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ORIGINAL ARTICLE

Radiation and exposure time in videofluoroscopic swallow studies: A 7-year analysis☆

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KEYWORDS
Videofluoroscopy;
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Abstract
Introduction: Videofluoroscopic swallow studies (VFSSs) are considered the gold standard for evaluating dysphagia. Since the technique involves ionizing radiation, reducing the radiation dose received by pediatric patients must be a priority. This requires the establishment of appropriate diagnostic reference levels.
Objectives: To evaluate and analyze the radiation dose and exposure time during VFSS in pediatric patients managed in a tertiary care center. Additionally, to determine the relationship between clinical variables and radiation exposure, and to compare the results with the European diagnostic reference levels.
Material and methods: We conducted a retrospective and descriptive study between 2015 and 2022. The dose-area product and fluoroscopy time were analyzed, along with clinical and epidemiological variables and their association with VFSS findings. We also compared the results to the European pediatric imaging diagnostic reference levels (PiDRL) for VFSS.
Results: A total of 322 VFSS were analyzed. Dysphagia was present in 68.6% of cases, and was most commonly oropharyngeal (65%), with combined impairment of swallowing efficiency and safety (61.1%). Dysphagia was more frequent and severe in patients with neurological disorders. Aspiration and/or penetration events were observed in two-thirds of the patients, with approximately 80% being silent (i.e., without cough). The median dose-area product was 9.2 cGy/cm^2 (IQR, 5.1—15) and the median exposure time was 123 s (IQR, 85—167.3), both values below the thresholds recommended by the 2018 European guidelines and similar studies.

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We found a direct correlation of both radiation dose and exposure time to age, the degree of disability, the presence of dysphagia, the Bolus Residue Scale (BRS) score, and impairment of swallowing efficiency and safety.
Conclusions: The radiation dose and fluoroscopy time were lower than those reported in previous studies, probably due to technical improvements in the procedure. Establishing updated diagnostic reference levels for pediatric VFSS should be a priority in order to optimize radiation exposure in a population with greater radiosensitivity. This study also aims to contribute to the development of a standardized radiation protocol for pediatric VFSS to allow for more consistent and comparable data across centers.
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PALABRAS CLAVE
Videofluoroscopia;
Dosis radiación;
Niveles de referencia de diagnóstico;
Disfagia;
Trastornos deglutorios

Análisis de los niveles de radiación y tiempo de exposición en videofluoroscopias de deglución durante 7 años

Resumen
Introducción: El estudio de la deglución mediante videofluoroscopia (VFC) se considera el ''gold standard'' en la evaluación de la disfagia. Al utilizar radiación ionizante, la reducción de la dosis que reciben los pacientes pediátricos debe ser una prioridad, precisando para ello unos adecuados niveles de referencia de diagnóstico.
Objetivos: Evaluar y analizar la dosis-radiación y tiempo de radiación durante la realización de VFC en pacientes pediátricos de un centro de tercer nivel. Así mismo, se pretende determinar la relación entre las variables clínicas y la exposición a la radiación, y comparar los valores obtenidos con los niveles de referencia de diagnóstico europeos.
Material y métodos: Estudio retrospectivo descriptivo realizado entre 2015 y 2022, en el que se analizan el producto dosis área y tiempo de exposición, así como variables clínicas, epidemiológicas y su relación con los hallazgos en pacientes sometidos a VFC. También se comparan los resultados con los niveles de referencia de diagnóstico europeos (PiDRL) sobre VFC en población pediátrica.
Resultados: Se analizan 322 VFC, el 68,6% presentan disfagia, siendo la más frecuente la orofaríngea (65%), con alteración de la eficacia y la seguridad (61,1%). La disfagia era más frecuente y grave en los pacientes con enfermedades neurológicas. Se reportan aspiraciones y/o penetraciones en dos tercios de los pacientes, siendo aproximadamente un 80% silentes sin tos. La mediana del producto dosis-área fue de 9,2 cGy/cm2 (RIQ 5,1-15) y el tiempo de exposición de 123 segundos (RIQ 85-167,3); siendo estos valores menores que los recomendados en las guías europeas de 2018 y otros estudios similares. Se observó una relación directa entre la dosis y tiempo de exposición con la edad, grado de discapacidad, disfagia, puntuación en escala *Bolus Residue Scale* (BRS) y con la alteración en la eficacia y seguridad.
Conclusiones: La dosis de radiación y el tiempo de exposición fueron menores que en estudios previos, probablemente por las mejoras en las técnicas utilizadas. Establecer unos niveles de referencia de radiación actualizados para VFC en niños debería ser un objetivo, para optimizar la exposición en un individuo con mayor radiosensibilidad. Con este estudio se pretende establecer un protocolo común de dosificación de radiación en la VFC pediátrica, para que los datos puedan ser más comparables y unificados.
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Introduction

