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REVIEW

Radiation Exposure to Staff and Patient During Videofluoroscopic Swallowing Studies and Recommended Protection Strategies

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Abstract

Videofluoroscopic swallowing studies expose both the patients and the staff to ionising radiation. Although the radiation exposure is considered low compared to other diagnostic procedures, it is still prudent to keep the radiation dose as low as reasonably achievable. This review aims to summarise the latest literature pertaining to staff and patient radiation dose, as well as to make evidence-based recommendations on dose optimisation strategies. The evidence shows that patient radiation dose is low; nonetheless, care must be taken for patients that require multiple examinations. There are limited studies measuring the staff dose during videofluoroscopic swallowing procedures. However, the operator may receive radiation doses approaching 1 mSv per year. Recommendations for radiation protection strategies are summarised.

Keywords Videofluoroscopic swallowing studies · Radiation exposure · Effective dose · Radiation protection · Deglutition · Deglutition disorders

Introduction

Investigation of dysphagia using videofluoroscopic swallowing studies (VFSS) is a common diagnostic procedure performed by speech and language pathologists (SLP), radiographers and radiologists (the operators). Performed in the oral and pharyngeal phases of swallowing, the dynamic radiographic procedure provides useful information to specialists regarding swallowing disorders for a wide variety of patient groups. VFSS are performed on paediatric and adult patients who present with symptoms of dysphagia caused by various conditions. These include acute conditions, such as stroke, and chronic conditions, such as congenital abnormalities and progressive neurologic diseases like Parkinson's disease. Patients are administered an oral, radio-opaque bolus and instructed to swallow while radiographic images are acquired fluoroscopically, often in the seated position using X-rays with a lateral or anterior–posterior projection. The videofluoroscopic images are assessed for anatomic and physiologic abnormalities by the SLP and/or physicians who can then make the necessary recommendations for treatment and management of the patient.

The role of the performing specialist in the VFSS includes taking the medical history, preparing the bolus material, positioning the patient, sometimes feeding the patient as well as overseeing the acquisition and analysis of the images [1]. As a result of the proximity to the patient during the VFSS, the performing specialist can be exposed to the primary X-ray beam and scattered X-ray radiation from the patient [1, 2]. The exposure of operators and other staff members to the direct or scattered X-rays increases their long-term risk for radiation-induced cancers. The doses received by operators will vary depending on the clinical needs of the patient and the fluoroscopic parameters used. It is essential that appropriate steps be taken to minimise the dose to operators and other staff members and ensure they receive necessary training in radiation safety.

Depending on the clinical indications, some patients may require multiple VFSS procedures. Repeated

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exposures increase the patient's long-term risk of radiation-induced cancers as well as potential tissue reactions, such as damage to the lens of the eyes. Based on the review of recent epidemiological data, it is considered that the threshold for developing radiation-induced cataracts from either "acute or protracted exposure" is as low as 0.5 Gy [3]. Dose optimisation is essential to ensure that the radiation exposure is kept as low as reasonably achievable (ALARA) while achieving the required medical objective [4–7]. Dose optimisation for paediatric patients is particularly important given their greater inherent radiosensitivities and potentially longer life expectancies than adult patients [5, 8].

This review aims to provide an up-to-date review of the doses received by patients and operators (performing specialists such as SLPs in particular) from VFSS as well as evidence-based recommendations for radiation dose optimisation and safety.

Radiation Awareness

Radiation awareness is paramount to any radiation safety program. Understanding the risks as well as means to mitigate radiation exposure can lead to good radiation safety practices. A survey of 1581 United States SLPs found that the primary methods for acquiring radiation knowledge were on the job training and in-services (57.52%) followed by medical practicum (17.93%) [9]. In the same survey, the majority (25.96%) of respondents reported that they received their radiation safety knowledge from an SLP co-worker or supervisor as opposed to a radiation safety officer (14.01%) or medical physicist (1.06%). The authors concluded that the results indicate that the SLPs' radiation knowledge and safety practices are insufficient and require improvement [9].

