

# Feeding Interventions Are Associated With Improved Outcomes in Children With Laryngeal Penetration

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## ABSTRACT

**Objectives:** To determine if children with laryngeal penetration on video-fluoroscopic swallow study (VFSS) who received feeding interventions (thickened liquids, change in liquid flow rate, and/or method of liquid delivery) had improved symptoms and decreased hospitalizations compared with those without intervention.

**Methods:** We performed a retrospective cohort study of children under 2 years with laryngeal penetration on VFSS at our institution in 2015 to determine initial and follow-up VFSS findings, symptom improvement at follow-up, and hospitalization risk before and after VFSS. Proportions were compared with Fisher exact test and hospitalizations with paired *t* tests.

**Results:** We evaluated 137 subjects with age  $8.93 \pm 0.59$  months who had laryngeal penetration without aspiration on VFSS. Fifty-five percent had change in management, with 40% receiving thickening and 15% a change in flow rate. There was significant improvement in symptoms for children that had feeding intervention and this improvement was the greatest with thickening (OR 41.8, 95% CI 12.34–141.69,  $P < 0.001$ ). On repeat VFSS, 26% had evidence of aspiration that was not captured on initial VFSS. Subjects had decreased total and pulmonary hospitalizations with feeding intervention and decreased pulmonary nights with thickening ( $P < 0.05$ ).

**Conclusions:** Laryngeal penetration appears to be clinically significant in children with oropharyngeal dysphagia and interventions to decrease its occurrence are associated with improved outcomes including decreased symptoms of concern and hospitalization nights. Thickening or other feeding intervention should be considered for all symptomatic children with laryngeal penetration on swallow study.

**Key Words:** oropharyngeal dysphagia, swallowing disorders, thickened feeds

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## What Is Known

- There is debate about the clinical significance of laryngeal penetration on videofluoroscopic swallow study and there is great variability in the clinical approach to these patients.
- No prior studies have examined the benefits of feeding interventions in these patients.

## What Is New

- Laryngeal penetration is not transient in children under 2 years of age and may be indicative of aspiration risk.
- Symptomatic patients with laryngeal penetration who receive feeding interventions, and especially those who receive thickening, have improved symptoms and decreased hospitalizations compared with those with no change in management.

There is debate about the clinical significance of laryngeal penetration on videofluoroscopic swallow study (VFSS) and as a result there is great variability in the clinical approach to these patients (1,2). With the increasing survival of premature infants and other children with chronic medical conditions, feeding and swallowing disorders are increasing in prevalence (3–6). Patients with these conditions are frequently managed by both specialist and generalist medical providers and have instrumental or clinical swallow evaluations performed in a variety of settings; therefore, an understanding of swallow study abnormalities is essential for their appropriate management (3,7,8). However, there is limited evidence to guide treatment for children with oropharyngeal dysphagia and isolated laryngeal penetration; many providers feel that penetration is a normal finding that does not merit intervention whereas other providers consider these patients at risk for future aspiration and manage their swallowing issues as they would in a patient who frankly aspirated during VFSS.

The gold standard test for evaluation of swallow function in children is the VFSS, a radiologic examination in which the patient is fed different consistencies of barium via various methods of delivery to formally test for oropharyngeal dysphagia (8,9). Laryngeal penetration occurs when material enters the laryngeal inlet but does not extend below the level of the vocal cords and can vary in terms of frequency and depth. Penetration can occur for a variety of reasons including anatomic abnormalities, laryngopharyngeal sensory deficits, and developmental/neurologic conditions, but is

thought to primarily occur because of disrupted swallow function in which some amount of material from the oral cavity travels inappropriately to the laryngeal inlet instead of esophagus (10–13).

Many clinicians focus their attention on aspiration and are often reassured when only laryngeal penetration is seen on VFSS. Similarly, most of the scientific literature has also narrowly focused on aspiration, leading to a relative lack of understanding of the clinical significance of penetration. In studies that have considered penetration to be an abnormal finding, children with penetration are typically analyzed in combination with aspiration, making it difficult to discern the actual contribution of patients with isolated laryngeal penetration (11–16).

Several small studies in adults and children have suggested that penetration is associated with negative clinical outcomes, including increased risk of pneumonia and occurrence of aspiration (2,17–19). Other studies, however, have suggested that penetration is a normal variant, but much of this work is in the older adult population and it is difficult to know how to apply these findings to pediatrics (20–22).

