Research Article

Relationships Between Radiation Exposure Dose, Time, and Projection in Videofluoroscopic Swallowing Studies

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Purpose: Clinicians are trained to rely on radiation exposure time as an indicator of patient radiation exposure in Videofluoroscopic Swallowing Studies (VFSSs). However, it has been shown in other medical uses of fluoroscopy that dose area product (DAP), the amount of radiation delivered to the patient, is a better indicator of overall patient radiation exposure than radiation exposure time. This study sought to understand the relationship of DAP in VFSSs with radiation exposure time and projection used (lateral vs. posterior–anterior [PA]).

Method: DAP, radiation exposure time, and projection were recorded in 200 adults undergoing clinically indicated VFSSs conducted in accordance with the Modified Barium Swallow Impairment Profile guidelines. Data were analyzed using Spearman correlation and related sample Wilcoxon test.

Results: DAP and radiation exposure time did not correlate significantly in the lateral or upper PA projections. DAP was significantly higher in the PA compared to lateral projection ($p < .01$); however, time was shorter in PA versus lateral ($p < .01$). The average mGy-cm² per second was 7 for lateral projections, 14 for upper PA projections, 17 for middle PA projections, and 34 for lower PA projections.

Conclusions: Radiation exposure time and DAP do not strongly correlate across VFSSs. Specifically, this means that 1 patient can have a low radiation exposure time with a high DAP relative to another person with a higher radiation exposure time but a lower DAP. The results of this study question the common clinical practice of using time (specifically the 5-min indicator) as a threshold for radiation exposure during a VFSSs.

Approximately one in every 25 adults in the United States will experience a swallowing problem each year (Bhattacharyya, 2014). The videofluoroscopic swallowing study (VFSS; Martin-Harris & Jones, 2008; Martin-Harris, Logemann, McMahon, Schleicher, & Sandidge, 2000) is the primary diagnostic test used to identify abnormalities in oropharyngeal swallowing physiology and detect the presence and etiology of aspiration.

Most importantly, VFSSs are used to identify the physiologic targets of treatment and to test the effectiveness of these targets prior to making treatment recommendations to improve swallowing function (Logemann, 1998; Martin-Harris et al., 2000). Although the VFSS is an important diagnostic tool for the evaluation of swallowing function, it does require precautions to minimize patient cancer risk, similar to other medical uses of ionizing radiation. One key precaution used in the clinic is monitoring the radiation exposure time (Killewich & Singleton, 2011).

Radiation exposure time, also known as fluoroscopy time, is commonly monitored during VFSSs. Reducing time is one of the three main radiation safety methods taught to clinicians, along with increasing distance and use of shielding (Brateman, 1999; Le Heron, Padovani, Smith, & Czarwinski, 2010). Typically, fluoroscopy units are preset to indicate (beep) when a time threshold has been met, such as 5 min (Killewich & Singleton, 2011). This indicator leads clinicians to assume that 5 min is an important threshold related to the amount of radiation patients are

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exposed to during the VFSS; however, this assumption is unsubstantiated.

To quantify radiation exposure for a given patient, the dose area product (DAP) can be used and is readily available, on modern fluoroscopy units, to clinicians conducting the exam. DAP is the total amount of radiation used in a radiographic examination (Nickoloff, Lu, Dutta, & So, 2008). DAP, along with exam and patient characteristics, is used to assess radiation risks from X-ray exams. Research in other medical applications of fluoroscopy found a stronger relationship between DAP and patient skin dose, in comparison to radiation exposure time and skin dose. This led us to question our use of (and reliance on) radiation exposure time as the clinically relevant factor that should be monitored during VFSSs (Chida et al., 2006). Although radiation exposure time is directly related to the dose occurring in one exam, we speculated that time is not an accurate measure of radiation exposure across patients or across exams. Thus, this study sought to better understand the relationship of DAP with radiation exposure time in VFSSs.

