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Vocal Fold Paralysis/Paresis as a Marker for Poor Swallowing Outcomes After Thoracic Surgery Procedures

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Abstract

(1) To examine the association between vocal fold paresis/paralysis (VFP) and poor swallowing outcomes in a thoracic surgery cohort at the population level, and (2) to assess utilization of ENT/speech-language pathology intervention in these cases. The National Inpatient Sample (NIS) represents a 20% stratified sample of discharges from US hospitals. Using ICD-9 codes, discharges undergoing general thoracic surgical procedures between 2008 and 2013 were identified in the NIS. Sub-cohorts of discharges with VFP and those who utilized ENT/SLP services were also identified. Weighted logistic regression models were used to compare binary outcomes such as dysphagia, aspiration pneumonia, and other complications; generalized linear models with generalized estimating equations (GEE) were used to compare total hospital costs and length of stay (LOS). We identified a weighted estimate of 673,940 discharges following general thoracic surgery procedures. The weighted frequency of VFP was 3738 (0.55%). Compared to those without VFP, patients who discharged with VFP had increased odds of dysphagia (6.56, 95% CI 5.07–8.47), aspiration pneumonia (2.54, 95% CI 1.74–3.70), post-operative tracheotomy (3.10, 95% CI 2.16–4.45), and gastrostomy tube requirement (2.46, 95% CI 1.66–3.64). Discharges with VFP also had a longer length of stay and total hospital costs. Of the discharges with VFP, 15.7% received ENT/SLP intervention. VFP after general thoracic procedures is associated with negative swallowing-related health outcomes and higher costs. Despite these negative impacts, most patients with VFP do not receive ENT/SLP intervention, identifying a potential opportunity for improving adverse swallowing-related outcomes.

Keywords Vocal fold paralysis · Esophagectomy · Database analysis · Speech-language pathology · Deglutition · Deglutition disorders

Introduction

Vocal fold paresis/paralysis (VFP) after thoracic procedures such as pneumectomy, lobectomy, and mediastinoscopy is a common adverse event with a reported rate of 6–31% [1–5]. VFP after thoracic surgery is a clinically significant complication that can result in morbidity that can impair a critical airway protection mechanism during swallowing with the potential for clinically significant oropharyngeal dysphagia. Aspiration has been identified in approximately 33–42% of individuals with VFP [6–9]. These impairments may result in patients requiring tracheostomy and/or gastrostomy tube placement to mitigate the risk of aspiration and to restore safe nutrition.

Otolaryngologists (ENT) and speech-language pathologists (SLP) can evaluate and provide therapies for VFP to limit morbidity. SLP providers may offer non-invasive

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alternative swallowing strategies and voice therapies. ENT surgeons can offer vocal fold augmentation to medialize a paretic vocal fold with improvement in swallowing-related outcomes [4–9].

We have previously reported on the VFP prevalence and ENT/SLP utilization rate in esophagectomy patients and found that ENT/SLP providers were under-utilized despite a significant rate of adverse events related to VFP [10]. Because patients undergoing thoracic procedures other than esophagectomy are also at risk for VFP and adverse swallowing-related outcomes, we sought to characterize VFP prevalence and ENT/SLP utilization in a general thoracic surgery cohort. The specific objectives of this study were: (1) to identify the prevalence of VFP and swallowing-related complications following thoracic procedures at the population level in the United States and (2) to characterize the involvement of ENT/SLP providers in managing these patients.

Methods

This study was reviewed by the Duke University Medical Center Institutional Review Board (IRB) and deemed exempt from formal review (Protocol # Pro00074265).

Study Population

A retrospective analysis of discharges following general thoracic procedures between 2008 and 2013 was performed using discharge data from the National Inpatient Sample (NIS), the largest publicly available all-payer inpatient health care database developed for the Healthcare Cost and Utilization Project (HCUP) by the Agency for Healthcare Research and Quality (AHRQ). The NIS database is a national claims database that represents a 20% stratified sample of discharges from hospitals in the United States. The International Classification of Disease, Ninth Revision Clinical Modification (ICD-9-CM) procedure codes were used to identify relevant hospitalizations for general thoracic procedures that could pose a risk to the recurrent laryngeal nerves based on the literature [1–5] and in consultation with practicing thoracic surgeons: [pneumonectomy: 32.50, 32.5, 32.59; lobectomy: 32.49, 32.4, 32.41; segmentectomy: 32.30, 32.39, 32.3; lung biopsy: 33.28, 33.20; mediastinal: 34.22, 34.26, 34.3; other thoracic procedures: 32.6 (radical dissection of thoracic structures), 32.20 (thoracoscopic excision of lesion or tissue of lung), 32.22 (lung volume reduction surgery), 32.2 (local excision or destruction of lesion or tissue of lung), 32.9 (other excision of lung), 34.4 (excision or destruction of lesion of chest wall), 34.5 (pleurectomy), 34.59 (other excision of pleura), 32.1 (other excision

of bronchus), 32.29 (other local excision or destruction of lesion or tissue of lung)].