Although there continues to be active debate about the clinical significance of penetration seen on VFSS, few groups have studied whether interventions specifically targeted at decreasing penetration can improve clinical outcomes and no prior studies have examined the benefits of feeding interventions in these children. The primary aim of this study was to determine if children with laryngeal penetration who received feeding interventions (thickened liquids, change in liquid flow rate, and/or method of liquid delivery) after their swallow study had improved symptoms and decreased hospitalizations compared with those without intervention. Secondary aims were to determine if presenting characteristic could predict finding laryngeal penetration on VFSS and if penetration was persistent over time. We hypothesized that children receiving feeding interventions would have improved symptoms and fewer hospitalizations compared with those who did not receive interventions.

## METHODS

We reviewed the records of all children under 2 years who had isolated laryngeal penetration and no aspiration on VFSS performed at Boston Children's Hospital in 2015. Subjects were identified by Informatics for Integrating Biology and the Bedside software (23). The primary aims were to determine if there was symptom improvement and change in hospitalization in patients who were and were not treated with feeding interventions (i.e. change in liquid flow rate or thickening of formula) for their laryngeal penetration. Additional aims were to determine if any presenting characteristics could predict finding penetration on VFSS and if penetration was persistent over time. Records were reviewed to determine subject characteristics, presenting symptoms, initial and follow-up VFSS findings, whether there was symptom improvement at follow-up, and hospitalization risk before and after VFSS. All VFSS were performed by speech-language pathologists (SLP) with pediatric radiologists in standard fashion (8,9,24). Proportions were compared with Fisher exact test and hospitalizations were compared with paired *t* tests. Data were analyzed using SPSS Statistics (version 23). The present study was approved by the Institutional Review Board at Boston Children's Hospital (IRB-P00023746, approved 10/19/16). For detailed methods, see Supplemental Methods section (Supplemental Digital Content 1, <http://links.lww.com/MPG/B497>).

## RESULTS

We evaluated 137 subjects with mean age  $8.93 \pm 0.59$  months who had isolated laryngeal penetration without evidence of aspiration on their first VFSS. Baseline characteristics, subspecialty of provider that ordered the VFSS, subject comorbidities, and

symptoms present at time of referral are in Table 1. These are shown for the cohort overall and also compared between those with and those without a feeding intervention after they were found to have penetration. Subjects that received intervention were 2.5 months younger than those that did not receive an intervention ( $P = 0.029$ ). Subjects with oxygen requirement were less likely to receive intervention ( $P = 0.04$ ). Of note, none of the other baseline characteristics, including ordering providers, comorbidities, or presenting symptoms differed significantly between the groups.

There was significant variability in the management of these patients, as shown in Figure 1. Overall, 60% ( $n = 82$ ) were maintained on thin liquids, 9% ( $n = 12$ ) were treated with half-nectar, 29% ( $n = 39$ ) were treated with nectar, and 3% ( $n = 4$ ) were treated with honey consistency. Approaches varied depending on which specialty cared for the patient and ordered the VFSS, with thickening rates of 37% for general pediatrics, 38% for gastroenterology, 48% for pulmonology, 43% for otolaryngology, and 0% for neurology.

The depth and consistency of laryngeal penetration was varied in the cohort. Sixty-two percent ( $n = 80$ ) of subjects had deep penetration and 32% (41) had shallow penetration. Thirty-one percent ( $n = 40$ ) had consistent penetration, 54% ( $n = 70$ ) had inconsistent penetration, and 15% ( $n = 20$ ) had only one episode of penetration, as shown in Supplemental Figure 1 (Supplemental Digital Content 2, <http://links.lww.com/MPG/B498>). Subjects with deep/consistent penetration were more likely to receive intervention compared with shallow/inconsistent or only 1 episode ( $P < 0.0001$ ). Thirty-six percent ( $n = 47$ ) described the penetration that was observed as "clinically insignificant" whereas the other characteristics of these subjects' penetration were quite varied, with 60% shallow, 40% deep, 57% inconsistent, 13% consistent, and 30% just 1 episode.

Change in management largely depended on depth/frequency of penetration observed, with subjects having deep/consistent penetration most likely to receive thickening compared with those with shallow/inconsistent penetration, but even subjects with inconsistent penetration had symptom improvement after receiving thickening ( $n = 41$  vs  $n = 3$ ,  $P < 0.0001$  for deep and  $n = 13$  vs  $n = 6$ ,  $P = 0.008$  for inconsistent), as shown in Supplemental Figure 2 (Supplemental Digital Content 2, <http://links.lww.com/MPG/B498>).