Another underdiscussed yet relevant aspect of VFSSs is the relative radiation exposure between different projections (lateral vs. posterior–anterior [PA]). In a standard VFSS protocol, some swallows are elicited in the lateral projection and some in the PA projection. In PA projection, a follow-through is conducted, starting at the level of the oropharynx (subsequently denoted as “upper PA”), down to the esophagus (“middle PA”), and completing at the level of the stomach (“lower PA”). As part of a larger investigation into the radiation exposure and associated cancer risks for adults undergoing VFSSs, we have anecdotally noticed that DAP varies with projection. The physical rationale for such variance is straightforward—images created in lateral and upper PA projections include a fair amount of air outside the body, whereas images in middle and lower PA entirely include body mass. Further, middle and lower PA projections are focused on imaging parts of the body with more mass than upper PA and lateral projections. More mass directly relates to a need for greater radiation exposure to penetrate the body with sufficient energy to capture an image with appropriate quality. However, there has been no systematic analysis of the differences of DAP by VFSSs projection. Thus, this study also sought to better understand the relationship of DAP in VFSSs with projection used (lateral vs. PA).

Method

Participants

We retrospectively collected data from 200 adult consecutive in- or outpatients who underwent a routine VFSS at the Medical University of South Carolina. Patients were excluded if they were younger than 21 years old, if no current information on their body mass index was available, or if the VFSS was (accidentally) not conducted at 30 pulses per second.

Videofluoroscopic Swallowing Studies

All VFSSs were conducted in accordance with the guidelines of the standardized and validated Modified Barium Swallow Impairment Profile (MBSImP; Martin-Harris et al., 2008). The MBSImP protocol includes nine different swallow tasks conducted in the lateral projection (e.g., cup sip thin liquid, sequential swallows of nectar thick liquid, teaspoon pudding), and two different swallow tasks in the PA projection (teaspoon nectar-thick liquid, teaspoon pudding). In the PA projection, a follow-through going from the upper to middle and lower PA is performed to assess pharyngeal contraction and esophageal clearance in the upright position because of known associations and treatment implications for incomplete oropharyngeal and esophageal clearance in the upright position (Gullung, Hill, Castell, & Martin-Harris, 2012). See Figure 1 for images related to the different projections.

Following the MBSImP guidelines, any safety concerns (e.g., significant airway invasion or lack of bolus clearance) require that the clinician omits challenging swallow tasks or stops the entire VFSS. Further, technical constraints might hinder complete execution of the standard protocol (e.g., if a patient is positioned in a wheelchair that prevents the X-ray tube to move down for a follow through). Thus, because of different clinical and technical reasons, VFSSs might not follow the full MBSImP protocol.

The use of a PA versus anterior to posterior (AP) projection will depend on the technical set up of the X-ray machine used. The machine dictates how the patient will be positioned between the X-ray source and image intensifier and, thus, if the X-rays will be transmitted from PA or from AP through the patient. In a study of effective dose conversion factors, we have determined that radiation doses are a factor of three times larger for AP than PA projections and, thus, advocate for using a PA projection (Bonilha, Wilmskoetter, Tipnis, Martin-Harris, & Huda, 2017). In our study, all VFSSs were performed with a GE Precision 500D fluoroscopy unit. Patients were assessed in lateral and PA projections; thus, results are not applicable to clinicians using AP projections. VFSSs were performed with 30 pulses per second and recorded with 30 frames per second using a TIMS DICOM system.

Data Extraction and Statistical Analysis

We extracted DAP and radiation exposure time from the digital DICOM images for each projection separately using TIMS DICOM review software. The beginning and end of each projection (lateral, upper PA, middle PA, and lower PA) were determined by a speech-language pathologist. Demographic information was extracted from electronic medical records.

We assessed the distribution of the variables, DAP and time, by visual inspection and the Shapiro–Wilk test for normality. Both variables were nonnormally distributed;

Figure 1. Projections from a VFSS; PA = posterior–anterior.

thus, we applied the nonparametric Spearman correlation and the related sample Wilcoxon test. The data were also used to create a model that allocates the percentage of DAP in the various projections (lateral, PA, etc.). We set the significance level at $\alpha = .05$. We used SAS statistical software (Version 9.4, released 2016, SAS Institute, Inc.) for data analysis. The study was approved by our institutional review board.