Medical/surgical complications were collected based on ICD-9-CM diagnosis codes consistent with prior publications using NIS [11]. The specific medical and surgical complications and related codes are listed in Table 1. Discharge demographics (age, gender, race), hospital characteristics (teaching status, bed size), geographic region (northeast, Midwest, south, west), and insurance (Medicare, Medicaid, private, self-pay) were also recorded (Table 2). Urgent admission based on admission through the emergency department (ED) was included in the model as patients with ED admission may differ from non-ED admissions with regard to different disease severity or access to care. The 29 AHRQ-identified comorbidities of the NIS coexisting medical conditions were used to calculate the Elixhauser-based comorbidity score [12]. We further identified sub-cohorts of general thoracic discharges with VFP (ICD-9-CM diagnosis codes 478.30, 478.31, 478.32, 478.33, 478.34) and those who received ENT/SLP services (ICD-9-CM procedure codes: vocal fold injection 31.0; other operations larynx 31.98; speech/dysphagia therapy 93.72, 93.74, 93.75).

Outcomes

In discharges following the selected general thoracic operations, the primary outcome was the diagnosis of VFP. Secondary outcomes included diagnosis of dysphagia, diagnosis of aspiration pneumonia, diagnosis of dysphonia, tracheostomy placement, the need for gastrostomy, and length of stay (LOS) from general thoracic procedure to discharge, in-hospital death and total hospital encounter costs (ICD-9-CM codes in Table 1). Hospital-related charges for each hospital discharge were converted to cost estimates by multiplying total charges with the appropriate cost-to-charge ratios from the HCUP Cost-to-Charge Ratio Files. All costs were then adjusted for inflation based on US Bureau of Labor Statistics indices to 2013 USD [13]. Due to the redesign of the NIS database in 2012, national cost estimates were obtained using revised NIS Trend Weights Files to reweight all discharges. Discharges with extreme LOS or cost (less than 1% or greater than 99%) were excluded from LOS or cost analyses. Within the sub-cohort of general thoracic procedure discharges with VFP, the outcome of interest was the utilization of ENT/SLP services.

Statistical Analyses

To account for stratification, clustering, and unequal weighting of the NIS survey design, discharge trend weights, NIS hospital number, and stratum used to sample hospital were utilized to generate nationally representative estimates. As we analyzed multiple years of NIS data, year was added as

