RESEARCH ARTICLE

Infant Videofluoroscopic Swallow Study Testing, Swallowing Interventions, and Future Acute Respiratory Illness

Eric R. Coon, MD, MSCI,[a] Rajendu Srivastava, MD, FRCPC, MPH,[a,b] Gregory J. Stoddard, MS,[c] Sheena Reilly, PhD, FASSA,[d] Christopher G. Maloney, MD, PhD,[a] Susan L. Bratton, MD, MPH[e]

ABSTRACT

OBJECTIVES: Tube feedings are commonly prescribed to infants with swallowing abnormalities detected by videofluoroscopic swallow study (VFSS), but there are no studies demonstrating efficacy of these interventions to reduce risk of acute respiratory illness (ARI). We sought to measure the association between swallowing interventions and future ARI, among VFSS-tested infants.

METHODS: Retrospective cohort of all infants (<12 months) tested with VFSS at a children's hospital between January 1, 2010, and January 1, 2012. Hospital ARI encounters (emergency, observation, or inpatient status) in a 22-hospital integrated health care delivery system, between the first VFSS and age 3 years, were measured. VFSS results were grouped by normal, intermediate, and oropharyngeal aspiration (OPA), with OPA further subdivided by silent versus cough and thin versus thick liquid OPA. Cox regression modeled the association between swallowing interventions (thickened or nasal tube feedings) and ARI, accounting for changes in swallowing and interventions over time.

RESULTS: 576 infants were tested with a VFSS in their first year of life, receiving a total of 1051 VFSSs in their first 3 years of life. More than 60% of infants received a measured feeding intervention. With the exception of infants with silent OPA who received thickened feedings, neither thickening nor nasal tube feedings, compared with no intervention, were associated with a decreased risk of subsequent ARI.

CONCLUSIONS: Swallowing interventions and repeated testing are common among VFSS-tested infants. However, the importance of diagnosing and intervening on VFSS-detected swallowing abnormalities for the majority of tested infants remains unclear.

[a]Divisions of Pediatric Inpatient Medicine, and [e]Pediatric Critical Care Medicine, University of Utah School of Medicine, Primary Children's Hospital, Salt Lake City, Utah; [b]Institute for Health Care Leadership, Intermountain Healthcare, Salt Lake City, Utah; [c]Division of Epidemiology, University of Utah School of Medicine, Salt Lake City, Utah; and [d]Menzies Health Institute Queensland, Griffith University, Brisbane, Australia

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Address correspondence to Eric R. Coon, MD, Department of Pediatrics, Division of Inpatient Medicine, University of Utah School of Medicine, Primary Children's Hospital, 100 North Mario Capecchi Dr, Salt Lake City, UT 84113. E-mail: eric.coon@hsc.utah.edu

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Swallowing problems, particularly aspiration, are believed to contribute to acute respiratory illness (ARI), chronic lung disease, and mortality.[1,2] However, little supportive evidence exists that the passage of acidic and/or bacteria-laden material into the respiratory tract causes clinically important disease. Descriptive case series[3–5] and studies that use subjective definitions of aspiration without radiographic confirmation have been reported in children.[6,7] The largest observational pediatric study examining the relationship between radiographically diagnosed aspiration and pneumonia did not detect an association after adjusting for age, symptoms, and other diagnoses.[8]

Assessment and treatment of abnormal swallowing are particularly challenging in infants, because infants experience natural physiologic and anatomic changes over time. Videofluoroscopic swallow study (VFSS) is the gold-standard radiographic test for evaluating swallowing,[9] and VFSS abnormalities are common among infants clinically thought to have difficulty swallowing.[10–13] Which infant characteristics predict VFSS abnormalities and whether interventions designed to protect the airway are efficacious remain unclear. An observational study in infants with neurologic impairment did not find a decrease in respiratory admissions after fundoplication.[14] Otherwise, the assumption that interventions for swallowing abnormalities decrease the future risk of ARI among infants has not been tested. The current study describes patient characteristics and interventions received among VFSS-tested infants and measures the association between swallowing interventions and the future risk of ARI.

METHODS

Setting

The study was conducted at Primary Children's Hospital (PCH), a 289-bed tertiary care children's hospital serving a referral area including 5 states (Montana, Idaho, Wyoming, Nevada, and Utah). PCH is owned and operated by Intermountain Healthcare, Inc, a large, not-for-profit, vertically integrated health care system with 22 hospitals and 185 outpatient clinics. The University of Utah Institutional Review Board approved this study.