Dysphagia refers to difficulties in swallowing solids or fluids and is estimated to affect 1% of the pediatric population, although its incidence may increase to up to 80% among children with cerebral palsy and other neurodevelopmental disorders.[1]

In children, dysphagia is usually a functional disorder, most commonly involving the mouth and pharynx. It is associated with predisposing conditions, such as neurologic abnormalities, musculoskeletal disorders, malformations of the oral cavity, pharynx, or esophagus, prematurity, prolonged non-oral feeding and chronic lung disease.[2]

The diagnosis is made through a clinical evaluation and instrumental methods. A bedside swallow assessment should be conducted by a speech language pathologist.[3,4] Diagnostic tests are indicated if any abnormalities are detected in the clinical assessment, and the videofluoroscopic swallow study (VFSS) is considered the imaging gold standard for evaluation of dysphagia.

The videofluoroscopic swallow study is a dynamic imaging evaluation of swallowing function in which a series of lateral projection images is acquired while the patient swallows contrast medium in various consistencies and volumes. It allows assessment of the safety and efficiency of oral intake in the patient in real time.[5] It can also be used to assess the effectiveness of the therapeutic approach implemented to correct the observed impairment and to adjust treatment to the recommended postural adjustments and/or adaptive feeding devices.[6] Based on the severity observed in the test, oral intake recommendations are provided to the patient, alone or in addition to swallowing therapy/rehabilitation.

Although the radiation dose in VFSSs is relatively low, since the test involves exposure to ionizing radiation and pediatric patients are particularly sensitive to its effects, reducing the dose according to the ''as low as reasonably achievable'' (ALARA) principle should be considered a priority.[7]

To guide dose optimization according to the ALARA principle, the International Commission on Radiological Protection(ICRP) has promoted the use of diagnostic reference levels (DRLs) to prevent the delivery of radiation amounts in excess of the effective dose that do not contribute any additional useful information.[7] In general, DRL values are set at the third quartile (75th percentile) of the median values used in a sample of procedures, although use of the median has also been recommended. Use of local DRLs, when available, is recommended, using national DRLs in their absence[8] or, if neither are available, European DRLs.

Air kerma-area product (P_{KA}) values are not always available to set DRLs, in which case it is possible to the dose-area product (DAP) as a value equivalent to the P_{KA}. Since radiology terms are complex, in this article we will use the terms DAP, radiation dose or received dose interchangeably to refer to the DAP, which is the value that is actually obtained in VFSSs.

In Europe, the first pediatric imaging DRLs (PiDRLs) were published in 2018, but only a couple of isolated studies were available to develop the reference levels for fluoroscopy.[9] In addition, there are no national DRLs for pediatric patients in Spain, which precludes adequate optimization of the technique and comparisons across centers in Spain.

For this reason, we conducted a study with the aim of describing the radiation dose and the duration of exposure in patients that underwent VFSSs at a tertiary care children's hospital and comparing them to the European DRLs, in addition to assessing the association between VFSS results and different clinical variables.

Material and methods

We conducted a retrospective and descriptive study through the review of the data included in the documentation and reports of VFSSs conducted in a tertiary care hospital over a seven-year period (2015–2022).

