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Radiation exposure from videofluoroscopic swallow studies in children with a type 1 laryngeal cleft and pharyngeal dysphagia: A retrospective review

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ABSTRACT

Introduction: Radiation exposure is recognized as having long term consequences, resulting in increased risks over the lifetime. Children, in particular, have a projected lifetime risk of cancer, which should be reduced if within our capacity. The objective of this study is to quantify the amount of ionizing radiation in care for children being treated for aspiration secondary to a type 1 laryngeal cleft. With this baseline data, strategies can be developed to create best practice pathways to maintain quality of care while minimizing radiation exposure.

Methods: Retrospective review of 78 children seen in a tertiary pediatric aerodigestive center over a 5 year period from 2008 to 2013 for management of a type 1 laryngeal cleft. The number of videofluoroscopic swallow studies (VFSS) per child was quantified, as was the mean effective dose of radiation exposure. The 78 children reviewed were of mean age 19.9 mo (range 4 mo–12 years). All children were evaluated at the aerodigestive center with clinical symptomatology and subsequent diagnosis of a type 1 laryngeal cleft. Aspiration was assessed via VFSS and exposure data collected. Imaging exams where dose parameters were not available were excluded.

Results: The mean number of VFSS each child received during the total course of treatment was 3.24 studies (range 1–10). The average effective radiation dose per pediatric VFSS was 0.16 mSv (range: 0.03 mSv–0.59 mSv) per study. Clinical significance was determined by comparison to a pediatric CXR. At our facility a CXR yields an effective radiation dose of 0.017 mSv. Therefore, a patient receives an equivalent total of 30.6 CXR over the course of management.

Conclusions: Radiation exposure has known detrimental effects particularly in pediatric patients. The total ionizing radiation from VFSS exams over the course of management of aspiration has heretofore not been reported in peer reviewed literature. With this study's data in mind, future developments are indicated to create innovative clinical pathways and limit radiation exposure.

1. Introduction

Exposure to ionizing radiation via medical imaging exams is recognized as having long term consequences, particularly in the pediatric population [1,2]. Children with swallow dysfunction may undergo several videofluoroscopic swallow studies (VFSS) over the course of management of aspiration.

Since the videofluoroscopic swallow study subjects patients to

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radiation, it is important to consider the risk/benefit tradeoff and attempt to minimize the amount of radiation exposure. The ALARA principal ("as low as reasonable achievable"), is the underlying fundamental principle for the safe use of radiological studies [1,2]. It is summarized by applying the concept of using the smallest amount of radiation to gain the necessary information. This principle not only applies to as low as possible exposure within each videofluoroscopic swallow study, but certainly would necessitate consideration on the total number of VFSS over the course of a diagnosis and management of swallow dysfunction in the setting of a pathology, for instance, an airway anomaly such as a type 1 laryngeal cleft.

A laryngeal cleft is a rare congenital anomalous connection between the larynx and esophagus. The most common classification system for laryngeal clefts used today was developed by Benjamin and Inglis (1989). Type 1 clefts are supraglottic interarytenoid clefts above the level of the true vocal folds. Type 2 clefts extend past the level of the true vocal folds, into the cricoid cartilage, but not through the cricoid cartilage. Type 3 clefts extend entirely through the cricoid cartilage into the cervical tracheoesophageal wall. Type 4 clefts extend through the majority of the tracheoesophageal wall [3].

Symptomatic laryngeal clefts present with choking episodes while feeding, aspiration, chronic cough, recurrent pulmonary infections, and/or failure to thrive [4]. Diagnosis is made by a multidisciplinary team including pediatric otolaryngologists, pulmonologists, gastroenterologists, and speech pathologists. Initial evaluation includes a thorough history and physical exam, office flexible laryngoscopy, and swallow exam [5–9]. Objective swallow exam can be implemented with a videofluoroscopic swallow study (VFSS), or functional endoscopic evaluation of swallowing (FEES) [10].