Design and Data Source

Data for our retrospective cohort study were obtained by using Intermountain Healthcare's Enterprise Data Warehouse, an organized, integrated, and searchable administrative database storing 8 million patient encounters, which includes clinical, laboratory, and radiologic data from all inpatient settings with a linked unique identifier for each patient.[15]

Participants

Inclusion criteria were as follows: (1) receipt of a VFSS at PCH between January 1, 2010, and January 1, 2012, and (2) subject age at first VFSS $<$365 days, limiting the cohort to children with swallowing difficulty presenting in infancy.

VFSS

Pediatric radiologist VFSS impressions were manually reviewed. Studies were scored as positive if the radiologist described any degree of oropharyngeal aspiration (OPA) and were further subdivided on the basis of the thickest consistency of food aspirated (dichotomized into thin or thick) and whether the aspiration was silent or accompanied by a cough. An intermediate group had no evidence of OPA on VFSS, but the radiologist used phrases such as penetration, pooling, delayed initiation of swallow, and dis-coordinated pharyngeal phase of swallowing. The lack of any such abnormality during the pharyngeal phase of swallowing and lack of OPA were categorized as normal. In all, 6 potential VFSS results were coded as follows: normal, intermediate, thin OPA, thick OPA, OPA with cough, and silent OPA. Thin versus thick OPA were mutually exclusive, as were cough versus silent OPA. However, overlap certainly occurred between thin or thick with cough or silent OPA.

Infants could be tested with VFSS more than once during the study period, and all results were reviewed. An infant's VFSS test result status was updated with each new VFSS received, until study observation was completed. Intervals between VFSS tests were assigned the test result of the previous VFSS (last observation carried forward).

Major Diagnostic Categories

In an effort to group patients by the primary reason for presentation at the time of initial VFSS, a classification system developed by the Agency for Healthcare Research and Quality was used. Agency for Healthcare Research and Quality Clinical Classification Software aggregates International Classification of Diseases, Ninth Revision (ICD-9), diagnosis codes into clinically meaningful and mutually exclusive major diagnostic categories.[16] The primary diagnosis code for the encounter associated with each patient's first VFSS was used to assign each a major diagnostic category.

Comorbid Conditions

Complex chronic conditions (CCCs) were defined according to a previously published taxonomy[17] and could be measured at any recorded encounter at an Intermountain facility. Gastric tube codes were removed from the gastrointestinal CCC group because gastric tubes were a measured intervention in this study. Without this alteration, gastric tubes would be inappropriately included in regression analysis twice.

The CCC taxonomy includes a premature group composed of neonates born at $\leq$26 weeks' gestation and/or with a birth weight of $\leq$750 g. Because less severe prematurity may be an important factor affecting infant swallowing, a moderate premature group was created for this study, composed of ICD-9 codes comprising gestational age $>$26 and $\leq$34 weeks and birth weight $>$750 and $\leq$2499 g. Infants with codes for both CCC prematurity and the newly created moderate prematurity group were assigned to CCC prematurity, making the 2 groups mutually exclusive. Understandably, the gastrointestinal CCC group does not include gastroesophageal reflux disease (GERD). Again, given the potential of GERD to moderate infant risk of ARI in the setting of swallowing problems, ICD-9 codes for GERD (530.11, 530.81) were used to create an additional GERD covariate.

Recommended Interventions

Interventions recommended to families after VFSS to mitigate or prevent the risk of aspiration-related complications included

thickening feedings, nasogastric or nasojejunal (collectively called nasal tube going forward) feedings, gastric tube placement, and fundoplication. Thickening and nasal tube feedings were ascertained by reviewing charts for speech language pathologist recommendations, which are provided at PCH after all VFSSs. Therefore, infant status for these 2 interventions could be updated at each VFSS, with periods between VFSS tests assigned the intervention status of the most recent VFSS (last observation carried forward). Gastric tube placement was ascertained by using the ICD-9 procedure codes 43.19, 43.11, and 97.02 and diagnosis codes V44.1 and V55.1. Fundoplication was ascertained by using the ICD-9 procedure codes 44.66 and 44.67. The presence of gastric tubes and fundoplication were included if the procedure occurred during or after the first VFSS encounter.