Of the 137 subjects, 84% ( $n = 115$ ) were seen in clinic for follow-up during the study period at a mean of  $78.3 \pm 12.5$  days following first VFSS. Of these, 88% ( $n = 101$ ) were reportedly following their recommended intervention (thickening, change in flow rate, some combination of these 2 approaches, or no intervention). There was significant improvement in presenting symptoms for children that had feeding intervention and improvement was the greatest for those that received thickening, as shown in Table 2. In a comparison of symptom improvement between subjects that received thickening versus change in liquid flow rate alone, those that received thickening had significantly higher rates of improvement (odds ratio [OR] 17.55, 95% confidence interval (CI) 3.91–78.76,  $P < 0.001$ ).

Subjects receiving any feeding intervention (change in flow rate or thickening) had decreased total and pulmonary hospitalizations and patients receiving thickening had decreased pulmonary hospitalization nights as shown in Table 3. In patients who did not receive an intervention at the time of VFSS, there was no significant decrease in hospitalizations after VFSS compared with the time period before VFSS, suggesting that symptom improvement does not improve naturally over time. Notably, 30% ( $n = 6$ ) of the subjects that were reported to have a single episode of laryngeal penetration on their VFSS and 26% ( $n = 12$ ) of the subjects that were described as having penetration that was thought to be

TABLE 1. Baseline characteristics, videofluoroscopic swallow study ordering provider, and presenting symptoms

Demographic characteristics, provider that ordered VFSS, comorbidities, and symptoms present at time of referral to VFSS are shown with a comparison between subjects who received feeding intervention for their laryngeal penetration and those who did not receive a feeding intervention

	All subjects (n = 137)	Feeding intervention (n = 75)	No feeding intervention (n = 62)	P value
<b>Baseline characteristics</b>				
Male	61% (84)	57% (43)	66% (41)	0.378
Age at VFSS (months)	8.93 ± 0.59	7.73 ± 0.69	10.37 ± 0.97	0.029
Symptom duration before VFSS (months)	6.28 ± 0.93	6.82 ± 1.28	5.71 ± 1.39	0.565
<b>VFSS ordering provider</b>				
Gastroenterology	34% (47)	33% (25)	36% (22)	0.857
General pediatrics	26% (35)	28% (21)	23% (14)	0.556
Pulmonology	18% (25)	17% (13)	19% (12)	0.826
Otolaryngology	10% (14)	11% (8)	10% (6)	1.000
Other subspecialty	8% (11)	9% (7)	7% (4)	0.754
Neurology	4% (5)	1% (1)	7% (4)	0.176
<b>Comorbidities</b>				
Prematurity	35% (48)	37% (28)	32% (20)	0.592
Neurologic	22% (30)	16% (12)	30% (18)	0.065
Gastrointestinal	18% (24)	20% (15)	15% (9)	0.500
Pulmonary	15% (21)	13% (10)	18% (11)	0.487
Cardiac	10% (13)	11% (8)	8% (5)	0.772
Metabolic	10% (13)	8% (6)	11% (7)	0.567
<b>Presenting symptom</b>				
Choking/gagging	41% (56)	40% (30)	42% (26)	0.862
Reflux	34% (47)	35% (26)	34% (21)	1.000
Vomiting	30% (41)	33% (25)	26% (16)	0.356
Poor feeding	23% (31)	24% (18)	21% (13)	0.688
Slow feeding	9% (12)	8% (6)	10% (6)	0.769
Coughing	66% (91)	69% (52)	63% (39)	0.470
Noisy breathing	29% (39)	32% (24)	24% (15)	0.346
Congestion	22% (30)	24% (18)	19% (12)	0.541
Spells	19% (26)	21% (16)	16% (10)	0.515
Respiratory distress	14% (19)	12% (9)	16% (10)	0.621
Recurrent pneumonia	12% (17)	12% (9)	13% (8)	1.000
Oxygen requirement	3% (4)	0% (0)	7% (4)	0.040
Symptoms during meals	78% (105)	77% (57)	78% (48)	0.839
Symptoms after meals	34% (47)	41% (30)	27% (17)	0.147
Symptoms both during and after meals	24% (33)	30% (22)	18% (11)	0.113
No relation to meals	12% (16)	12% (9)	11% (7)	1.000

Data are expressed as % (n) and mean ± standard error. VFSS = videofluoroscopic swallow study. P value is based on the comparison between patients who did and did not have feeding intervention.