Pharyngeal dysphagia in children with anatomic laryngeal anomalies, in particular, a type 1 laryngeal cleft, can often be distinguished from children with neurological etiologies for dysphagia. Swallow dysfunction in children with a type 1 laryngeal cleft is frequently characterized by aspiration or penetration during the swallow with liquids. Solid food dysphagia is often not a predominant factor [11]. In contrast, the literature suggests that children with marked neurologic deficits as the primary etiology of their aspiration (e.g. cerebral palsy, Down syndrome) may present with oropharyngeal dysfunction with both liquids and solids [28]. Dysphagia may be characterized by impaired oral motor control resulting in premature propulsion of the bolus and aspiration prior to the swallow. A weak or uncoordinated pharyngeal stripping wave in this neurological population can also result in inefficient clearing of the bolus from the pharynx, resulting in aspiration of post-swallow residue [12,13]. Our institution's focus on patients with a type 1 laryngeal cleft with swallow dysfunction allowed for specific investigation and analysis based frequently on pharyngeal dysphagia patterns of aspiration or penetration during the swallow with liquids.

The gold standard for definitive diagnosis of a laryngeal cleft has been described as microlaryngoscopy with palpation of the interarytenoid space [9]. At our institution we prefer suspension laryngoscopy with implementation of either infant or pediatric vocal fold distractors. This facilitates inspection and palpation of the interarytenoid space. Chien et al. developed a functional algorithm for diagnosis and management of type 1 laryngeal clefts addressing when to proceed to surgical intervention from conservative management [6]. The algorithm was later updated by Ojha, which included postoperative management [7].

Currently, there is variation in the literature regarding postoperative management strategies [4,10,14–16]. A swallow evaluation is an integral component to postoperative assessment. At our institution, we perform a postoperative VFSS and/or clinical examination as detailed by Ojha's algorithm. Execution of this exam, particularly in pediatrics, challenges the clinician to balance obtaining adequate objective data to establish a safe diet, while limiting radiation exposure. While performing a fiberoptic endoscopic evaluation of swallowing (FEES) on some children may be a consideration, given the age group of this population (mean of 19.9 months) the FEES exam may not be a viable option for accurate results given significant compliance and participation limitations in the toddler years [7].

While reducing radiation in children is well documented, there is only a small body of research to date which focuses on pediatric exposure from pediatric VFSS [19], and there are no publications to date which examine the total number of VFSS exams a patient may undergo over the course of management of any one medical diagnosis. The literature contains information regarding radiation exposure during adult VFSS exams [20–22], however there are no reported studies which have evaluated radiation dose using continuous fluoroscopy with pediatric patients. While the use of pulse fluoroscopy to capture aspiration or penetration continues to be debated in the literature [23,24], our institution employs continuous fluoroscopy for all VFSS exams. Weir (2007) [19] studied a population of pediatrics, however their imaging techniques included the use of pulse fluoroscopy. Chau (2009) included a subset of their patient population to assess pediatric effective doses (N = 31 pediatric patients of their total sample size of 398 cases), however it is not stated if this was via use of pulse fluoroscopy or continuous fluoroscopy [22]. Furthermore, there was no reference to organ tissue dosing based on age.

The goal of this study was to quantify the total radiation exposure from the VFSS medical imaging exam, throughout the management of a type 1 laryngeal cleft repair. To achieve this, we determined the radiation dose per study at our institution and applied it to retrospective data on the number of VFSS exams each patient received over the management course of a type 1 laryngeal cleft.

2. Methods

We performed a retrospective review of 78 children seen in a tertiary pediatric aerodigestive center for management of a type 1 laryngeal cleft from September 2008 to 2013. Our two clinical objectives were 1) to calculate the number of VFSS exams patients receive over the course of the management of a type 1 laryngeal cleft, and 2) to determine the amount of ionizing radiation children exposed to per VFSS and highlight the clinical significance of this exposure.