Outcomes

The primary outcome measure was an emergency department visit or hospital admission (observation or inpatient status) at an Intermountain facility for ARI, occurring between the child's first VFSS and his or her third birthday. ARI ICD-9 diagnosis codes included aspiration pneumonia (507.0), pneumonia (480–486), bronchiolitis (466, 467), and asthma (493). An encounter was coded as an ARI if any of 40 discharge diagnosis codes contained an ARI ICD-9 diagnosis code. Previous studies have taken a similarly broad approach, not limiting ARI to aspiration pneumonia, because determining the contribution of aspiration to ARI is subjective and imprecise.[14]

Statistical Analysis

Patient characteristics were summarized by using frequencies and percentages, with intermediate and OPA infants compared with VFSS normal infants with the use of Poisson regression. Comparison of interventions and additional testing according to first VFSS result were performed with a linear trend test, with logistic regression used for categorical outcomes.

The association between recommended swallowing interventions and subsequent ARI was measured by using a shared frailty Cox regression model with time-varying covariates, allowing for multiple failures (ie, including all ARIs after the index VFSS, rather than simply modeling time to first ARI). A shared frailty Cox regression is the analogue of a mixed-effects regression model, accounting for lack of independence among the multiple hospital encounters within the same participant. For this analysis, all VFSS results were used, not just those for the first study. Thickened and nasal tube feeding statuses were the primary predictors and updated at each VFSS, as previously described, with the last observation carried forward. Gastric tube and fundoplication were not analyzed because of ambiguity of their status over time. Specifically, there is no ICD-9 procedure code for the removal of a gastric tube and, similarly, no way to know from administrative data if a fundoplication remained intact. Covariates included in the model were age at time of first VFSS and comorbid conditions. Once a comorbid covariate was documented during an encounter for an infant, the covariate was assumed to be present from that encounter forward, given that comorbidities are chronic, generally long-term conditions.

In the context of this time-dependent analysis, Cox regression estimated the association between recommended interventions and the risk of ARI during follow-up, stratified by all VFSS result intervals experienced by participants. For example, a participant who received only 1 VFSS contributed person-months to the model for that particular VFSS result from the time of test receipt until the close of follow-up. On the other hand, participants who received multiple VFSSs had their contribution of person-months divided between the VFSS results according to the quantity of time elapsed between VFSS tests. Statistical analyses were performed by using Stata version 13 (StataCorp, College Station, TX).

RESULTS

Study Cohort and VFSS Results

Five hundred seventy-six infants were tested with a VFSS in their first year of life, receiving a total of 1051 VFSSs in their first 3 years of life. One hundred twenty-eight (22%) infants received ≥3 VFSSs, including 11 infants who received between 6 and 9 VFSSs in their first 3 years of life. Table 1 describes the cohort at the time of first VFSS, in terms of demographic characteristics and coded diagnoses, compared according to VFSS normal, intermediate, and OPA groups. Of 576 infants, 199 (35%) showed OPA on their initial study. Most infants were <6 months of age (75%), male (59%), white (85%), inpatients (64%), commercially insured (58%), and had at least 1 comorbidity (77%). OPA infants were significantly younger and more likely to be inpatients at the time of their first VFSS.

Major Diagnostic Categories

The most common primary diagnosis codes of infants tested with a first VFSS are summarized by the major diagnostic categories in Table 1. Each major diagnostic category listed encompasses at least 10% of primary diagnosis codes for an individual VFSS test result (normal, intermediate, OPA). To give a clearer picture of patients within a given diagnostic category, the most common ICD-9 codes for each category are provided in parentheses. Three major diagnostic categories, (1) cardiac and circulatory congenital anomalies, (2) other congenital anomalies, and (3) short gestation, low birth weight, and fetal growth retardation, were associated with OPA. These appear to represent infants with anatomic conditions that predispose them to aspirate. The other 3 frequent major diagnostic categories represent infants with difficulty feeding judged by an observer, but these codes were not associated with an increased risk of OPA.

Comorbid Conditions

Only those comorbid conditions most clinically relevant to infant swallowing are presented in Table 1. Compared with the absence of any comorbid condition, cardiovascular and respiratory comorbidities were associated with OPA. Neither moderate prematurity nor GERD was significantly associated with OPA.