An earlier Australian survey of 69 SLPs in 2007 found that approximately 50% of respondents had received radiation safety training in the previous 12-month period with the most common methods being workplace in-service or advice from fellow SLPs [1]. While, in general, the authors concluded that the majority of respondents had "a more than adequate knowledge of the basics of radiation protection," ten participants claimed they had not received any training, and of those, 70% believed this was adequate [1]. The authors recommend that radiation protection and safety education be provided at a university level during the training of the SLPs.

A recent study by Choi et al. found that after radiographers and radiology registrars received a 1-h radiation safety training course, there were significant decreases in fluoroscopy time and the number of acquisition images, resulting in lower median dose-area product (DAP) values. Additionally, they reported increases in the use of collimation in various fluoroscopic examinations of the gastrointestinal tract in adults [10]. Table 1 summarises the commonly used relevant radiation dose metrics.

Patient Radiation dose

Typical Dose

It is agreed that the radiation doses to VFSS patients are lower than doses received from other common fluoroscopic and interventional radiology procedures such as endoscopic retrograde cholangiopancreatography, upper gastrointestinal barium meal, barium enema and coronary angiography [2, 11–13]. However, given that many patients may require multiple VFSS procedures over a few weeks, the cumulative effect of the repeated exposures must be kept in mind. The estimated doses naturally vary between institutions and patients, with differing fluoroscopy equipment, local VFSS protocols as well as the clinical indications and physical size and limitations of the patient [12, 14–17]. Table 2 summarises the patient doses from VFSS procedures reported in the literature since 2000.

Moro et al. estimated an effective dose of 0.35 mSv from DAP measurements and concluded that VFSS procedures are relatively low risk, with a 1 in 39,000 chance of a patient developing a fatal radiation-induced cancer [11]. They found that the most significant contributor to the effective dose was the thyroid dose (median 6 mGy). Bonilha et al. used the relationship established by Moro et al. to interpolate and estimate a mean effective dose of 0.44 mSv from their mean fluoroscopy time of 174 s [18]. It has been reported that screening times range from 18 to 1080 s in the published literature [19]. In a recent study by Bonilha et al., the researchers concluded that swallowing impairment scores and clinician experience were significantly associated with increased fluoroscopy time, however, factors such as medical diagnosis category and the use of a standardised protocol were not [18]. The authors note that other factors, such as individual patient characteristics, may also significantly influence fluoroscopy times.

Morishima et al. concluded that the estimated mean patient entrance skin dose of 12.79 mGy for a typical VFSS procedure at their institution is significantly lower than doses received by other common fluoroscopic procedures such the upper gastrointestinal barium meal [2]. However, even though the doses may be low the authors do caution that patient dose should be carefully monitored given that some patients require multiple VFSS procedures and some will be paediatrics. Hersh et al. found that paediatric patients with type 1 laryngeal cleft had up to 10

Table 1 Radiation dose metrics

Term	Definition	Units
Absorbed dose	The energy absorbed per unit mass at a certain point in the irradiated object	Gray, Gy
Dose-area product (DAP)	The absorbed dose multiplied by the area irradiated. Used to assess radiation risk during diagnostic X-ray and interventional radiology procedures. Can be used to estimate Effective Dose by multiplying by a conversion factor. This is also known as kerma-area product (KAP)	Gy cm^2
Effective dose	The sum of the tissue and organ equivalent doses each multiplied by the appropriate tissue weighting factor which accounts for variations in radiation sensitivity of different organs and tissues to the induction of stochastic effects. Represents the stochastic health risk to the whole body (the probability of cancer induction) for an average adult	Sievert, Sv
Entrance dose	The absorbed dose at the surface of the skin	Gy
Equivalent dose	The mean absorbed dose in a tissue or organ multiplied by a weighting factor that accounts for the relative biological effectiveness of the radiation in inducing stochastic effects at low doses	Sv
Reference air kerma	The quantity of energy from ionising radiation absorbed by air at the interventional reference point, which is located at 15 cm from the isocentre towards the X-ray tube	Gy
Skin dose	Also known as Entrance Skin Dose. The radiation dose to the irradiated area of skin estimated by multiplying the entrance dose by a backscatter factor. Used to determine risk of tissue effects to the exposed skin (e.g. skin reddening or burns)	Gy

VFSS procedures during the total course of their treatment [20].

