow in management of patients with dysphagia. Otolaryngol Head Neck Surg. 1997;116:335–8.
4. Baker G. Ionising radiation regulations. Vet Rec. 1985;117:646.
5. International Commission on Radiological Protection. 1990 recommendations of the International Commission on Radiological Protection, Annals of the ICRP 21. Oxford: Pergamon; 1991.
6. Chau KH, Kung CM. Patient dose during videofluoroscopy swallowing studies in a Hong Kong public hospital. Dysphagia. 2009;24:387–90.
7. Geise RA. Fluoroscopy: recording of fluoroscopic images and automatic exposure control. Radiographics. 2001;21:227–36.
8. Tsushima Y, Taketomi-Takahashi A, Takei H, Otake H, Endo K. Radiation exposure from CT examinations in Japan. BMC Med Imaging. 2010;10:24.
9. Smith-Bindman R, Lipson J, Marcus R, Kim KP, Mahesh M, Gould R, Berrington de Gonzalez A, Miglioretti DL. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med. 2009;169:2078–86.
10. Calvanio R, Levine D, Petrone P. Elements of cognitive rehabilitation after right hemisphere stroke. Neurol Clin. 1993;11: 25–57.
11. Geschwind N. The apraxias: neural mechanisms of disorders of learned movement. Am Sci. 1975;63:188–95.
12. Kelly H, Brady MC, Enderby P. Speech and language therapy for aphasia following stroke. Cochrane Database Syst Rev. 2010;5: CD000425.
13. Kuon E, Glaser C, Dahm JB. Effective techniques for reduction of radiation dosage to patients undergoing invasive cardiac procedures. Br J Radiol. 2003;76:406–13.
14. Ector J, Dragusin O, Adriaenssens B, Huybrechts W, Willems R, Ector H, Heidbuchel H. Obesity is a major determinant of radiation dose in patients undergoing pulmonary vein isolation for atrial fibrillation. J Am Coll Cardiol. 2007;50:234–42.

Hong Min Kim MD

Kyoung Hyo Choi MD, PhD

Tae Woo Kim MD