Table 1 ICD-9-CM diagnosis or procedure codes for complications and procedures

Variable	ICD-9-CM codes
Aspiration pneumonia	507, 507.0
Dysphagia	787.2, 787.20, 787.21, 787.22, 787.23, 787.24, 787.29
Tracheostomy (procedure)	31.1, 31.2, 31.29, V440, V550
Gastrostomy (procedure)	V551, V441, 93.36, 43.1, 43.11, 43.19, 97.02
Lung cancer	197.0, 197.1, 197.2, 197.3, 196.1, V10.11, 162, 162.0, 162.2, 162.3, 162.4, 162.4, 162.5, 162.8, 162.9, 163, 163.0, 163.1, 163.8, 163.9
Dysphonia or voice disturbance	784.4, 784.40, 784.41, 784.42, 784.49
Medical complications	
Acute cardiac event	410, 4100, 41000, 41001, 41002, 4101, 41010, 41011, 41012, 4102, 41020, 41021, 41022, 4103, 41030,41031, 41032, 4104, 41040, 41041, 41042, 4105, 41050, 41051, 41052, 4106, 41060, 41061, 4107, 41070, 41071, 41072, 4108, 41080, 41081, 41082, 4109, 41090, 41091, 41092, 4111, 4118, 4150, 4200, 4209, 4209, 4210, 4211, 4219, 4220, 4229, 4270, 4271, 4272, 4273, 42731, 42732, 4274, 42741, 42742, 4275, 428, 4280, 4281, 4282, 42820, 42821, 42822, 42823, 4283, 42830, 42831, 42832, 42833, 4284, 42840, 42841, 42842, 42843, 4289
Acute pulmonary edema/failure	518.4, 518.81, 518.82, 518.84
Acute cerebrovascular event	997.00, 997.01, 997.02, 997.09
Acute renal failure	584.5, 584.6, 584.7, 584.8, 584.9
Acute hepatic failure	570
Sepsis	995.9, 038.0, 038.1, 038.10, 038.11, 038.12, 038.19, 038.2, 038.4, 038.40, 038.41, 038.42, 038.43, 038.44, 038.49, 999.3
Urinary tract infection	599.0, 996.64, 996.31, V13.02
Pneumonia/infectious pneumonia	480, 480.0, 480.1, 480.2, 480.3, 480.8, 480.9, 481, 482, 482.0, 482.1, 482.3, 482.30, 482.31, 482.32, 482.39, 482.40, 482.41, 482.42, 482.49, 482.8, 482.81, 482,82, 482.83, 482.84, 482.89, 482.9, 483, 483.1, 483.8, 484, 484.1, 484.3, 484.5, 484.6, 484.7, 484.8, 485, 487.0, 997.31, V12.61
Surgical complications	
Shock	998.00, 998.01, 998.02, 998.09
Hemorrhage, hematoma, or seroma	998.1, 998.11, 998.12, 998.13
Accidental perforation or laceration of blood vessel, nerve, or organ	998.2
Wound dehiscence	998.3, 998.30, 998.31, 998.32, 998.33
Foreign body	998.4
Post-operative infection	998.5, 998.51, 998.59
Post-operative fistula	998.6
Nonhealing surgical wound	998.83
Other unspecified procedural complications	998.8, 998.81, 998.89, 998.9

a stratification variable. We adopted the analytic procedures and weighting strategy suggested by AHRQ for analyzing subpopulations and providing national estimates. Continuous variables were summarized with mean, standard errors, median, interquartile ranges and range in the weighted sample, and compared using Wald F tests. The Taylor series linearization method was applied to estimate standard errors. Categorical variables were summarized with weighted frequency and percentages, and compared by second-order Rao–Scott Chi Squared tests.

For all multivariable models, backward variable selection with Bayesian Information Criterion (BIC) was adopted on all candidate confounders, except that the key predictor was not a candidate for removal. The primary outcome, diagnosis of VFP, and other binary outcomes (dysphagia, pneumonia, G-tube placement, tracheotomy, length of stay, total hospital encounter costs, and in-hospital death) were modeled with weighted logistic regression models and adjusted odds ratios with 95% confidence intervals (CI) were reported. To account for clustering of the data, a GEE approach using generalized linear models with a log-link function was employed to examine the association of diagnosis of VFP with LOS and total costs. The level of significance was set to 0.05 for all analyses. All analyses were performed in SAS 9.4 (SAS Institute, Cary, NC).

Table 2 Summary statistics of demographic characteristics and outcomes with univariate analysis stratified by vocal fold paralysis/paresis in NIS adult general thoracic patient cohort