The clinical variables under consideration were: age (and the age groups recommended for setting PiDRLs), underlying disease, degree of neurologic impairment through the Gross Motor Function Classification System (GMFCS).[10]

Modified swallow studies were performed with a Siemens Iconos R200 series 4501 system, which allows lateral plane imaging. Fluoroscopy was performed at a voltage of 50–56 kV, with a current of 0.2 to 0.4 mA and at a rate of 12.5 (FPS) frames per second. The object-image distance was 1 m. Collimation was performed by a radiology department nurse under the supervision of a radiologist. The different consistencies were prepared with a water-soluble contrast medium (Visipaque) that is flavorless to improve palatability. A thickener (Resource Clear) was used to prepare nectar-thick and spoon-thick consistencies, which, along with thin liquid, were the tested consistencies. The test protocol included these three consistencies, all administered at three different volumes in increasing order, measured with a syringe, with volumes based on age (2, 4 and 6 mL in children < 3 years; 3, 5 and10 mL in older children). If a volume proved not safe on account of aspiration, the test did not progress to greater volumes. The same applied to consistencies: if aspiration occurred with nectar-thick consistency, the following step with thin liquid was not performed, as it would be less safe. In infants aged less than 4 months, the test started with the liquid consistency and, if there was evidence of dysphagia, the nectar consistency was tested.

During the test, one or both caregivers were allowed into the room for the administration of the different consistencies, in addition to toys or electronic devices to produce a more relaxed atmosphere so the test could be completed quicker.

Once the VFSS concluded, the following was determined: presence or absence of dysphagia, severity of dysphagia (mild: small-volume [<10% ingested volume] penetrations or aspirations, moderate: penetrations or aspirations of 10% to 50% of ingested volume, severe: penetrations or aspirations of more than half of the ingested volume), type of dysphagia (oral, pharyngeal, esophageal or a combination thereof), type of abnormality (efficiency, safety or both), detection of aspiration/penetration (aspiration, penetration, or both), type of aspiration (silent, with secondary cough, both silent and with cough), score in the Bolus Residue Scale (BRS),[11] radiation dose (in cGy/cm^2), and duration of radiation exposure (in seconds).

The statistical analysis was conducted with the software package SPSS version 26 (SPSS Inc; Chicago, IL, USA.). We used the Shapiro-Wilk test and the Kolmogórov-Smirnov test to assess normality. In the descriptive analysis, we summarized quantitative data with the median and interquartile range, as the variables did not follow a normal distribution, producing charts and tables to represent the results. We used the Pearson correlation coefficient to compare quantitative variables, the χ^2 test to compare qualitative variables, and the Kruskal-Wallis test with the Bonferroni correction to assess for differences between groups in comparisons of multiple quantitative and qualitative variables. We considered *P* values of less than 0.05 statistically significant.

Table 1 Clinical characteristics of patients assessed with VFSS ($n = 322$).

	n	%
Age in months, median (IQR)	*48 (18.6—96)*	
Age groups recommended for PiDRLs		
0 y (<1 month)	6	1.9
1 y (1 month-4 years)	159	49.4
5 y (4—10 years)	105	32.6
10 y (10—14 years)	45	14
15 y (14—18 years)	7	2.1
Underlying disease		
Neurologic	233	72.4
GMFCS		
I	46	14.3
II	39	12.1
III	55	17.1
IV	44	13.7
V	49	15.2
Digestive system	31	9.6
Respiratory	58	18

Abbreviations: GMFCS, Gross Motor Function Classification System; PiDRL, European diagnostic reference levels for pediatric imaging; VFSS, videofluoroscopic swallow study; y, years.

We obtained the informed consent of the parents for participation in the study. The study protocol was approved by Clinical Research Ethics Committee of Aragón (January 12, 2022; minute no. 01/2022; code PI12/512).