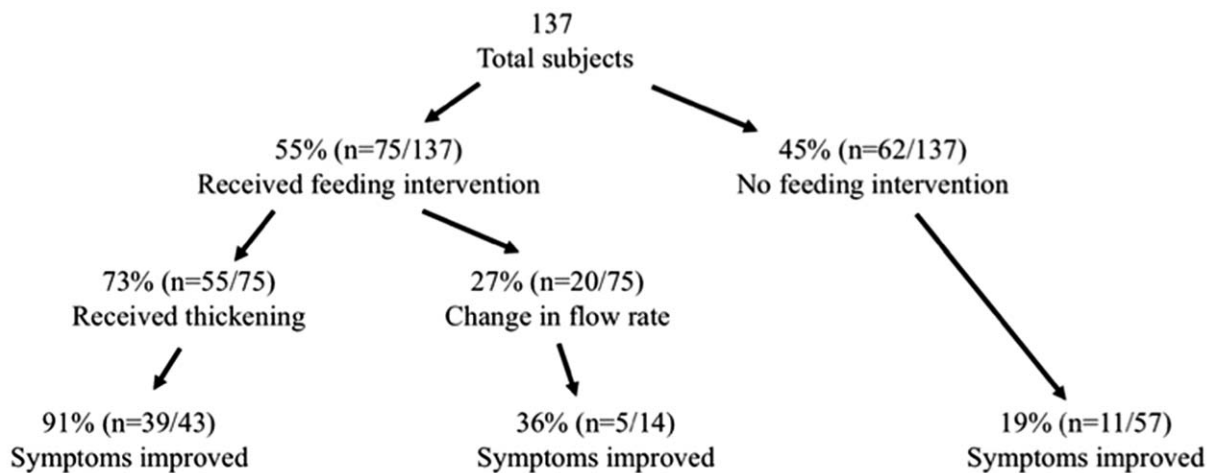


FIGURE 1. Study population. The flow diagram shows the percentage and numbers of subjects in each group, how many subjects had each type of feeding intervention for their laryngeal penetration, and how many subjects, of those that were seen in follow-up and following their prescribed feeding intervention, that had symptom improvement in the follow-up period.

TABLE 2. Symptom improvement at follow-up compared by feeding intervention

At follow-up visits, subjects who received feeding intervention for their laryngeal penetration had significantly higher rates of symptom improvement compared with those who did not receive intervention and this difference was most striking for subjects who received thickening

	Symptom improved	Symptom not improved	Odds ratio (95% CI)	P value
Any feeding intervention vs no feeding intervention				
Any feeding intervention	77% (44)	23% (13)	17.89 (6.47–49.49)	<0.001
No feeding intervention	16% (7)	84% (37)		
Thickening formula vs no feeding intervention				
Thickening formula	91% (40)	9% (4)	41.8 (12.34–141.69)	<0.001
No feeding intervention	19% (11)	81% (46)		
Thickening formula vs change in flow rate				
Thickening formula	91% (39)	9% (4)	17.55 (3.91–78.76)	<0.001
Change in flow rate	36% (5)	64% (9)		

Data are expressed as percentage (n) or odds ratio (95% confidence interval). CI = confidence interval.

“clinically insignificant” had at least 1 hospital admission during the follow-up period.

In the cohort overall, there was a mean of  $1.44 \pm 0.07$  swallow studies performed per subject during the study period. Of the 137 subjects, 31% (n = 42) went on to have a second VFSS and on that study, 31% (n = 13) had normal swallow function, 41% (n = 17) had persistent penetration, and notably 26% (n = 11) now

had evidence of aspiration that was not captured on their initial VFSS. Of these, 91% (n = 10) did not have neurologic impairments or other comorbidities that might have been expected to cause a decline in swallow function.