2.1. Videofluoroscopic procedures

Barium Administration: Standard administration of Barium volumes and viscosities frequently constitute adult studies. Pediatric studies, alternatively, require an individualized approach due to the nature and challenge of participation and compliance in this young age group, often presenting the most critical viscosity and volume first. For this population of children with a suspected laryngeal cleft, liquids only of varying viscosities are typically examined under fluoroscopy. Preformulated Barium viscosities (thin, nectar, honey, and if indicated pudding) from Varibar E-Z-EM, (Lake Success, NY) may be presented. In addition, institution developed standardized modifications are offered (ultra-thin, half-strength nectar and half-strength honey thick barium). Liquids are presented from the child's typical drinking device (i.e., bottle, sip cup, straw cup, syringe, open cup).

Positioning equipment: The patients are seated in a tumbleform chair mounted on a videofluoroscopic chair. For infants, a sidelying position may be offered if this best approximates their feeding position in the home environment. All children were viewed in the lateral projection only.

Fluoroscopic techniques: All studies were conducted using our General Electric, Precision 500D. fluoroscopic unit. Use continuous, non-pulsed fluoroscopy with images generated at a rate of 15 or 30 frames per second. To allow for the evaluation of impact of fatigue, fluoroscopy was turned off while the child continues to feed. Fluoroscopy is turned on intermittently to capture images of consecutive swallow segments over time.

Digital fluoroscopy was used for obtaining images. Columniation was implemented to restrict field of view from the nasopharynx to the mid chest region, pending the patient's ability to restrict their body movement. Magnification was used for babies under 6 months of age.

Interpretation: One of 4 SLPs interpreted the studies and identified aspiration versus deep penetration versus mild to moderate penetration [25]. Experience level of the SLPs included two junior SLPs and two senior SLPs with experience level of interpreting VFSS exams from 1 to 25 years of experience.

2.2. Calculations

To address our first clinical objective, the number of VFSS each child received throughout the management of the laryngeal cleft was recorded. Retrospective chart review allowed for the tabulating of the number of VFSS exams per child. Review of outside hospital (OSH) records in addition to parent report and/or communication with OSH speech pathologists allowed for a very conservative collection of number of VFSS prior to being seen in our tertiary pediatric aerodigestive center. In addition, review of in-house radiological documentation from within two radiology suites allowed for accurate tabulation of the number of VFSS exams over the course of treatment. Clinical practice at our institution during the study period included postoperative VFSS exams at 6 weeks, if indicated, 12 weeks and 6 months after repair of a type 1 laryngeal cleft [7].

The second component of data analysis for this study facilitated investigation for our second clinical objective, and included obtaining the average effective radiation dose per VFSS. Radiation dosing was available for Absorbed dose (mGy) which represents energy absorbed from ionizing radiation per unit mass. This does not factor in specific age of the patient, tissues exposed or "risk." Calculations were applied to obtain equivalent dose (mSv) which converts absorbed dose to equivalent tissue damage. However, ultimately, an algorithm was applied to obtain Effective dose (mSv). Effective Dose adequately conveys risk based on age and different tissue radiosensitivity and assigns the proportion of the risk of stochastic effects resulting from irradiation of that tissue compared to a uniform whole body irradiation [26,27]. The software Childose was used to estimate the effective dose. By selecting the patient age and inputting examination specific parameters such as kVp (Peak kilo Voltage), HVL (Half Value Layer in mm of aluminum) and DAP (dose-area-product) defined as the absorbed dose multiplied by the area irradiated, expressed in gray square centimeters (Gy cm^2), and tissue weighting factors based on the susceptibility of organs exposed, the software calculates the effective dose for the selected X-ray imaging procedure based on the data in British National Radiological Protection Board report NRPB-SR279. (Normalised Organ Doses for Paediatric X-Ray Examinations Calculated using Monte Carlo Techniques.)

To determine the appropriate conversion factors for organ weighting, our team selected the Left Lateral Chest Exam conversion factor (Table 1) given that the thyroid and superior portion of the lung may be exposed during VFSS. The effective dose for the chest exam can be considered as the upper limit of the VFSS exam [18].