Weir et al. reported an effective dose range for paediatric patients of 0.01–0.25 mSv, the dose decreasing with age and relative radiosensitivity [17]. Hersh et al. report a similar effective dose range of 0.03–0.59 mSv, however, did not report fluoroscopy time nor stratify the data with respect to patient age or size [20]. Unfortunately, there is limited paediatric VFSS data published and a limitation of most of them is that they do not stratify the paediatric data with respect to age or patient size and typically use a DAP conversion factor for adults [14, 15, 20].

When using DAP data to estimate the effective dose to a patient, it is important that the correct factors are used for the examination. These factors must include adult or paediatric, beam projection, anatomical field of view, and beam quality. Bonilha et al. have generated adult DAP conversion factors for a range of adult patient sizes, X-ray beam projections and anatomical fields of view [21]. Software such as NRPB-R279 and Childose have been designed for calculating effective dose and organ doses for paediatric X-ray examinations [22, 23]. The software PCXMC is also commonly used for estimating effective and organ doses from X-ray examination for adults and children [24].

There has also been some limited work done in estimating effective and organ doses using anthropomorphic phantoms, with authors providing conversion factors for minutes of fluoroscopy time [25, 26]. The same limitations noted above for DAP conversion factors are also applicable here.

Dose Optimisation Strategies

Where possible, the X-ray beam should be routinely collimated to ensure that the eyes are not in the primary beam [2]. The thyroid is typically within the primary beam [2, 11]. Morishima et al. recommend that the exposure to the thyroid should be considered and minimised especially for those patients requiring multiple VFSS procedures [2]. Bonilha et al. recommend using a posterior–anterior beam projection instead of anterior–posterior where possible to reduce the dose to the thyroid [21]. Fluoroscopy units normally have several fields of view (FOV) and magnification modes. Magnification modes typically provide higher spatial resolution for a smaller FOV but with an increased dose rate. Ideally a larger FOV should be used with the collimators utilised to reduce the effective FOV and minimise the patient dose. The relationship between FOV and dose rate is an increase of dose approximately equal to $1/FOV^2$ for image intensifier systems and 1/FOV for flat panel detector systems [27].

In a fluoroscopy procedure with no acquisitions, fluoroscopy time can be a useful indicator of patient dose [11]. Thus, minimising the exposure time to the patient is also fundamental in reducing the dose to the patient. SLPs can minimise exposure time through careful planning of the procedure and ensuring the patient and other operators involved understand what is required [28–31].

A more accurate means of assessing patient dose is the total DAP. This is available on all modern fluoroscopy equipment. If the accuracy of the DAP system is known, the reported values can be used to estimate the dose to the

Table 2 Patient and staff radiation dose per procedure

Authors	Publication year	Mean patient dose (mSv)	Mean fluoroscopy time (mins)	Operator dose (μSv)
Crawley et al.	2004	0.85[1]	3.7 (median)	12[2] (whole body) 36[2] (extremities) 20[2] (lens of the eye)
Moro and Cazzani	2006	0.4	2.6	Not done
Weir et al.	2007	0.12 (≤ 1 years)[3] 0.07 (1–3 years)[3] 0.05 (> 3 years)[3]	2.47	Not done
Zammit-Maempel et al.	2007	0.2[4]	3.5	Not done
Chau and Kung	2009	0.31 (all cases)[4] 0.26 (paediatric)[4]	4.23 (all cases) 4.49 (paediatric)	Not done
Hayes et al.	2009	Not done.	Not reported	1.5 μGy[5]
Kim et al.	2013	1.27 (adult)[4] 0.48 (paediatric)[4]	3.37 (adult) 2.42 (paediatric)	Not done
Bonilha et al.	2013	0.44[6]	2.9	Not done
Morishima et al.	2016	12.79 mGy (entrance skin dose)	8.2	16[7] (whole body) 44[8] (lens of the eye)
Hersh et al.	2016	0.16[9]	Not reported	Not done
Sulieman et al.	2017	0.2 (paediatric barium swallow)	3.0	Not done

[1]Estimated by authors from DAP measurements using ODS60 software

[2]Based on dosimeters worn on the lower trunk under a lead apron (whole body), hands (extremities) and forehead (eyes) and extrapolation of patient workload