Variable	Level	No vocal fold paralysis/paresis weight $N=670,203$	Vocal fold paralysis/paresis weighted $N=3738$	Total weighted $N=673,940$	p value
Procedure context variables					
Urgent admission					**< 0.0001**
	Yes	113,170 (16.89%)	469 (12.54%)	113,639 (16.86%)	
Age					0.8606
	<65	356,096 (53.16%)	1927 (51.56%)	358,024 (53.15%)	
	65–79	263,652 (39.36%)	1503 (40.21%)	265,155 (39.36%)	
	≥80	50,134 (7.48%)	307 (8.22%)	50,441 (7.49%)	
Race					0.3655
	White	465,053 (69.39%)	2547 (68.15%)	467,601 (69.38%)	
	Black	59,751 (8.92%)	337 (9.02%)	60,088 (8.92%)	
	Other	70,594 (10.53%)	492 (13.15%)	71,085 (10.55%)	
	Unknown	74,804 (11.16%)	362 (9.67%)	75,166 (11.15%)	
Sex					**0.0241**
	Male	346,346 (51.74%)	2082 (55.71%)	348,429 (51.76%)	
	Female	323,077 (48.26%)	1655 (44.29%)	324,732 (48.24%)	
Primary expected payer					0.2147
	Medicare	315,233 (47.11%)	1822 (48.82%)	317,055 (47.12%)	
	Medicaid	57,507 (8.59%)	362 (9.69%)	57,869 (8.6%)	
	Private	253,388 (37.87%)	1388 (37.19%)	254,776 (37.87%)	
	Other	42,978 (6.42%)	161 (4.3%)	43,138 (6.41%)	
Hospital bed size					**0.0082**
	Small	51,940 (7.81%)	217 (5.85%)	52,157 (7.8%)	
	Medium	132,113 (19.87%)	627 (16.89%)	132,740 (19.85%)	
	Large	480,852 (72.32%)	2869 (77.26%)	483,721 (72.35%)	
Teaching status of hospital					**< 0.0001**
	Teaching	419,960 (63.16%)	2824 (76.06%)	422,784 (63.23%)	
Region of hospital					0.5823
	Northeast	151,738 (22.64%)	1045 (27.97%)	152,784 (22.67%)	
	Midwest	156,310 (23.32%)	838 (22.42%)	157,148 (23.32%)	
	South	244,759 (36.52%)	1151 (30.8%)	245,910 (36.49%)	
	West	117,396 (17.52%)	703 (18.82%)	118,099 (17.52%)	
Elixhauser comorbidity index (29 comorbidities)					**< 0.0001**
	Mean (SE)	5.7 (0.05)	9.68 (0.42)	5.72 (0.05)	
Pre-operative lung cancer diagnosis					**< 0.0001**
	Yes	354,440 (52.89%)	2708 (72.46%)	357,149 (52.99%)	
Post-operative complications					
Number of medical complications					**< 0.0001**
	Mean (SE)	0.44 (0)	0.56 (0.03)	0.44 (0)	
Number of Surgical complications					**< 0.0001**
	Mean (SE)	0.07 (0)	0.12 (0.01)	0.07 (0)	
Dysphagia					**< 0.0001**
	Yes	10,395 (1.55%)	576 (15.41%)	10,971 (1.63%)	
Aspiration pneumonia					**< 0.0001**
	Yes	8364 (1.25%)	179 (4.79%)	8543 (1.27%)	

Table 2 (continued)

Variable	Level	No vocal fold paralysis/paresis weight $N=670,203$	Vocal fold paralysis/paresis weighted $N=3738$	Total weighted $N=673,940$	*p* value
Dysphonia/voice disturbance					**< 0.0001**
	Yes	1411 (0.21%)	423 (11.32%)	1834 (0.27%)	
Thoracic procedure types					
Pneumonectomy					**< 0.0001**
	Yes	17,161 (2.56%)	632 (16.91%)	17,793 (2.64%)	
Lobectomy					**0.0026**
	Yes	205,620 (30.68%)	952 (25.46%)	206,571 (30.65%)	
Segmentectomy					0.1489
	Yes	42,775 (6.38%)	191 (5.11%)	42,966 (6.38%)	
Lung biopsy					0.0808
	Yes	75,230 (11.22%)	341 (9.13%)	75,571 (11.21%)	
Mediastinal					**< 0.0001**
	Yes	94,436 (14.09%)	1388 (37.14%)	95,824 (14.22%)	
Other thoracic procedure					**< 0.0001**
	Yes	318,884 (47.58%)	1027 (27.47%)	319,911 (47.47%)	
Revision thoracic procedure					**< 0.0001**
	Yes	101,206 (15.1%)	828 (22.16%)	102,034 (15.14%)	
Post-operative interventions needed					
Gastrostomy					**< 0.0001**
	Yes	8039 (1.2%)	245 (6.55%)	8284 (1.23%)	
Tracheostomy					**< 0.0001**
	Yes	13,782 (2.06%)	305 (8.16%)	14,087 (2.09%)	
ENT/SLP					**< 0.0001**
	Yes	263 (0.04%)	587 (15.7%)	850 (0.13%)	
Encounter outcomes					
Adjusted total costs to 2013 (USD)					**< 0.0001**
	Median (Q1, Q3)	$18,027.56 (12,279.16, 28,292.3)	$27,515.39 (17,132.03, 47,853.0)	$18,060.4 (12,291.08, 28,373.04)	
Length of stay from thoracic procedure to discharge (Days)					**< 0.0001**
	Median (Q1, Q3)	4.21 (2.37,6.99)	6.42 (3.6,11.68)	4.22 (2.37,7.01)	
In-hospital death					0.9408
	Yes	20,941 (3.13%)	119 (3.17%)	21,060 (3.13%)	