Results

The study included data for 322 patients, whose clinical characteristics are detailed in Table 1, where it can be seen that more than two thirds had underlying neurologic disease.

A total of 221 patients (68.6%) received a diagnosis of dysphagia, classified as mild in 95 cases (43%), moderate in 86 (38.9%), and severe in 40 (18.1%). Classifying cases by the affected phase of the swallow, 143 patients had oropharyngeal dysphagia (65%), 36 pharyngeal dysphagia (16%), 13 oral dysphagia (6%), 9 esophageal dysphagia (4%), 3 pharyngoesophageal dysphagia (1%), and in 17 patients (8%), all phases were affected. The test detected aspirations/penetrations in 179 patients (55.6%), with aspiration only in 45 patients (14%), penetration only in 73 patients (22.7%) and both in 61 patients (18.9%). It is worth noting that most aspirations were silent, that is, occurred in absence of apparent secondary cough or choking and could only be detected by videofluoroscopy (76 patients, 71.7% of aspirations), with patients with neurologic disease accounting for 90.3% ($n = 65$) of these cases.

Neurologic impairment was associated with a higher frequency of dysphagia (81.5%) and severe dysphagia (90% of patients with severe dysphagia were in the neurologic disease group) compared to gastrointestinal or respiratory disease, and these differences were statistically significant ($P < .05$). We also found an association between more severe neurologic impairment assessed with the GMFCS and an increase in the proportion of patients with aspiration, which reached 75.5% in patients classified as grade V (Fig. 1). These differences were statistically significant ($P < .05$).

As regards the primary outcomes, the median DAP was 9.2 cGy/cm^2 (interquartile range [IQR], 5.1—15) and the median exposure time was 123 s (IQR, 85—167.3). We assessed the correlation between the quantitative variables (age, exposure time and DAP) with the Pearson correlation coefficient, r. We found statistically significant correlations between exposure time and dose ($P < .05$, two-tailed) with a correlation coefficient of 0.56 and a coefficient of determination, R^2, of 0.31; that is, a moderate average correlation, with the DAP increasing by 0.09 cGy/cm^2 with each additional second of exposure during the procedure and 31% of the DAP variance explained by the duration of the procedure.

We also found a statistically significant association between age and DAP ($P < .01$ bilateral), with an r of 0.3 and an R^2 of 0.09; that is, a weak positive correlation. The results showed that age explained 9% of the DAP variance (Fig. 2).

We used the Kruskal-Wallis test with the Bonferroni correction to analyze the association between primary and

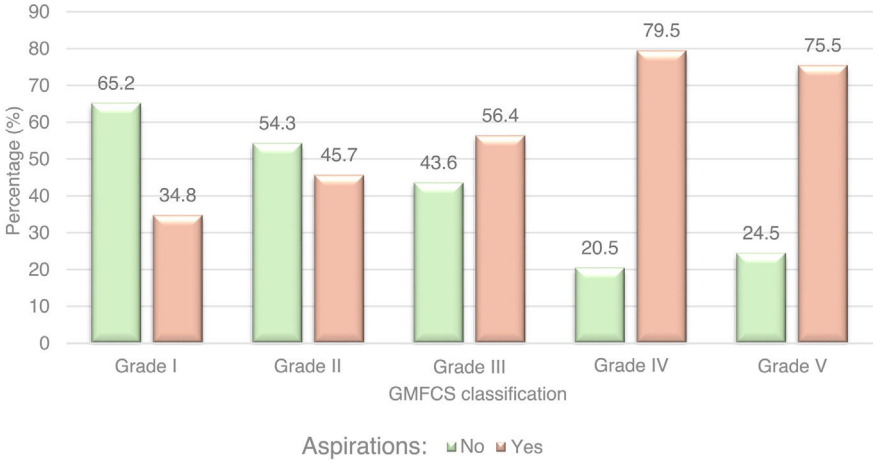

Figure 1 Percentage distribution of patients with aspirations according to the Gross Motor Function Classification System category.