[3]Authors used PCXMX software to calculate effective dose from measured DAP values

[4]Authors used NRPB-R262 DAP conversion factor to estimate effective dose (~ 0.13 mSv/Gy cm^2)

[5]Estimated from electronic dosimeters placed outside of a lead apron

[6]Authors estimated an effective dose from an interpolation of data in the Moro & Cazzani publication

[7]Measured using a dosimeter under a lead apron (0.35-mm lead equivalent) on the chest

[8]Measured using a dosimeter at collar outside of lead apron

[9]Authors used CHILDOSE software to calculate effective dose from measured DAP values

patient. The fluoroscopy time and DAP should be recorded in the patient's procedure notes as an aid for monitoring their exposure and review by a suitably qualified professional, especially for those patients having multiple procedures [28, 32].

The dose rate during fluoroscopy is significantly lower than during acquisitions, particularly for pulsed fluoroscopy. While the image quality of an acquisition is much greater, it is at the cost of a much higher dose to the patient which may not be justifiable [32]. Institutional work instructions for VFSS procedures, formalised or other, should be reviewed to determine whether any acquisitions routinely acquired are clinically justified and investigated as to whether the same information can be obtained via stored fluoroscopy images. It is acknowledged that one standard VFSS protocol cannot be used for all patients but must be tailored to the clinical needs and physical properties and abilities of the patient [11, 32]. This optimisation step should be performed at the beginning of the investigation when taking the patient's medical history of dysphagia symptoms.

Determining the optimal parameters for the VFSS procedure for a range of patient sizes is also important [11]. Most fluoroscopic equipment will have more than one dose setting and the ability to change the pulse and frame rates. In this context, pulse rate refers to the X-ray pulses per second during fluoroscopic screening and frame rate refers to the number of images displayed per second during image acquisition. Appropriate manipulation of these settings can reduce the radiation dose to the patient at the cost of reduced temporal resolution; however, it has been shown that lower pulse rates can still provide sufficient clinical information [21, 33, 34]. It should be noted that reducing the pulse rate does not correlate with a linear reduction in dose rate (or skin entrance dose) as the dose rate is also dependent on the pulse width, tube current (mA), kVp and filtration which can all be varied by the system as the pulse rate decreases. The pulse (or frame) rate, however, should not be lowered to the extent that it affects the clinical judgement of swallowing impairment and treatment recommendations [19, 35]. As noted by Bonilha et al., the oropharyngeal swallow takes approximately one second and therefore reducing the pulse rate from 30 pulses per second to 15 pulses per second means that the number of unique images for SLPs and other physicians to review reduces from 30 to 15 [19]. Cohen found that full-depth supraglottic penetration was seen on only one image frame in VFSS studies performed using continuous fluoroscopy (30 frames per second) in seven out of ten paediatric patients [35]. Subsequently, Cohen advises against imaging below 30 frames per second to avoid missing crucial details that may adversely affect the recommended course of treatment [35].

Weiss et al. report significant reductions in patient dose while maintaining diagnostic quality imaging by using a low-dose pulsed VFSS protocol on a modern flat-panel detector system [34]. Without changing the pulse rate of 30 images per second, their low-dose protocol operated with approximately 1/6th of the tube current and 0.9 mm copper filtration, instead of 0.2 mm copper [34]. Increasing the thickness of aluminium or copper filtration in the primary beam has been shown to significantly reduce the entrance skin dose to patients [36]. Increasing the beam filtration hardens the beam, removing more of the lower X-ray energies. This can reduce the fine detail and contrast in soft tissues which may negatively impact the image quality in some situations; therefore, this should be used with caution and after appropriate testing. Additionally, increased beam filtration may not always be possible, for example with larger patients, due to the limits of the X-ray tube output. Regular testing and quality assurance measurements by a suitably trained professional as part of a Quality Assurance program will enable institutions to ensure the optimisation of dose and image quality [4].