We additionally evaluated each presenting symptom for evidence of association with laryngeal penetration. Coughing was the only symptom that was significantly associated with

TABLE 3. Hospitalization risk before and after interventions for laryngeal penetration

## A. Hospitalization risk for subjects that received feeding intervention (n = 75)

	Any feeding intervention	After feeding intervention	P value
Total admissions	$0.69 \pm 0.13$	$0.40 \pm 0.08$	0.035
Total nights	$2.85 \pm 0.68$	$2.60 \pm 1.40$	0.87
Pulmonary admissions	$0.35 \pm 0.09$	$0.13 \pm 0.06$	0.032
Pulmonary nights	$1.21 \pm 0.35$	$0.59 \pm 0.37$	0.218
GI admissions	$0.15 \pm 0.06$	$0.07 \pm 0.04$	0.159
GI nights	$0.77 \pm 0.42$	$0.30 \pm 0.17$	0.263

## B. Hospitalization risk for subjects that received thickened feeds (n = 55)

	Before thickening	After thickening	P value
Total admissions	$0.60 \pm 0.12$	$0.44 \pm 0.10$	0.261
Total nights	$2.27 \pm 0.69$	$1.00 \pm 0.29$	0.077
Pulmonary admissions	$0.33 \pm 0.09$	$0.15 \pm 0.07$	0.058
Pulmonary nights	$1.20 \pm 0.43$	$0.31 \pm 0.17$	0.048
GI admissions	$0.16 \pm 0.07$	$0.09 \pm 0.05$	0.322
GI nights	$1.00 \pm 0.57$	$0.41 \pm 0.23$	0.307

## C. Hospitalization risk for subjects that did not receive feeding intervention (n = 62)

	Before VFSS	After VFSS	P value
Total admissions	$0.53 \pm 0.16$	$0.45 \pm 0.13$	0.639
Total nights	$2.03 \pm 0.72$	$1.36 \pm 0.51$	0.431
Pulmonary admissions	$0.19 \pm 0.06$	$0.16 \pm 0.07$	0.718
Pulmonary nights	$0.52 \pm 0.20$	$0.58 \pm 0.39$	0.867
GI admissions	$0.00 \pm 0.00$	$0.03 \pm 0.02$	0.159
GI nights	$0.00 \pm 0.00$	$0.07 \pm 0.05$	0.208

Hospitalization numbers were found to be decreased after feeding interventions and formula thickening but not for subjects who did not receive intervention for their laryngeal penetration. Data are expressed as mean  $\pm$  standard error. GI = gastrointestinal; VFSS = videofluoroscopic swallow study.

laryngeal penetration (OR 1.792, 95% CI 1.166–2.753,  $P = 0.008$ ). Odds ratios for all other symptoms ranged from 0.497 to 2.008 ( $P > 0.10$ ).

## DISCUSSION

Laryngeal penetration is a common finding in the field of pediatric swallow disorders with a relevance that remains fiercely debated, perhaps because of the paucity of studies addressing its true clinical significance (1,2,20,25). In the present study, we showed that interventions for penetration are associated with improvements in presenting symptoms and hospitalization risk in young children, both of which are clinically significant markers that suggest a potentially large effect of such a small intervention. Although all feeding interventions were associated with improved outcomes, thickening of formula seemed to have the single greatest impact on symptom improvement. This therapeutic approach can make these children feel better, relieve parental concern, and actually improve clinical outcomes with an inexpensive intervention that would likely decrease costs by preventing expensive hospitalizations. In contrast, we found that outcomes are not changed for patients who do not get interventions for their penetration. Thus, without intervention, there is no improvement in hospitalizations and limited symptom improvement at follow-up.

One finding in this study was the diverse range of providers ordering these studies, which may result in great variability in management approaches to penetration. Swallowing abnormalities such laryngeal penetration are increasing in frequency in the pediatric population as more premature infants and other children with chronic medical conditions survive (4,13,14). Therefore, this issue will likely become only more important in the future and, as our results suggest, more medical providers will be involved in the management of these patients.

There is a wide range of approaches to laryngeal penetration and some SLPs and/or radiologists will comment in their reports that nonclinically significant penetration is present, which may result in providers not offering intervention to these patients, even when such patients are persistently symptomatic in our clinical experience, and we show in this study that this assumption of normalcy may affect clinical outcomes. In many institutions, interventions are not commonly pursued after finding penetration on swallow study for several possible reasons (20–22). Some providers consider penetration a normal variant, and therefore, do not believe it needs treatment. Others feel that it is not indicative of aspiration risk. Still others might worry that the risk of thickening agents or other feeding interventions might outweigh any benefit of intervention. On the basis of the results of the present study, we feel that any finding of laryngeal penetration in a symptomatic child should be considered clinically significant and a change in management should be considered.