All values were estimated to yield national representative estimates for the U.S. population. Sum of sample sizes across categories may not equal the total weighted sum due to missing values. Outliers of total costs and length of stay were removed before summary. *p* values were calculated using SAS PROC SURVEYFREQ (second-order Rao–Scott Chi Squared test) for categorical variables, and PROC SURVEYREG (Wald *F* test) for continuous variables, which took the complex survey design into consideration

Significant associations bolded for emphasis

Results

Predictors of VFP in General Thoracic Cohort

There were 152,096 raw discharges in the NIS general thoracic cohort, representing a weighted estimate of 673,940 discharges. The weighted frequency of VFP was 3738 (0.55%), and no VFP was diagnosed in 670,203 (99.45%). In univariate analyses, the distribution of all covariates in the general thoracic VFP cohort were assessed (Table 2). In univariate analysis, a higher prevalence of VFP was associated with male gender, large

bed-size hospital, teaching hospital, higher comorbidity score, medical and surgical complications, dysphagia, aspiration pneumonia, dysphonia/voice disturbance, lung cancer, pneumonectomy, mediastinal, revision thoracic procedure, gastrostomy, and tracheostomy. Urgent admission, lobectomy and other thoracic procedures were associated with a lower prevalence of VFP. In the backward selection, multivariate weighted logistic regression model, larger hospital size, teaching hospital, higher comorbidity score, lung cancer diagnosis, pneumonectomy, mediastinal procedures and surgical complications were associated with higher odds of VFP. In contrast, discharges treated at hospitals located in the south compared to the northeast, urgent admission, lobectomy, segmentectomy and other thoracic procedures were associated with lower odds of VFP (Table 3).

Impact of VFP in the General Thoracic Procedure Cohort

Swallowing-related complications were more common in discharges with VFP after thoracic procedures compared to discharges without VFP. Compared to discharges without VFP, those with VFP had roughly 10 times the rate of dysphagia, 3.8 times the rate of aspiration pneumonia, 5.5 times as many gastrostomy tubes, and 4 times the tracheotomy rate (Table 2). After adjustment for potential

Table 3 Backward selection weighted logistic regression parameter estimates of vocal fold paralysis/paresis in general thoracic cohort

Parameter	Level	Adjusted OR (95% CI)	p value
Urgent admission	**Yes**	**0.75 (0.59, 0.95)**	**0.0183**
Hospital bed size	Medium	1.25 (0.89, 1.75)	0.2027
	Large	**1.53 (1.14, 2.06)**	**0.0051**
	Small	Reference	N/A
Hospital type	Teaching	**1.88 (1.55, 2.29)**	**< 0.0001**
Hospital region	West	0.99 (0.73, 1.34)	0.9319
	South	**0.73 (0.58, 0.93)**	**0.0102**
	Midwest	0.80 (0.64, 1.00)	0.0546
	Northeast	Reference	N/A
Comorbidity index		**1.03 (1.03, 1.04)**	**< 0.0001**
Lung cancer Dx.	Yes	**1.96 (1.61, 2.34)**	**< 0.0001**
Pneumonectomy	Yes	**4.03 (3.09, 5.25)**	**< 0.0001**
Lobectomy	Yes	**0.63 (0.50, 0.80)**	**0.0002**
Segmentectomy	Yes	**0.69 (0.48, 1.01)**	**0.0532**
Mediastinal	Yes	**2.90 (2.42, 3.47)**	**< 0.0001**
Other thoracic procedure	Yes	**0.62 (0.49, 0.78)**	**< 0.0001**
No. surg complication		**1.25 (1.04, 1.50)**	**0.0156**

Significant associations bolded for emphasis

OR odds ratio, *CI* confidence interval, *Dx* diagnosis, *Surg* surgical

confounders, VFP was associated with increased odds of dysphagia, aspiration pneumonia, gastrostomy tubes, and tracheotomy (Table 4).

VFP also was associated with hospitalization outcomes. The median LOS from thoracic procedure to discharge for the overall cohort was 4.2 days (interquartile range [IQR] 2.4 to 7). Discharges with VFP had a median length of stay of 6.4 days (IQR 3.6 to 11.7), which is longer than discharges without VFP (median: 4.2, IQR 2.4 to 7, p value < 0.0001). Total hospital costs were higher in those with VFP than those without VFP [median cost: $27,515 (IQR $12,279 to $28,292) vs. $18,028 (IQR $17,132 to $47,853), p value < 0.0001]. In-hospital mortality rates were similar between discharges with VFP and without VFP (3.2% vs. 3.1%, p value = 0.9408). After adjustment of potential confounders, VFP was associated with longer LOS and 22% higher costs (Table 4).