Diagnostic reference levels (DRLs) are a useful tool for institutions to compare their current practices against national benchmarks. Not all countries have local DRLs for VFSS producers. The Health Protection Agency (HPA) in the United Kingdom have published national reference doses for many X-ray procedures including a barium swallow video [13]. This procedure is defined by the HPA as a video recording of the throat after swallowing a suspension of barium sulphate performed mostly for speech therapy. Based on a survey of adult patients, the recommended national reference dose for a barium swallow video is a DAP of 3.4 Gy.cm^2 and 3.5 min of fluoroscopy time per exam [13]. There were not enough data available to provide a paediatric value. However, the recommended national reference doses for a paediatric barium swallow range from 0.2 Gy cm^2 (0 years) to 3.0 Gy cm^2 (15 years) [13]. Bibbo et al. calculated local paediatric DRLs for various fluoroscopic procedures based on measured DAP values, including the barium swallow and meal [37]. The local DAP DRLs range from 0.43 Gy cm^2 (0– < 1 years) to 2.85 Gy cm^2 (10 + years) which the authors note are lower than those previously reported by Hiorns et al. [37, 38]. The American College of Radiology recommends that a qualified professional, such as a Medical Physicist, regularly audits patient dose indices including DAP and fluoroscopy time by comparing them with diagnostic reference levels [32].

The use of the anti-scatter grid should be reviewed for each patient, especially for paediatric patients [39]. Most fluoroscopy units have a removable grid which is placed between the patient and the detector to absorb the scattered radiation and improve image quality. However, it does so at an increased dose to the patient. It is generally recommended that grids are removed when imaging small patients or thin body parts [40], with some advising it is only essential when the anatomy being imaged is greater than 12 cm thick [41]. Bibbo et al. note that the use of the grid is dependent on the patient's body habitus and that it is normally used for patients weighing 65 kg or greater [37]. Grids were not used for the paediatric patient examinations in the work published by Sulieman et al. [31].

There are other useful resources for radiation dose optimisation such as the Image Gently [42] and Image Wisely [43] campaigns. These campaigns were founded to raise awareness about methods to reduce radiation dose to patients during medical imaging exams.

Operator Radiation Dose

Typical Dose

At the time of review, three publications have estimated the exposure to the operator during VFSS studies (see Table 2). Morishima et al. measured the radiation dose rates from patients for common VFSS procedures [2]. Measurements were acquired at different distances from the patient and different locations over the operators' bodies. Morishima et al. concluded that the potential risk to operators from scattered radiation exposure in VFSS procedures is lower than for other common fluoroscopic procedures [2]. However, their conclusion is based on personal dosimetry measurements of a single physician who performed 56 VFSS procedures at their institution. The results estimated the whole body effective dose is 0.9 mSv/year (~ 16 µSv per procedure) and an equivalent dose of 2.3 mSv/year to the lens of the eye. It is unclear if the physician wore the dosimeters during every procedure and what the monitoring period was. These results are comparable to earlier work by Crawley et al. who estimated a whole body effective dose is 0.6 mSv/year (~ 12 μSv per procedure) and an equivalent dose of 1 mSv/year to the lens of the eye based on an annual workload of 50 procedures [16].

Hayes et al. measured the radiation dose to SLPs using an electronic dosimeter worn on the outside of a lead apron at the chest wall [29]. They concluded that the average dose to their SLPs is 10–20% of the 0.0015 mGy per procedure measured using an electronic dosimeter worn on the outside of a lead apron. The dose to the SLP's thyroid was estimated to be 5–10% of the 0.0015 mGy per procedure.

The number of VFSS procedures an operator performs also influences the long-term cumulative exposure and radiological risk. A 2003 survey of 121 SLPs in Northern America found that 67% of respondents reported performing between 2 and 10 VFSS procedures per week with a further 10% reported conducting more than 10 VFSS procedures per week [44]. In 85% of cases in the same survey, it was the SLP who administered the bolus to the patients during the procedure.

Radiation Protection Strategies

The International Commission on Radiological Protection (ICRP) and the International Atomic and Energy Agency (IAEA) recommend an effective dose limit for occupational exposures in planned exposure situations of 20 mSv per year averaged over five years with a maximum of 50 mSv in any 12 month period [6, 7, 45]. It is a legal requirement for an occupationally exposed person who is likely to receive more than 1 mSv in any 1 year to be provided with a suitable personal radiation monitoring device [4]. Operators and other staff directly involved in VFSS procedures are considered to be occupationally exposed persons. As seen in the literature, the radiation exposure to the operator approaches the dose constraint for a member of the public. As such, depending on the workload of the operator, it may be recommended to monitor the operator routinely [1, 28]. Additionally, a secondary monitor worn at the collar to estimate the dose to the lens of the eye may be warranted. The correct and consistent wearing of dosimeters should be emphasised.