Recommended Interventions After VFSS and Additional VFSS Testing

Recommended swallowing interventions were analyzed for all 1051 VFSSs, stratified

TABLE 1 Cohort Demographics and Coded Diagnoses at the Time of First VFSS

	Patients, *n* (%)			Regression Models, RR (95% CI)	
	Normal VFSS (*N* = 298)	Intermediate VFSS (*N* = 79)	OPA VFSS (*N* = 199)	Intermediate Versus Normal VFSS	OPA Versus Normal VFSS
Age at time of first VFSS					
<3 months	149 (50)	40 (51)	123 (62)	Ref	Ref
3–6 months	66 (22)	15 (19)	37 (19)	0.9 (0.51–1.48)	0.8 (0.59–1.06)
>6 months	83 (28)	24 (30)	39 (20)	1.1 (0.67–1.65)	0.7 (0.54–0.95)*
Male sex	182 (61)	47 (59)	108 (54)	0.9 (0.63–1.41)	0.8 (0.68-1.04)
White race	215 (82)	60 (90)	146 (87)	1.7 (0.81–3.48)	1.3 (0.88–1.83)
Inpatient	169 (57)	42 (53)	157 (79)	0.9 (0.60–1.31)	1.9 (1.44–2.54)*
Medicaid	138 (46)	30 (38)	78 (39)	0.8 (0.50–1.14)	0.8 (0.67–1.04)
Major diagnostic categories for primary diagnosis of index VFSS (most common ICD-9)					
Other nutritional, endocrine, and metabolic disorders (feeding problem)	61 (20)	20 (25)	27 (14)	1.2 (0.79–1.92)	0.7 (0.52–1.01)
Cardiac and circulatory congenital anomalies (coarctation of aorta)	39 (13)	14 (18)	50 (25)	1.3 (0.80–2.16)	1.5 (1.22–1.91)*
Dysphagia (dysphagia nos)	36 (12)	14 (18)	20 (10)	1.4 (0.86–2.30)	0.9 (0.60–1.27)
Other perinatal conditions (feeding problem newborn)	38 (13)	5 (6)	22 (11)	0.5 (0.22–1.22)	0.9 (0.63–1.28)
Other congenital anomalies (laryngotracheal anomaly nec)	13 (4)	1 (1)	22 (11)	0.3 (0.05–2.22)	1.6 (1.23–2.16)*
Short gestation, low birth weight, and fetal growth retardation (35–36 weeks' gestation)	12 (4)	3 (4)	20 (10)	1.0 (0.34–2.67)	1.6 (1.21–2.16)*
Comorbid conditions					
No comorbid condition (*n* = 133)	75 (25)	23 (29)	35 (18)	Ref	Ref
Cardiovascular (*n* = 158)	66 (22)	23 (29)	69 (35)	1.48 (0.85–2.58)	1.99 (1.42–2.80)*
Other congenital or genetic (*n* = 96)	49 (16)	13 (16)	34 (17)	1.65 (0.90–3.01)	1.37 (0.81–2.30)
Premature and neonatal (*n* = 81)	40 (13)	10 (13)	31 (16)	1.53 (0.51–4.55)	1.68 (0.85–3.29)
Neurologic and neuromuscular (*n* = 77)	34 (11)	11 (14)	32 (16)	1.15 (0.50–2.68)	1.11 (0.62–2.00)
Respiratory (*n* = 70)	27 (9)	5 (6)	38 (19)	0.76 (0.24–2.36)	1.76 (1.13–2.76)*
Gastrointestinal (*n* = 33)	18 (6)	6 (8)	9 (5)	0.32 (0.01–7.31)	—
GERD (*n* = 244)	123 (41)	35 (44)	86 (43)	1.06 (0.65–1.72)	1.01 (0.69-1.49)
Moderate prematurity (*n* = 58)	26 (9)	11 (14)	21 (11)	1.38 (0.64–2.98)	1.17 (0.62–2.19)

All analyses were performed by using univariable Poisson regression, with the exception of comorbid conditions. Comorbid condition RR values were obtained with multivariable Poisson regression, adjusting for every other comorbid condition individually. *$P < .05$. CI, confidence interval; nec, not elsewhere classified; nos, not otherwise specified; Ref, reference; RR, relative risk; —, too few observations to estimate an RR.

according to normal, intermediate, or OPA (subdivided by consistency aspirated) VFSS results as shown in Table 2. Although interventions were commonly prescribed in the setting of an OPA result, a relatively large proportion of interventions were prescribed for patients with VFSS normal and intermediate results (41% and 57%, respectively). Thickened feedings were most often recommended for findings of thin OPA (76%), whereas feeding diversion was most often prescribed for findings of thick OPA (46% nasal tube, 12% gastric tube). As the type of swallowing abnormality on VFSS worsened, children were more likely to receive each type of intervention and more likely to receive additional VFSS testing.