Results

Participants

In total, 200 VFSS from 200 different patients were included. Of those, 39 (19.5%) were full protocol studies, meaning that the MBSImP standard protocol was followed for the lateral and PA projections (at least 12 different swallows were administered, 10 in lateral, two in PA with complete follow-throughs). Table 1 shows demographic information for both patient cohorts.

DAP With Radiation Exposure Time

The average DAP for all 200 patients was 1.34 Gy cm^2 ($SD = 0.89$, range: 0.17–5.94), and average radiation

exposure time was 154.67 s ($SD = 64.28$, range: 23–387). Figure 2 shows a plot of DAP versus total fluoroscopy time for all 200 patients undergoing VFSS examinations ($N = 200$). The slope of this line was 7 mGy-cm^2 per second, and the correlation coefficient (r) was 0.54. For the 39 patients with full protocol VFSS, the average DAP was 1.34 Gy cm^2 ($SD = 0.55$, range: 0.49–2.77) and average radiation exposure time was 138.28 s ($SD = 33.53$, range: 86–209). Correlation of DAP with radiation exposure time was $r = -.08$, $p = .6490$.

DAP With Radiation Exposure Time by Projection

Figure 3 shows a plot of DAP versus total fluoroscopy time for all patients undergoing VFSS in the lateral projection. The slope of this line was 7 mGy-cm^2 per second, and the correlation coefficient (r) was .58.

Figure 4 shows a plot of DAP versus total fluoroscopy time for upper PA projections in patients undergoing VFSS. The slope of this line was 14 mGy-cm^2 per second, and the correlation coefficient (r) was .76.

Figure 5 shows a plot of DAP versus total fluoroscopy time for middle PA projections in patients undergoing VFSS. The slope of this line was 17 mGy-cm^2 per second, and the correlation coefficient (r) was .40.

Table 1. Demographic information.

Demographic variables		All patients (N = 200)	Patients with full protocol (N = 39)
Age, M (SD)		65.09 (14.58)	64.18 (14.03)
Sex, N (%)	Female	81 (40.5)	21 (53.85)
	Male	119 (59.5)	18 (46.15)
Race, N (%)	Black or African American	68 (34)	6 (15.38)
	White or Caucasian	127 (63.5)	33 (84.62)
	Other	4 (2)	0 (0)
	Unknown	1 (0.5)	0 (0)
Ethnicity, N (%)	Hispanic or Latino	2 (1)	0 (0)
	Not Hispanic or Latino	196 (98)	39 (100)
	Unknown	2 (1)	0 (0)
BMI, M (SD)		26.36 (6.77)	28.17 (6.35)

Note. N = number; BMI = body mass index.

Figure 6 shows a plot of DAP versus total fluoroscopy time for lower PA projections in patients undergoing VFSS. The slope of this line was 34 mGy-cm² per second, and the correlation coefficient (*r*) was .63.

DAP With Radiation Exposure Time for Full Protocol Studies

DAP was statistically significantly correlated with radiation exposure time for the middle and lower PA projections only ($r = .46$, $r = .57$, $p < .01$; see Table 2). DAP was significantly higher in the PA (total) compared to lateral projections ($p < .01$); however, time was longer in lateral versus PA (total; $p < .01$).

Figure 2. Plot of dose area product versus total fluoroscopy time for all 200 patients undergoing VFSS (N = 200).

DAP Allocation Model

Based on our results, the estimated allocation of DAP during VFSSs is 40% lateral, 20% upper PA, 10% middle PA, and 30% lower PA. This compares to a time allocation model of 75% lateral, 15% upper PA, 5% middle PA, and 5% lower PA.

Discussion

Any clinician using medical imaging that exposes patients to ionizing radiation must monitor radiation exposure and determine that the medical necessity of the exam outweighs the risks related to such radiation exposure (Zanzonico, 2016). During fluoroscopy exams, such as

Figure 3. Plot of dose area product versus total fluoroscopy time for lateral projections only for all 200 patients undergoing VFSS (N = 200).