ENT/SLP Utilization in General Thoracic Procedure Discharges with VFP

There were 772 discharges with VFP in the general thoracic cohort, representing a weighted estimate of 3738 discharges (Table 5). The weighted frequency of ENT/SLP services was 572 (18.1%) and no ENT/SLP services were provided in 2582 (81.9%). In univariate analysis, large bed size hospital, teaching hospital, northeast hospital, higher comorbidity score, lung cancer, pneumonectomy and revision thoracic procedures were associated with an increased odds of ENT/SLP service utilization. Urgent admission was associated with decreased odds of ENT/SLP intervention (Table 5). Discharges with ENT/SLP intervention had prolonged LOS (median: 8.0 days, IQR 5.8 to 12.5 days) compared to discharges without ENT/SLP intervention (median: 6.0 days, IQR 3.3 to 11.3 days, p value = 0.0328). Discharges with ENT/SLP intervention had significantly higher cost (median: $36,289, IQR $26,217 to $70,251) than discharges without ENT/SLP intervention (median: $25,578, IQR $15,810 to $43,891, p value = 0.0013).

In the backward selection, multivariate weighted logistic regression model, large bed-size hospital, northeast hospital, higher comorbidity score, pneumonectomy and lobectomy were associated with increased odds of ENT/SLP service utilization (Table 6).

Discussion

Understanding the implications of VFP in patients having general thoracic operations is an important component of patient care. VFP after general thoracic operations have a reported incidence of 6–31% in contrast to the 0.55% observed in this inpatient sample [1–5, 14].

Table 4 Parameter estimates of GEE generalized linear model and weighted logistic regressions of length of stay from general thoracic procedure to discharge, total hospital cost, in-hospital death, dysphagia, aspiration pneumonia, tracheotomy and gastrostomy tube placement

Weighted logistic regression—Dysphagia[a]		
Parameter	Adjusted OR (95% CI)	*p* value
Vocal fold paralysis/paresis	6.56 (5.07, 8.47)	< 0.0001
Weighted logistic regression—aspiration pneumonia[b]		
Parameter	Adjusted OR (95% CI)	*p* value
Vocal fold paralysis/paresis	2.54 (1.74, 3.70)	< 0.0001
Weighted logistic regression—tracheotomy[c]		
Parameter	Adjusted OR (95% CI)	*p* value
Vocal fold paralysis/paresis	3.10 (2.16, 4.45)	< 0.0001
Weighted logistic regression—gastrostomy tube placement[d]		
Parameter	Adjusted OR (95% CI)	*p* value
Vocal fold paralysis/paresis	2.46 (1.66, 3.64)	< 0.0001
GEE regression with log link—length of stay from surgery to discharge[e,f]		
Parameter	Adjusted length of stay ratio (95% CI)	*p* value
Vocal fold paralysis/paresis	1.25 (1.18, 1.33)	< 0.0001
GEE regression with log link—total hospital encounter cost[g,h]		
Parameter	Adjusted cost ratio (95% CI)	*p* value
Vocal fold paralysis/paresis	1.22 (1.16, 1.29)	< 0.0001
Weighted logistic regression—in-hospital death[i]		
Parameter	Adjusted OR (95% CI)	*p* value
Vocal fold paralysis/paresis	0.66 (0.41, 1.05)	0.081

[a]Controlled for: urgent admission, age, sex, primary payer, hospital teaching status, hospital region, comorbidity index, revision thoracic procedure, lung cancer, lobectomy, mediastinal, other thoracic procedure, aspiration pneumonia, dysphonia, medical complication, surgical complication

[b]Controlled for: urgent admission, age, sex, race, primary payer, hospital bed size, hospital teaching status, hospital region, comorbidity index, lung cancer, lobectomy, segmentectomy, dysphagia, medical complication, surgical complication

[c]Controlled for: urgent admission, age, race, primary payer, hospital bed size, hospital teaching status, hospital region, comorbidity index, revision thoracic procedure, lung cancer, pneumonectomy, lobectomy, segmentectomy, lung biopsy, mediastinal, aspiration pneumonia, dysphagia, medical complication, surgical complication

[d]Controlled for: urgent admission, sex, primary payer, hospital teaching status, comorbidity index, lung cancer, pneumonectomy, lobectomy, aspiration pneumonia, dysphagia, medical complication, surgical complication