There are several important practical considerations from our study. First, the present approach to laryngeal penetration is variable. In our cohort, only 55% of subjects had change in their management, with most receiving thickening but others receiving a change in liquid flow rate. Feeding interventions are typically made at the discretion and recommendation of the SLP that performs the study or by the ordering physician. One limitation to our study may be that only the most symptomatic patients received thickening, and thickening was not needed in the nonintervention patients. Our data suggests this is not the case with the patients who did not receive interventions showing no improvement in symptoms over time; 91% of subjects had symptom improvement with thickening, compared with only 19% improvement at follow-up in the group that received no intervention. Also notably, even some of the patients who were thought to have only transient penetration on

their swallow study and who, therefore, did not receive treatment ultimately went on to have both pulmonary/gastrointestinal hospitalizations, emphasizing the importance of treating any degree of laryngeal penetration.

Another important finding from the present study is that laryngeal penetration is not transient and may actually be indicative of aspiration risk. To our knowledge, no prior studies have evaluated whether the penetration can predict future aspiration; on repeat VFSS, 26% of subjects with prior laryngeal penetration were found to have frank aspiration that was not captured on initial VFSS and, importantly, the great majority of these patients were not neurologically impaired and did not have any other comorbidity, such as cardiac disease, that would have been expected to cause a decline in swallow function. This is consistent with the results of Friedman and Frazier (2), who showed that deep laryngeal penetration might also predict the occurrence of aspiration in children within individual swallow studies. These results combined highlight the transient nature of VFSS that captures only a very limited moment in time.

An additional practical consideration is our analysis of which presenting symptoms are suggestive of laryngeal penetration. Although multiple studies have shown that oropharyngeal dysphagia with aspiration is typically silent in this age group, including recent large studies from our own institution, it is less clear if children with penetration have clear symptoms that can be tied to their type of oropharyngeal dysphagia (16,26–28). Silva-Munhoz Lde (29) found an association between choking and finding isolated laryngeal penetration in a group of 15 children. Weir (26) also examined symptoms predictive of isolated laryngeal penetration and found no consistent correlation. In the present study with a larger cohort, we found an association between cough and the presence of laryngeal penetration.

Lastly, and perhaps of the greatest clinical significance, we showed that children who receive interventions for their laryngeal penetration have decreased hospitalizations. In particular, thickening and other feeding interventions were seen to affect pulmonary hospitalizations, suggesting additionally that laryngeal penetration puts children at increased risk for respiratory exacerbations. These results complement and add to prior studies in this field. Few studies have evaluated the impact of feeding interventions on improvement in symptoms and outcomes in any type of oropharyngeal dysphagia (25). Jackson showed symptom improvements from feeding interventions in a population of Down syndrome patients with aspiration (30). Coon et al (31) questioned the benefits of thickening for oropharyngeal dysphagia patients but found decreased acute respiratory hospitalizations for children with silent aspiration that received thickening. Khoshoo et al (32,33) showed that thickening decreased the occurrence of aspiration in a small group of infants with swallowing dysfunction associated with bronchiolitis. Krummrich et al (34) used a parental reporting tool and found that parents of young children with dysphagia reported a significant decrease in symptoms and increase in oral intake when their children were started on thickened liquids. None of these studies, however, evaluated outcomes in isolated laryngeal penetration.

There are a small number of other studies showing that there is clinical significance to penetration, though ours is the first to show that treatment is associated with improved outcomes. Gurberg et al (17) reported on 235 children with oropharyngeal dysphagia with a mean age of 5.6 years, of whom only 59 had laryngeal penetration, that children with laryngeal penetration have increased rates of pneumonia over the 3 years after the diagnosis of laryngeal penetration. Serel Arslan et al (18) also showed a positive correlation between penetration and recurrent pneumonia in a population of 274 children with a median age of 2.75 years with oropharyngeal dysphagia, of whom 89 had isolated laryngeal penetration. This

result is similar to adult studies showing a 4 times increased risk of pneumonia in patients with penetration (35). We also previously showed that oropharyngeal dysphagia is associated with the occurrence of brief resolved unexplained events (BRUE, formerly known as apparent life-threatening events) and in that study, 43% of subjects admitted after BRUE had isolated laryngeal penetration on VFSS, suggesting this is a clinically relevant entity (36).