Outcomes

Sixty percent of infants (*n* = 350) undergoing a VFSS did not receive hospital care for an ARI between their first VFSS and the age of 3 years old, including more than half of infants with a first VFSS OPA. For those who suffered an ARI, the median time from the first VFSS to the first ARI was 136 days (interquartile range: 27–323 days), with a median of 2 ARIs (interquartile range: 1–4 ARIs) experienced between their first VFSS and the age of 3 years old.

Table 3 presents hazard ratios of the association between recommended swallowing interventions and subsequent ARIs, stratified by VFSS result. With the exception of infants with silent OPA who received thickened feedings, thickened and nasal tube feedings were not associated with a decreased risk of subsequent ARIs.

TABLE 2 Recommended Interventions and Repeat VFSS for Infants Based on 1051 VFSS Results

	Normal (N = 484)	Intermediate (N = 150)	OPA		P-trend[a]
			Thin (N = 249)	Thick (N = 168)	
Any intervention recommended, *n* (%)	197 (41)	86 (57)	223 (90)	128 (76)	<.01
Type of intervention, *n* (%)					
Thickened feeding[b]	100 (21)	69 (46)	188 (76)	54 (32)	<.01
Nasal tube feeding[b]	93 (19)	26 (17)	97 (39)	77 (46)	<.01
Gastric tube[c]	84 (17)	14 (9)	25 (10)	20 (12)	<.01
Fundoplication[c]	20 (4)	2 (1)	8 (3)	7 (4)	<.01
Additional VFSS, *n* (%)	108 (22)	55 (37)	188 (76)	124 (74)	<.01

[a] Derived by using linear trend test with logistic regression.
[b] Measured and updated at the time of each VFSS.
[c] Counted only once, at first placement. Assigned to the VFSS result measured at the time of or just before intervention placement.

Among infants for whom VFSS results were normal, thickening and nasal tube feeding interventions were associated with an increased risk of subsequent ARIs. The association of gastric tubes and fundoplication with ARI is not presented because of the aforementioned ambiguity of their status over time (ie, no way to know from administrative data if these interventions remain in place).

DISCUSSION

In our single-center evaluation of 576 infants undergoing VFSS, the majority of infants shown to aspirate by VFSS did not experience subsequent ARIs requiring hospital care. Furthermore, interventions designed to mitigate swallowing problems were generally not associated with a decreased risk of future ARI. The results of this study raise important questions about assumptions regarding infants at risk of aspiration and the utility of VFSS testing and subsequent interventions.

Previous evaluations of the association between infant diagnoses and VFSS results have involved small numbers of children (and even smaller numbers of infants) and limited lists of diagnoses.[8,11,18] The present comprehensive approach identified cardiopulmonary comorbid conditions as risk factors for aspiration on VFSS, after adjusting for the presence of other CCCs. Although neurologic impairment, prematurity, and GERD are often assumed to be risk factors for aspiration, these conditions were not associated with an increased risk of abnormal VFSS results. Similarly, acute diagnoses in which a caregiver or provider perceived difficulty swallowing (eg, dysphagia or feeding problem) were not associated with abnormal VFSS results.