[e]Controlled for: urgent admission, age, sex, race, primary payer, hospital bed size, hospital teaching status, hospital region, comorbidity index, lung cancer, revision thoracic procedure, pneumonectomy, lobectomy, segmentectomy, mediastinal, other thoracic procedure, dysphagia, aspiration pneumonia, dysphonia, medical complication, surgical complication

[f]Adjusted length of stay ratio gives the ratio of expected length of stay of vocal fold paralysis/paresis group with respect to those without (reference group). An adjusted length of stay ratio of 1.25 means that the expected length of stay from general thoracic procedure to discharge of vocal fold paralysis group is 125% of the no vocal fold paralysis group

[g]Controlled for: urgent admission, age, sex, race, primary payer, hospital teaching status, hospital region, comorbidity index, lung cancer, revision thoracic procedure, pneumonectomy, lobectomy, segmentectomy, lung biopsy, mediastinal, dysphagia, aspiration pneumonia, dysphonia, medical complication, surgical complication

[h]Adjusted cost ratio gives the ratio of expected total cost of vocal fold paralysis/paresis group with respect to those without (reference group). An adjusted cost ratio of 1.22 means that the expected cost of vocal fold paralysis group is 122% of the no vocal fold paralysis group

[i]Controlled for: urgent admission, age, sex, race, primary payer, hospital region, comorbidity index, lung cancer, revision thoracic procedure, pneumonectomy, lung biopsy, mediastinal, dysphagia, aspiration pneumonia, medical complication, surgical complication

Table 5 Summary statistics of demographic characteristics and outcomes with univariate analysis stratified by utilization of OHN/SLP services in the NIS adult general thoracic discharge cohort

Variable	Level	No OHN/SLP weighted $N=3151$	OHN/SLP weighted $N=587$	Total weighted $N=3738$	p value
Procedure context variables					
Urgent/emergent admission					**0.0205**
	Yes	435 (13.8%)	34 (5.8%)	469 (12.54%)	
Age					0.2435
	≥65	1559 (49.48%)	251 (42.85%)	1810 (48.44%)	
Race					0.1263
	White	2100 (74.35%)	448 (81.11%)	2547 (75.45%)	
	Other	724 (25.65%)	104 (18.89%)	829 (24.55%)	
Sex					0.3328
	Male	1733 (54.99%)	350 (59.61%)	2082 (55.71%)	
	Female	1418 (45.01%)	237 (40.39%)	1655 (44.29%)	
Primary expected payer					0.2071
	Medicare	1575 (50.09%)	247 (42.03%)	1822 (48.82%)	
	Medicaid	302 (9.61%)	59 (10.13%)	362 (9.69%)	
	Other	1267 (40.3%)	281 (47.84%)	1548 (41.49%)	
Hospital bed size					**0.0074**
	Small/medium	788 (25.2%)	56 (9.62%)	844 (22.74%)	
	Large	2339 (74.8%)	530 (90.38%)	2869 (77.26%)	
Teaching status of hospital					**0.0052**
	Teaching	2298 (73.5%)	526 (89.67%)	2824 (76.06%)	
Region of hospital					**0.0348**
	Northeast	763 (24.22%)	282 (48.11%)	1045 (27.97%)	
	Midwest	733 (24.22%)	105 (17.92%)	838 (22.42%)	
	South	1024 (32.51%)	127 (21.65%)	1151 (30.8%)	
	West	631 (20.02%)	72 (12.33%)	703 (18.82%)	
Elixhauser comorbidity index (29 comorbidities)					**0.0184**
	Mean (SE)	9.22 (0.4)	12.16 (1.22)	9.68 (0.42)	
Pre-operative lung cancer diagnosis					**0.0024**
	Yes	2210 (70.14%)	498 (84.87%)	2708 (72.46%)	
Post-operative complications					
Number of medical complications					0.1210
	Mean (SE)	0.54 (0.03)	0.65 (0.07)	0.56 (0.03)	
Number of surgical complications					0.1067
Mean (SE)		0.11 (0.01)	0.18 (0.04)	0.12 (0.01)	
Aspiration pneumonia					0.3814
	Yes	160 (5.07%)	19 (3.3%)	179 (4.79%)	
Dysphagia					0.3782
	Yes	468 (14.86%)	108 (18.36%)	576 (15.41%)	
Dysphonia/voice disturbance					0.7630
	Yes	352 (11.16%)	71 (12.17%)	423 (11.32%)	
Thoracic procedure types					
Pneumonectomy					**<0.0001**
	Yes	364 (11.55%)	268 (45.7%)	632 (16.91%)	
Lobectomy					0.3993
	Yes	781 (24.79%)	170 (29.06%)	952 (25.46%)	
Segmentectomy					0.2968
	Yes	172 (5.46%)	19 (3.23%)	191 (5.11%)	
Mediastinal					0.0896
	Yes	1214 (38.52%)	174 (29.72%)	1388 (37.14%)	