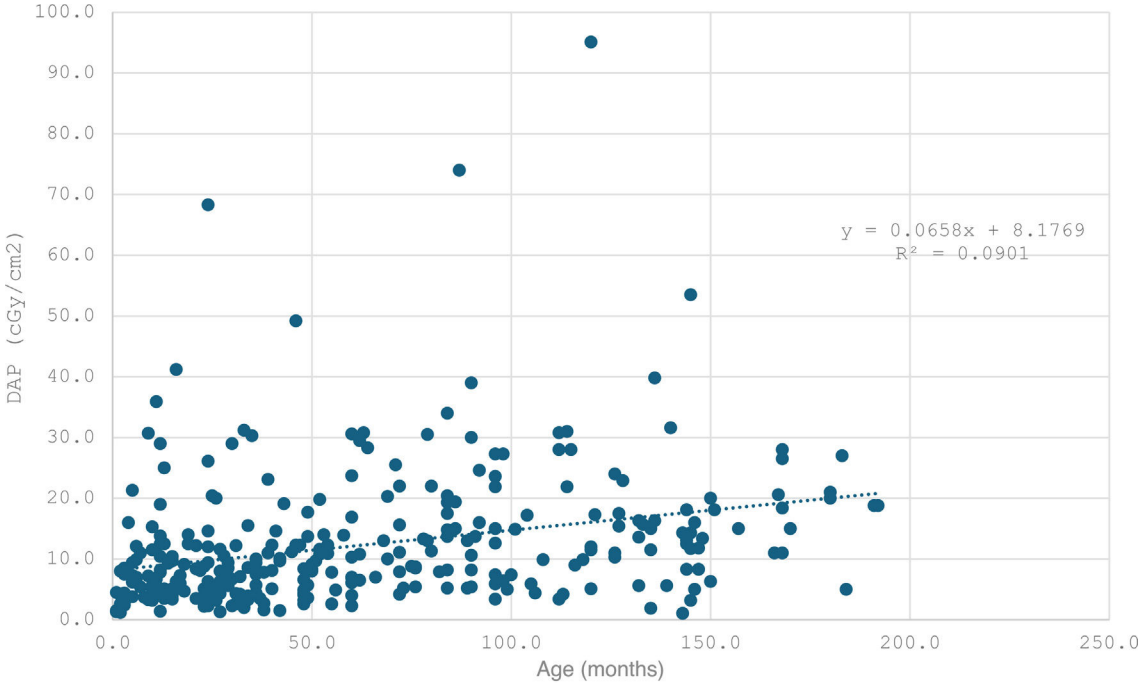

Figure 2 Scatter plot with best-fit line for the association between dose-area product (DAP) and age.