There are a number of limitations to the present study, including the retrospective nature of this study. At our institution, the SLP performing the VFSS in conjunction with the ordering physician makes decisions about what interventions to pursue during the course of the VFSS. The retrospective nature of this study limited our ability to consider any unmeasured factors that might have determined which patients received feeding interventions, thickening or no intervention for their penetration (ie, parent or provider preference in addition to results of prior clinical feeding evaluations, other medical/feeding history, or the medical team's understanding of the underlying pathophysiology of swallowing dysfunction) but importantly, apart from age and oxygen requirement, none of the other baseline characteristics, including ordering providers, comorbidities, or presenting symptoms differed significantly between the groups. It is also possible that thickening itself might have had other beneficial effects such as decreasing gastroesophageal reflux. In measuring symptom improvement, we relied on caregiver report, which is likely subjective but we believe still clinically relevant; for this reason, we also used hospitalization as an objective measure of comparison. Additionally, although we have the SLP and radiologists' categorization of severity of penetration, validated scoring such as the Penetration-Aspiration Score, was not used at the time of VFSS; however, lack of standardization in pediatric fluoroscopy is a national problem and our institution is not alone (37,38). Future studies will be needed to delineate outcomes for intervening based on specific degrees of penetration, nutritional symptoms such as failure to thrive, and use of standardized protocols in the approach to isolated laryngeal penetration.

## CONCLUSIONS

Laryngeal penetration appears to be clinically significant in symptomatic children and feeding interventions are associated with improved outcomes. Thickening or other feeding intervention should be considered for all symptomatic children with laryngeal penetration on VFSS. Close collaboration and follow-up with SLPs, ordering providers and patients is needed to insure that different feeding interventions are considered and to monitor efficacy and any side effects from interventions.

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## REFERENCES

- Delzell PB, Kraus RA, Gaisie G, et al. Laryngeal penetration: a predictor of aspiration in infants? *Pediatr Radiol* 1999;29:762–5.
- Friedman B, Frazier JB. Deep laryngeal penetration as a predictor of aspiration. *Dysphagia* 2000;15:153–8.
- Borowitz KC, Borowitz SM. Feeding problems in infants and children: assessment and etiology. *Pediatr Clin North Am* 2018;65:59–72.
- Bhattacharyya N. The prevalence of pediatric voice and swallowing problems in the United States. *Laryngoscope* 2015;125:746–50.
- Benfer KA, Weir KA, Bell KL, et al. Oropharyngeal dysphagia and cerebral palsy. *Pediatrics* 2017;140:pii: e20170731.
- McGrattan KE, McGhee H, DeToma A, et al. Dysphagia in infants with single ventricle anatomy following stage 1 palliation: physiologic correlates and response to treatment. *Congenit Heart Dis* 2017;12:382–8.
- Suterwala MS, Reynolds J, Carroll S, et al. Using fiberoptic endoscopic evaluation of swallowing to detect laryngeal penetration and aspiration in infants in the neonatal intensive care unit. *J Perinatol* 2017;37:404–8.
- Arvedson JC, Lefton-Greif MA. Instrumental assessment of pediatric dysphagia. *Semin Speech Lang* 2017;38:135–46.
- Hiorns MP, Ryan MM. Current practice in paediatric videofluoroscopy. *Pediatr Radiol* 2006;36:911–9.
- Aviv JE, Spitzer J, Cohen M, et al. Laryngeal adductor reflex and pharyngeal squeeze as predictors of laryngeal penetration and aspiration. *Laryngoscope* 2002;112:338–41.
- Durvasula VS, O'Neill AC, Richter GT. Oropharyngeal dysphagia in children: mechanism, source, and management. *Otolaryngol Clin North Am* 2014;47:691–720.
- Lefton-Greif MA, Carroll JL, Loughlin GM. Long-term follow-up of oropharyngeal dysphagia in children without apparent risk factors. *Pediatr Pulmonol* 2006;41:1040–8.
- Svystun O, Johannsen W, Persad R, et al. Dysphagia in healthy children: characteristics and management of a consecutive cohort at a tertiary centre. *Int J Pediatr Otorhinolaryngol* 2017;99:54–9.
- Newman LA, Keckley C, Petersen MC, et al. Swallowing function and medical diagnoses in infants suspected of dysphagia. *Pediatrics* 2001;108:E106.
- Lee JH, Chang YS, Yoo HS, et al. Swallowing dysfunction in very low birth weight infants with oral feeding desaturation. *World J Pediatr* 2011;7:337–43.
- Weir KA, McMahon S, Taylor S, et al. Oropharyngeal aspiration and silent aspiration in children. *Chest* 2011;140:589–97.
- Gurberg J, Birnbaum R, Daniel SJ. Laryngeal penetration on videofluoroscopic swallowing study is associated with increased pneumonia in children. *Int J Pediatr Otorhinolaryngol* 2015;79:1827–30.
- Serel Arslan S, Demir N, Karaduman AA. Both pharyngeal and esophageal phases of swallowing are associated with recurrent pneumonia in pediatric patients. *Clin Respir J* 2018;12:767–71.
- Strychowsky JE, Dodrill P, Moritz E, et al. Swallowing dysfunction among patients with laryngeal cleft: more than just aspiration? *Int J Pediatr Otorhinolaryngol* 2016;82:38–42.
- Allen JE, White CJ, Leonard RJ, et al. Prevalence of penetration and aspiration on videofluoroscopy in normal individuals without dysphagia. *Otolaryngol Head Neck Surg* 2010;142:208–13.
- Molfenter SM, Hsu CY, Lu Y, et al. Alterations to swallowing physiology as the result of effortful swallowing in healthy seniors. *Dysphagia* 2017;33:380–8.
- Daggett A, Logemann J, Rademaker A, et al. Laryngeal penetration during deglutition in normal subjects of various ages. *Dysphagia* 2006;21:270–4.
- Murphy SN, Weber G, Mendis M, et al. Serving the enterprise and beyond with informatics for integrating biology and the bedside (i2b2). *J Am Med Inform Assoc* 2010;17:124–30.
- Jadcherla SR, Stoner E, Gupta A, et al. Evaluation and management of neonatal dysphagia: impact of pharyngoesophageal motility studies and multidisciplinary feeding strategy. *J Pediatr Gastroenterol Nutr* 2009;48:186–92.
- Gosa MM, Carden HT, Jacks CC, et al. Evidence to support treatment options for children with swallowing and feeding disorders: a systematic review. *J Pediatr Rehabil Med* 2017;10:107–36.
- Weir K, McMahon S, Barry L, et al. Clinical signs and symptoms of oropharyngeal aspiration and dysphagia in children. *Eur Respir J* 2009;33:604–11.
- Velayutham P, Irace AL, Kawai K, et al. Silent aspiration: who is at risk? *Laryngoscope* 2018;128:1952–7.
- Duncan DR, Mitchell PD, Larson K, et al. Presenting signs and symptoms do not predict aspiration risk in children. *J Pediatr* 2018;201:141–6.
- Silva-Munhoz Lde F, Buhler KE, Limongi SC. Comparison between clinical and videofluoroscopic evaluation of swallowing in children with suspected dysphagia. *Codas* 2015;27:186–92.
- Jackson A, Maybee J, Moran MK, et al. Clinical characteristics of dysphagia in children with Down syndrome. *Dysphagia* 2016;31:663–71.