Table 1
Organ tissue dose weighting factor: conversion factors for chest exam.

Age	Conversion factor mSv/(Gy.cm^2)
0–0.5 years	1.18
0.6–2.5 years	0.486
2.6–7.5 years	0.255
7.6–12.5 years	0.168
12.6–17.5 years	0.115

For example, if a chest x-ray exam for a 1 year old child has a dose-area-product reading of 0.20 Gy. cm^2, the effective dose is 0.486 mSv/(Gy. cm^2) × 0.20 Gy. cm^2 = 0.097 mSv.

To obtain the mean effective dose of radiation exposure per study in milisiverts (mSv), access to the DAP recorded per study was required. There was no institutional data available for this prior to 2010, as this was not an institutional mandate. Therefore we used the data from 2011 to 2013 and extrapolated backwards, which felt comfortable because there were no significant changes in our internal protocols. Imaging exams where dose parameters were not available were excluded from the calculations. N = 33 patients for this calculation with reportable dose area product.

Permission was obtained from the Massachusetts Eye and Ear Human Studies Committee to publish these results.

3. Results

During the study period, 78 children received a diagnosis of a type 1 laryngeal cleft and were managed conservatively (thickened liquids) and/or surgically with a repair of a type 1 laryngeal cleft. The mean age 19.9 months (age range 4 months–12 years). Male: female ratio is 1:2.4. The mean number of VFSS each child received during the total course of treatment was 3.24 studies (range 1–10) (Fig. 1). Children were followed clinically for 2 years status post laryngeal cleft diagnosis given that over 90% of patients received their care over this time frame.

We calculated a mean effective dose per pediatric VFSS to be 0.16 mSv (range:0.03 mSv to 0.59 mSv). For OSH exams, an accurate radiation dose could not be obtained. Given that so many patients underwent VFSS exams in their community hospital prior to arriving at our tertiary pediatric aerodigestive center, our group decided to assign our mean dose of 0.16 mSv as the assumed

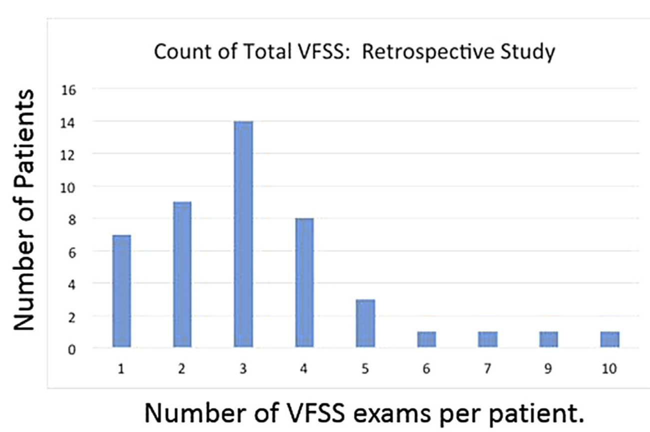

Fig. 1. Number of patients who underwent each total number of VFSS exams over the course of type 1 laryngeal cleft management. Mean is 3.24 VFSS exams. Range 1–10 exams.

Table 2
Comparing effective doses.

Imaging exam	Effective dose mSv	Equivalent to number of CXR
Single View CXR from current tertiary medical facility	0.017 mSv	1
VFSS: Pediatric	0.16 mSv	9.4 CXR
UGI: Pediatric	1.7 mSv[29]	100 CXR
Head CT	2mSv[1]	117.6 CXR

effective doses for the OSH VFSS exams.

As a comparison measure, the effective dose from chest X-rays at this tertiary medical facility was obtained and estimated by age. During a single chest X-ray, the radiation exposure for a 1 and 5-year-old child is 0.016 mSv and 0.018 mSv respectively. We used the mean exposure of 0.017 mSv as our exposure dose from a single pediatric chest X-ray. Using this value for comparison, the effective dose of one VFSS is equivalent to 9.4 chest X-rays. Table 2 compares the effective doses of various imaging modalities to a VFSS. Damilakis et al., 2006 found that during UGI contrast series, the mean effective dose 1.6 mSv for infants, 1.8 mSv for age 6–15 months (mean is 1.7 mSv) [29]. A Head CT effective dose is calculated to be 2 mSv for children [1].