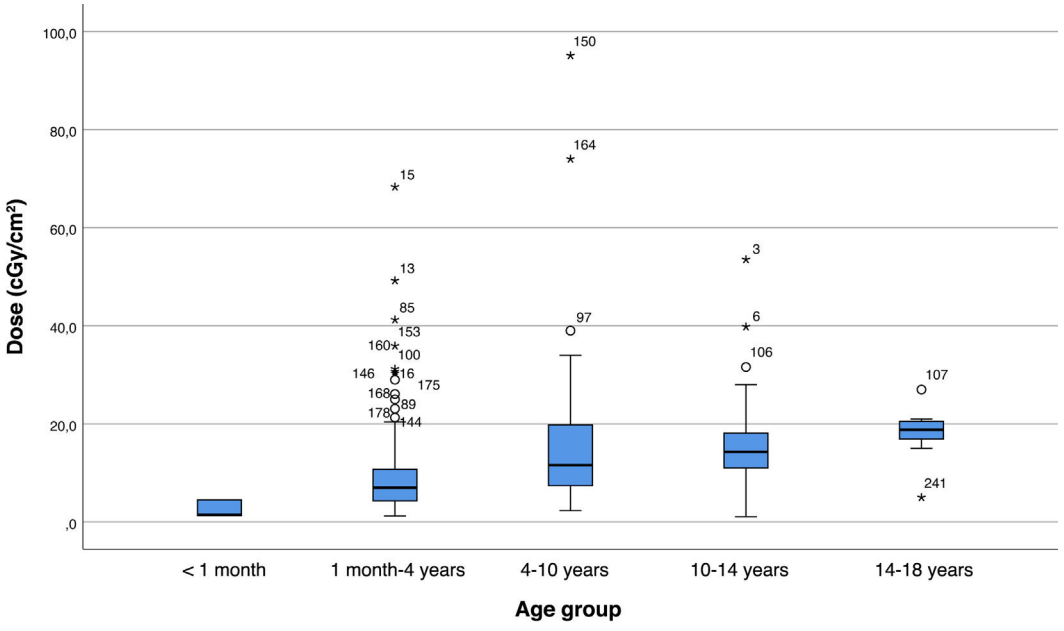

Figure 3 Median dose-area product (DAP) by age group.

secondary variables. In the comparison by age group, we found statistically significant differences in the received dose ($P < .05$; Fig. 3), but not in the duration of exposure, with the dose increasing with increasing age. Specifically, we found differences between patients aged less than 1 month and all other groups ($P < .05$), and between patients aged 1 month to 4 years and all other groups ($P < .05$). We found no significant differences between the rest of the groups (with a $P = .051$ in the group aged 4–10 years versus the group aged 14–18 years).

Table 2 summarizes the results of the analysis of the primary outcomes and the rest of the variables. Starting by the type of underlying disease, we found significant differences between the group of patients with neurologic disease compared to patients with gastrointestinal or respiratory disease ($P < .05$ for both DAP and time of exposure).

In relation to the degree of neurologic impairment (assessed by means of the GMFCS), we found differences in both exposure time and dose ($P < .05$), with both increasing with increasing neurologic impairment. Specifically,

Table 2 Dose-area product and exposure time according to clinical characteristics and fluoroscopy findings ($n = 322$).

	n	%	Time in seconds, Median (IQR)	DAP incGy/cm^2, Median (IQR)
Groups				
No age groups	322	100	123 (85—167.3)	9.2 (5.1—15)
<1 month (0 y)	6	1.9	120 (87.6—166)	1.5 (1.3—4.5)
1 month to 4 years (1 y)	159	49.4	129 (91—177)	7 (4.3—11)
4–10 years (5 y)	105	32.6	129 (91—177)	11.6 (7.2—20.1)
10–14 years (10 y)	45	14	128 (73.4—166.5)	14.3 (11—18.1)
14–18 years (15 y)	7	2.1	150 (95—191)	18.8 (15—21)
Underlying disease				
Neurologic	233	72.4	133 (95.5—175.5)	11 (6—18.6)
Respiratory	31	9.6	100 (66—141)	6.5 (3.4—9.4)
Digestive system	58	18	101 (63.9—153.5)	5.9 (3.9—12)
Degree of neurologic impairment (GMFCS)				
No impairment	89	27.6	98 (65—140)	6.2 (3.4—10.3)
I	46	14.3	112 (73—150.8)	6.3 (4.7—13)
II	39	12.1	133 (98—179)	8.8 (4.5—8.8)
III	55	17.1	141 (112—174)	12.5 (7—17.2)
IV	44	13.7	135 (82.3—188)	10.7 (7.1—19.9)
V	49	15.2	143 (98.5—205.4)	15.4 (8.3—25.3)
Severity				
No dysphagia	101	31.4	100 (64.5—143)	6.3 (4.3—11.5)
Leve	95	29.5	120 (90—158)	8.4 (5.1—13.9)
Moderate	86	26.7	154.5 (104.3—191.2)	13.4 (7.4—20.5)
Severe	40	12.4	137.5 (85—169)	12.5 (7.4—17.1)
Type of impairment				
No dysphagia	101	31.4	100 (64.5—143)	6.3 (4.3—11.5)
Efficiency	31	9.6	128 (98—167)	8.1 (5.4—12.5)
Safety	55	17.1	105 (77—153)	8.3 (4.4—13.4)
Both	135	41.9	147 (107—187)	12.6 (7.2—20.4)

Abbreviations: DAP, dose-area product; GMFCS, Gross Motor Function Classification System.

there were significant differences in exposure time between grades I and III as well as grades I and V ($P < .05$). When it came to the dose of radiation, there were significant differences between grades I and III, grades I and IV, grades I and V, and grades II and V ($P < .05$).