Implementing the radiation protection strategies discussed above for patients will also have the positive effect of reducing the radiation dose to operators and other people in the room during the time of the VFSS procedure.

The correct wearing of lead gowns (with 0.35 mm lead thickness equivalence), including thyroid shields, is a standard requirement for operators and ancillary staff during fluoroscopic procedures [1, 28]. The regular use of lead glasses is not commonplace but is widely recommended given the relatively low threshold of radiation-induced cataracts [2, 28]. Additional shielding, such as a moveable lead acrylic shield, may be warranted in situations where the SLP and other operators are unable to stand far enough away from the X-ray tube and patient to sufficiently reduce the radiation dose rate due to room constraints [29]. Hayes et al. noted that when the SLP was able to stand behind a lead acrylic screen for the duration of fluoroscopy, the dosimeter used in the study did not measure any radiation dose [29]. Morishima et al. recently reported on the effectiveness of an original lead-shielding device, in conjunction with extra X-ray beam filtration, to protect staff from the scattered radiation during VFSS procedures [36]. It was found that the dose to staff could be reduced by up to approximately 44% [36].

However, none of these protective measures will work adequately without the appropriate initial and ongoing education of SLPs and other VFSS operators. Personnel involved in VFSS procedures should attend a basic radiation safety training and follow-up refresher courses as needed that are provided by a suitably qualified professional [1, 9, 28, 32, 46]. The training session should cover the importance of the principles of time, distance and shielding and the correct use of any protective equipment provided. Ideally, the course should include dose optimisation strategies for patients. It is important for both the patients and the SLPs that SLPs are knowledgeable about the inherent radiation risks in VFSS procedures and the simple protective measures available to reduce these risks. The requirement to attend initial and regular training should be enforced.

Occupationally exposed pregnant females should be encouraged to declare a pregnancy and be part of the process to review the working conditions to ensure that the embryo or fetus is afforded the same level of protection as that of a member of the public for the remainder of the gestational period [7, 45]. However, it is unlikely that the radiation dose received by a pregnant staff member will result in a fetal dose greater than 1 mSv during the gestational period and continued work should not be discouraged as long as basic radiation safety principles are adhered to.

Summary and Research Recommendations

Based on the recent published literature, there is no evidence that SLPs performing VFSS procedures would be exposed to radiation levels that could be considered to have any significant risk. The same evidence indicates that in the majority of cases, SLPs would not exceed the public dose limits of 1 mSv per year. It is recommended that if a SLP is required to perform VFSS procedures regularly, they are provided with personal monitoring devices to ensure that they are below the occupational dose limits. Keeping the staff exposure as low as reasonably achievable can be guided by the recommendations given in this article.

There are limited published data in the literature pertaining to the occupational exposure of SLP and other VFSS staff. Studies assessing the occupational dose of VFSS staff whether through simulated procedures or clinical data are required to address this knowledge deficit. Researchers should include information regarding the VFSS procedure performed, including the typical X-ray parameters, procedure times, patient demographics and routine protection measures, such as mobile shields, used in the institution.

Further, there are limited studies that quantify the radiation dose to the patient's lens of the eye. With the decreased threshold for cataracts and the proximity of the patient's eyes to the primary beam, it would be prudent to assess the risk of cataract induction later in the patient's life. The utility of such information can be extended to justifying repeat studies for paediatrics as well as drive radiation protection methods for the lens of the eye.

Whole body radiation exposure to the patients during VFSS is typically lower than most fluoroscopically guided examinations. However, all efforts must be made to keep the radiation exposure as low as reasonably achievable. It is strongly recommended that the X-ray beam is collimated to avoid unnecessary exposure of organs that will provide no additional diagnostic information, such as the eyes. Finally, good record keeping is encouraged to allow for radiation dose estimates to repeat patients as well as paediatrics.

Compliance with Ethical Standards

Conflict of interest The authors declare no conflict of interest or financial funding.

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