31. Coon ER, Srivastava R, Stoddard GJ, et al. Infant videofluoroscopic swallow study testing, swallowing interventions, and future acute respiratory illness. *Hosp Pediatr* 2016;6:707–13.
32. Khoshoo V, Ross G, Kelly B, et al. Benefits of thickened feeds in previously healthy infants with respiratory syncytial viral bronchiolitis. *Pediatr Pulmonol* 2001;31:301–2.
33. Khoshoo V, Edell D. Previously healthy infants may have increased risk of aspiration during respiratory syncytial viral bronchiolitis. *Pediatrics* 1999;104:1389–90.
34. Krummrich P, Kline B, Krival K, et al. Parent perception of the impact of using thickened fluids in children with dysphagia. *Pediatr Pulmonol* 2017;52:1486–94.
35. Pikus L, Levine MS, Yang YX, et al. Videofluoroscopic studies of swallowing dysfunction and the relative risk of pneumonia. *AJR Am J Roentgenol* 2003;180:1613–6.
36. Duncan DR, Amirault J, Mitchell PD, et al. Oropharyngeal dysphagia is strongly correlated with apparent life-threatening events. *J Pediatr Gastroenterol Nutr* 2017;65:168–72.
37. Hind JA, Gensler G, Brandt DK, et al. Comparison of trained clinician ratings with expert ratings of aspiration on videofluoroscopic images from a randomized clinical trial. *Dysphagia* 2009;24:211–7.
38. Rosenbek JC, Robbins JA, Roecker EB, et al. A penetration-aspiration scale. *Dysphagia* 1996;11:93–8.