We also found differences in the primary outcomes based on the severity of dysphagia. When it came to exposure time, there were significant differences between patients without dysphagia and patients with dysphagia of any severity ($P < .05$), as well as between patients with mild versus moderate dysphagia ($P < .05$). With respect to dose, there were significant differences between patients without dysphagia and patients with dysphagia of any severity ($P < .05$), as well as between patients with mild versus moderate dysphagia ($P < .05$).

The analysis by type of abnormality, considering efficiency and safety, also identified significant differences. Specifically, there were differences in both dose and time of exposure between patients without impairment and patients in which both safety and efficiency were affected ($P < .05$), as well as between patients in whom only safety was affected versus patients in whom both efficiency and safety were affected ($P < .05$). The dose was higher in patients with reduced efficiency and safety compared to patients in whom only efficiency was affected. Exposure was longer in patients with reduced swallow efficiency compared to patients without abnormalities and to patients in whom only safety was affected. All these differences were statistically significant ($P < .05$). We did not find differences in the remaining intergroup comparisons.

When we compared the primary outcome results to the BRS scores, we found significant differences, with both the dose and the time of exposure increasing with increasing BRS score. Specifically, we found significant differences in the DAP and the time of exposure between patients with a BRS score of 0 compared to patients with scores of 3, 4, and 6 points ($P < .05$). We found no other differences between groups.

Discussion

Recent studies have reported that dysphagia is present in 75%–85% of neurologic patients, which is consistent with the findings of our study.[12] In addition, the frequency of aspiration observed in our patients (55.6%) was similar to the frequency described in the previous literature (approximately 50%).[2,13] The association between the degree of

Table 3 Comparison of radiation dose and time of exposure in our study versus previous studies and European DRLs, overall and by age group.

	DAP (cGy/cm^2)						Exposure time (s)					
	Total	0 y	1 y	5 y	10 y	15 y	Total	0 y	1 y	5 y	10 y	15 y
Present study[a] ($n = 322$)[b]	15	4.5	11	20.1	18.1	21	167.3	109	166	177	166.5	191
Chau et al.[23] ($n = 15$)[b]	210						269.4					
Kim et al.[24] ($n = 15$)[b]	371						145.2					
Hart et al.[25] ($n = 514$)[b]		56	115	101	240	317						
NRPB 2002 recommendations[25]		80	150	130	270	460						
Hiorns et al.[21] ($n = 446$)[b]		12.4	13	18.9								
Hart et al.[26] ($n = 594$)[b]		52.9	86.3	85.8	227.2	252.8						
HPA 2007 recommendations[26]		40	120	130	290	350						
Weir et al.[18] ($n = 90$)[b]	28.8	25.8	28.7	33			148.2	151.2	154.2	139.2		
Im et al.[20] ($n = 290$)[b]	578	515	537	601	817	578	161.4	151.8	150	171	208.2	
Hart et al.[27] ($n = 190$)[b]		27	31	88	147	279						
European DRLs.[a],[9] Source: Hart et al.[27]		20	40	50	180	300						

Abbreviations: DAP, dose-area product; HPA, Health Protection Agency. NRPB, National Radiological Protection Board; y, years.
[a] Third quartile.
[b] Number of pediatric patients.

neurologic impairment (assessed by means of the GMFCS) and both the severity of dysphagia and the frequency of aspiration has been consistently reported in recent studies.[13–16] Neurologic patients are more likely to exhibit dysphagia and have more severe dysphagia, and it is worth noting that increased impairment is associated with poorer patient cooperation during the procedure, which in turn increases exposure time and therefore the received dose, a finding that has been reported in several studies.[14–18]