Our data shows that over the course of management of a symptomatic type 1 laryngeal cleft with pharyngeal dysphagia, children are exposed to 3.24 VFSS exams. This translates to an exposure equivalent to 30.6 chest X-ray exams during clinical treatment.

4. Discussion

Reducing radiation exposure from medical procedures, wherever possible is an essential component to optimal patient care while adhering to the ALARA principle. This is especially important in the pediatric population where exposure is even more detrimental if not cautiously administered [27].

Data on the quantity of VFSS per child and the resulting ionizing radiation from this study is disturbing due to the high radiation exposure these children are exposed to over the course of the management and treatment of a type 1 laryngeal cleft. This intrigues us to investigate variables to best adhere to the ALARA principle while maintaining optimal patient outcomes.

The literature reviews some of the factors that may increase the radiation dose per VFSS exam. These include the use of a standardized protocol, which may either increase or decrease the exposure, experience of the clinician which may impact the duration of the study or number of swallows captured, and severity of the swallow dysfunction which may necessitate capturing swallows of more consistencies in attempt to offer safe diet recommendations [24]. However, one of the critical factors that has not been studied to date, is looking at the cumulative dose of radiation via cataloging of the number of studies a patient receives over the course of management of any one diagnosis.

The radiology literature has offered low exposure techniques to limit the dose of ionizing radiation in each exam including the use of pulsed fluoroscopy [1,17,23] and reducing frames per second. Although attractive alternatives, there is debate within the literature as these strategies may compromise the validity of the VFSS evaluation if used [23,24]. Currently, there are limited strategies to reduce radiation during a pediatric VFSS without impacting the physiological information obtained from this exam.

Optimizing the timing of postoperative VFSS exams may facilitate improved adherence to the ALARA principle and provide objective guidance when weighting the cost-benefit trade off of postoperative dysphagia assessment. This argues for a closer look at the diagnostic and treatment pathways, ideally to determine when to implement VFSS with the optimal goal of reducing the number of VFSS exams both preoperatively and postoperatively. A focused group of specialists from our institution (Pediatric ENT, SLP, Pulmonary, and Gastroenterology) are in the process of developing a best practice algorithm based on review of the data published by Ojha (2014) [7]. This study highlights that while a preliminary postoperative protocol of conducting a VFSS at 6 weeks following laryngeal cleft repair revealed improved swallow function with modest diet advancement, none of the patients in the study were safe to transition to thin liquids. Findings suggested a delay of the VFSS until 12 weeks postoperatively for some patients with conservative management via thickened liquid. Ohja (2014) further suggested that there was a statistically significant relationship between increased aspiration risk comorbidities and an overall successful outcome [7]. This published data in addition to our multidisciplinary team's outcomes can be the catalyst for the development of a proposed clinical pathway algorithm for management decisions for children with an identified type 1 laryngeal cleft. This algorithm and results of a prospective study will be available shortly.

5. Conclusion

Radiation dose is being recognized as having long term consequences, resulting in increased risk of cancer over the lifetime. Children, in particular, have a projected lifetime risk of cancer, which should be reduced if within our capacity while providing excellent patient care [27].

This is the first study detailing the radiation exposure burden to children being diagnosed and treated for symptomatic type 1 laryngeal clefts. The mean radiation exposure from videofluoroscopic swallow studies for these children over the course of treatment approximates a total effective dose of 0.52 mSv (3.24 videofluoroscopic swallow studies x 0.16 mSv per study) which is comparatively equivalent to 30.6 pediatric chest X-rays.

Future work is indicated with this data in mind, to continue development of best practices to maintain outcomes and reduce radiation exposure burden.

Conflicts of interest and financial disclosures

There are no known no conflicts of interest and no financial disclosures.

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