Figure 4. Plot of dose area product versus total fluoroscopy time for upper posterior–anterior (PA) projections only for 144 patients undergoing VFSSs.

the VFSS, clinicians have been trained to use radiation exposure time to monitor the amount of radiation delivered to the patient. However, the results of this study indicate that radiation exposure time and DAP do not strongly correlate across VFSS. Specifically, this means that one patient can have a low radiation exposure time

Figure 5. Plot of dose area product versus total fluoroscopy time for middle posterior–anterior (PA) projections only for 51 patients undergoing VFSS.

with a high DAP relative to another person with a higher radiation exposure time but a lower DAP. This is possible because fluoroscopy units are set to use automatic brightness control. Automatic brightness control detects the energy captured at the image intensifier and modifies key aspects of the fluoroscopy exam (kV, mA, and filtration) to maintain the energy at the necessary levels to capture an image of appropriate quality.

When further investigating the relationship between radiation exposure time and DAP, we discovered that it was influenced by projection. That is, the relationship was statistically significant and moderate to strong in the middle and lower PA projections but not significant in the upper PA and lateral projections. Whereas DAP was significantly higher in the middle and lower PA projections, conversely, radiation exposure time was lower in these projections. This result emphasizes the importance of understanding the relationship of radiation exposure time and the amount of radiation delivered to the patient especially when using radiation exposure time to determine a meaningful threshold for stopping a clinical exam in an effort to limit radiation exposure.

Although DAP provides more information about the amount of radiation than radiation exposure time, it should not be interpreted as a measure of cancer risk (Huda, 2014). Cancer risk from radiation exposure varies based on patient and exam characteristics (Huda, 2014). Some relevant characteristics that influence risk are patient size and image size.

The results of this study supported our anecdotal observation that DAP varied by projection and found that, on average, 40% of DAP is from the lateral projection

Figure 6. Plot of dose area product versus total fluoroscopy time for lower posterior–anterior (PA) projections only for 48 patients undergoing VFSS.

Table 2. Correlation of dose area product (DAP) and time for each projection.

Projection	DAP (in Gy cm ²), M (SD)	Radiation exposure time (in s), M (SD)	Correlation coefficient	p Value
Lateral	0.52 (0.22)	102 (32)	.29	.0710
Total PA	0.80 (0.48)	33 (10)	.12	.4759
Upper PA	0.29 (0.20)	21 (7)	.25	.1532
Middle PA	0.13 (0.16)	5 (4)	.43	.0120
Lower PA	0.35 (0.27)	7 (6)	.56	.0006

Note. PA = posterior–anterior.

whereas 60% of DAP is from the PA projection (upper, middle, and lower combined). It is important that this information be correctly interpreted to ensure educated clinical decisions. In general, the radiation exposure and related cancer risks from VFSSs in adults are extremely low (Bonilha, Huda, Wilmskoetter, Martin-Harris, & Tipnis, 2019; Bonilha et al., 2017, 2019). Thus, there is no evidence that VFSSs in adults should be modified or limited to reduce radiation exposure if those modifications/limits would reduce the information gained from the exam. VFSSs provide information critical for the appropriate diagnosis and treatment of patients with dysphagia. ALARA, as low as reasonably achievable, is the guiding principle of radiation exposure (Brateman, 1999). In the cases of diagnostic tests that use ionizing radiation, the determination of being reasonably achievable must be based on the ability to gather critical clinical information from the exam. Clinicians, who do choose to limit VFSSs due to radiation risks, should consider using a DAP threshold instead of relying on radiation exposure time.

Conclusions

Exposure time is not a good indicator of the amount of radiation used to perform VFSSs. One reason for this is that more radiation is required to penetrate thicker body parts such as the middle and lower PA projections. Clinicians should be aware that the relationship between exposure time and radiation delivered to the patient (DAP) is dependent on the exam projection. A model of DAP allocation in VFSSs indicates that approximately 40% of DAP is from the lateral projection and 60% of DAP is from the PA projection. It is critical that this information be interpreted in combination with the overall low risk of radiation from VFSSs for adults to make informed clinical decisions. The results of this study questions the common clinical practice of using time (specifically the 5-min indicator) as a threshold for radiation exposure during an VFSS.

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