Trials examining thickened feedings in the setting of swallowing difficulties report conflicting results for reducing the future risk of ARI and have only been conducted in adult populations.[19–21] Even less is known about the effect of nasal tube feeding on the risk of ARI. With the exception of thickened feedings after a silent OPA test result, we did not find an association between thickened or nasal tube feedings and a decreased risk of ARI for infants with any VFSS result. An increased risk of ARI was found among infants with normal VFSS results who received thickened or nasal tube feedings, a finding that could be explained by uncontrolled confounding. For example, that 41% of infants with a normal VFSS received a feeding intervention suggests that the intervention may have been prescribed for indications besides an abnormal VFSS result, including the following: (1) diagnoses apart from

TABLE 3 Test Result, Recommended Interventions, and Subsequent ARIs

VFSS Result	Intervention					
	None		Thickening		Nasal Tube Feedings	
	HR	Person-Months	HR[a] (95% CI)	Person Months	HR[a] (95% CI)	Person-Months
Normal	Ref	6335	2.18 (1.69–2.81)*	2070	1.56 (1.18–2.07)*	1935
Intermediate	Ref	1001	1.30 (0.73–2.29)	1003	2.15 (0.75–6.18)	413
OPA						
Any	Ref	175	0.59 (0.35–1.02)	2213	0.80 (0.45–1.43)	1099
Thin	Ref	20	0.49 (0.16–1.42)	1679	0.47 (0.12–1.87)	670
Thick	Ref	155	0.40 (0.15–1.07)	534	0.63 (0.28–1.42)	429
Cough	Ref	26	1.31 (0.26–6.76)	1044	2.64 (0.53–13.18)	463
Silent	Ref	149	0.49 (0.26–0.90)*	1169	0.72 (0.35–1.48)	636

*P < .05. CI, confidence interval; HR, hazard ratio; Ref, reference.
[a] Analyzed by using shared frailty Cox regression with subsequent ARIs as outcome, adjusting for age at time of first VFSS and comorbid conditions.

swallowing problems, such as failure to thrive or oral aversion; (2) parent-reported patient swallowing symptoms; or (3) concerning swallowing findings observed on examination by the speech language pathologist not noted by the radiologist on the VFSS. Nevertheless, consideration must also be given to the possibility that swallowing interventions could increase the risk of ARI among infants without abnormalities detected by VFSS.

Despite ambiguity with regard to which infant characteristics warrant VFSS testing and unclear benefits to swallowing interventions, repeated testing and recommendations to alter feeding were common. Although treatment decisions can be affected by factors beyond VFSS results, the frequency of interventions and repeat testing among those with normal VFSS results is worrisome for unnecessary testing and radiation exposure. Future studies should further clarify the clinical significance of infant swallowing abnormalities detected by VFSS, and the possibility that certain swallowing abnormalities revealed by VFSS may be of limited clinical importance should be acknowledged. Given that some degree of aspiration has been shown in healthy adults,[22,23] a portion of swallowing abnormalities discovered by VFSS in infants may represent variations of normal.[24] Infant aspiration has been previously hypothesized to be an example of overdiagnosis: the diagnosis is accurate, but the infant does not benefit from the diagnosis and may even be harmed.[25]

Study limitations should be considered. This is a single-center study and the degree to which the present findings are generalizable is unknown. Although this is the largest cohort of infants evaluating an association between thickened or nasal tube feedings and ARI, it may be that a larger study could discern smaller, but statistically significant effect sizes for some of the comparisons. The measurement of intervention status was varied and incomplete. Nasal tube feedings were identified by manual chart review of notes from the speech language pathologist, but gastric tubes and fundoplication were identified through administrative data, limiting verification that the latter two interventions were placed for feeding problems specifically. Furthermore, adherence to recommended feeding regimens could not be assessed and receipt of outpatient services such as dysphagia therapy could not be quantified. Outcome ascertainment could bias our results to the null if infants with swallowing interventions were more likely than infants without swallowing interventions to receive care for an ARI at an Intermountain facility. Although this bias is possible, Intermountain Healthcare provides 82% of pediatric inpatient care in the state of Utah for the ARIs measured in the current study (E. Donnelly, personal communication, January 20, 2015) and 92% of patients in the present cohort had at least 1 visit to an Intermountain facility after their index VFSS. Although we attempted to adjust for important medical conditions increasing the risk of ARI, other confounding factors may be present that could not be accounted for in a retrospective analysis. For example, 2 patients may share the same neurologic comorbid label but have very different functional realities from the standpoint of tone, strength, and cognition.

CONCLUSIONS

In a retrospective cohort study in infants tested by VFSS, recommended changes to infant feeding and repeated VFSS testing were common, but interventions were generally not associated with a reduction in future ARIs. The degree to which infants are benefitting from diagnosis of and intervention for VFSS-detected abnormalities needs further investigation by multicenter and/or prospective studies.

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