Another salient finding that, while expected, may seem paradoxical was the longer duration of the procedure and higher received dose in patients with moderate dysphagia compared to those with severe dysphagia. This is explained that the test is cut short in patients with severe dysphagia upon detection of swallow abnormalities with a serious impact on safety, such as clinically significant aspiration, which precludes assessment at riskier consistencies and therefore results in shorter exposures and lower doses compared to patients with moderate dysphagia.[18]

The findings of our study are consistent with those of similar studies that have found a direct correlation between exposure time and the DAP, confirming that longer screening times result in an increased radiation dose ($r = 0.56$; $R^2 = 0.31$),[17–22] which underscores the importance of minimizing the duration of the exam. On the other hand, the weak but significant association between age and the DAP, also reported by Ko et al.,[22] could be related to the increase in the dimensions of the area to be screened with increasing patient age, in addition to the increase in the volumes and consistencies administered for examination of older patients. Other studies that included data on weight or body surface area also found a positive correlation between them and DAP.[18–22] In fact, Weir et al.[18] found that body length, and, specifically, the proportion of the head and neck relative to the total body length, were associated with the received dose.

Another relevant aspect was the comparison of the observed DAP with the recommended European PiDRLs[9] and to similar studies,[18,20,21,23–27] as we obtained significantly lower values (Table 3). However, the absence of national DRLs and of specific protocols for the performance of VFSS in children complicates comparisons with other centers.

Using a lower frame rate (12.5 FPS) was one of the key methodological adjustments in our study. This modification results in a substantial reduction of the received dose, which is particularly relevant in pediatric patients, compared to the 30 FPS applied in most centers.[11,19,23] This results in a reduction of practically a two-thirds in the radiation delivered over a given time interval, but, on the other hand, it yields only a third of the images that would be acquired in other centers. Bonilha et al.[17] demonstrated that reducing the frame rate allowed a relevant decrease in dose without compromising the diagnosis, despite the limited number of images available for detailed analysis. In our hospital, to prevent loss of images and facilitate their review, the images are recorded. The debate whether the frame rate of 30 FPS applied in adults should be maintained in pediatric VFSSs is still heated and ongoing, with some centers using 15 FPS[13,22,28] while others conduct studies seeking to demonstrate that a rate of 30 FPS offers greater benefits to the patients, even with the resulting radiation dose.[23]

The optimization of the procedure through strategies like adequate collimation is another crucial factor in minimizing the radiation dose. Collimation consists in the reduction of the area of the x-ray beam to the patient's anatomy that requires visualization, thus reducing the volume of tissue that is irradiated.[29] An adequate balance must be maintained between excessive collimation, which results in a field of view that is too small, and insufficient collimation, in which the expanded field does not offer any additional benefits yet increases the radiation dose unnecessarily. Other strategies used in our hospital (help from family members, distraction, pleasant environment) are key elements in optimizing the process.

The association of the level of experience of radiology technicians and the supervising radiologist with exposure

time and DAP has also been studied, with evidence of lower doses and shorter exposure in centers with more experience.[30,31] In our study, a radiologist was present during the performance of VFSSs, so there was greater control of radiation doses and fluoroscopy times compared to centers where the procedure is performed by otolaryngologists or rehabilitation physicians alone.[32]

In conclusion, the VFSS continues to be the gold standard for swallowing assessment, as it allows for objective evaluation. Optimizing the process through strategies like collimation or a lower frame rate and leveraging the experience of the center are crucial factors in reducing the radiation dose received by patients. Given the heterogeneity in the radiation doses reported in the literature, it would be advisable to implement standardized protocols for pediatric VFSS in order to reduce the amount of radiation to which patients are exposed, facilitate the comparison of data, and undertake the establishment of national diagnostic reference levels.

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Declaration of competing interest

The authors have no conflicts of interest to declare.

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