Table 5 (continued)

Variable	Level	No OHN/SLP weighted $N=3151$	OHN/SLP weighted $N=587$	Total weighted $N=3738$	p value
Other thoracic procedures					0.2506
Yes		893 (28.35%)	134 (22.76%)	1027 (27.47%)	
Revision thoracic procedures					**0.0029**
Yes		631 (20.03%)	197 (33.57%)	828 (22.16%)	
Post-operative interventions needed					
Gastrostomy					0.7963
Yes		203 (6.43%)	42 (7.21%)	245 (6.55%)	
Tracheostomy					0.1658
Yes		275 (8.73%)	30 (5.11%)	305 (8.16%)	
Encounter outcomes					
Adjusted total costs to 2013 USD					**0.0013**
Median (Q1, Q3)		25,578 (15,810, 43,891)	36,289 (26,217, 70,251)	27,518 (17,542, 47,141)	
Length of stay from thoracic procedure to discharge					**0.0328**
Median (Q1, Q3)		6.00 (3.31, 11.26)	7.99 (5.83, 12.53)	6.44 (3.69, 11.56)	

All values were estimated to yield nationally representative estimates for the U.S. population. Sum of sample sizes across categories may not equal the total weighted sum due to missing values. Outliers of total costs and length of stay were removed before summary. p values were calculated using SAS PROC SURVEYFREQ (second-order Rao–Scott Chi Squared test) for categorical variables, and PROC SURVEYREG (Wald F test) for continuous variables, which took the complex survey design into consideration

Significant associations bolded for emphasis

Table 6 Backward selection weighted logistic regression parameter estimates of OHN/SLP service utilization in general thoracic cohort with vocal fold paralysis/paresis

Parameter	Level	Adjusted OR (95% CI)	p value
Sex	Male	1.29 (0.82, 2.05)	0.2709
	Female	Reference	N/A
Primary expected payer	Medicaid	1.05 (0.46, 2.41)	0.9055
	Other	1.33 (0.77, 2.30)	0.3072
	Medicare	Reference	N/A
Hospital bed size	**Large**	**2.74 (1.20, 6.28)**	**0.0169**
	Small/medium	Reference	N/A
Hospital type	Teaching	2.32 (0.92, 5.84)	0.0739
	Non-teaching	Reference	N/A
Hospital region	West	**0.41 (0.21, 0.79)**	**0.0074**
	South	**0.44 (0.22, 0.85)**	**0.0155**
	Midwest	**0.47 (0.23, 0.96)**	**0.0381**
	Northeast	Reference	N/A
Comorbidity index		**1.02 (1.00, 1.05)**	**0.0386**
Pneumonectomy	Yes	**9.68 (5.13, 18.28)**	**< 0.0001**
Lobectomy	Yes	**2.77 (1.51, 5.06)**	**0.0009**
Other thoracic procedure	Yes	1.48 (0.84, 2.59)	0.1714
No. surg complications		1.42 (0.74, 2.71)	0.2934

Significant associations bolded for emphasis

OR odds ratio, *CI* confidence interval, *Surg* surgical

Methodological differences across studies likely explain the differences in VFP prevalence rates. For example, in the present study, the frequency of VFP was determined by ICD codes that were used for billing and administrative purposes, whereas other studies prospectively used laryngoscopy to diagnose VFP. In addition, our cohort is likely more heterogeneous and contains more types of operations beyond the predominant lobectomy and pneumonectomy in previous reports [1–4]. Pneumonectomy and mediastinal surgery were independent risk factors

associated with post-operative VFP (Table 3), consistent with other reports [3]. This is most likely due to the proximity of the recurrent laryngeal nerve to other anatomic structures being manipulated, resected or divided, such as the thymus and main pulmonary vasculature. Common mechanisms of injury include cautery/heat, traction or transection [15]. Despite the varied prevalence rates, VFP is an adverse outcome with serious potential sequelae.

In this national population level cohort, VFP was associated with adverse swallowing outcomes. We found that VFP identified after general thoracic procedures was linked to increased odds of dysphagia, aspiration pneumonia, gastrostomy tube placement, and tracheotomy placement. Moreover, discharges with VFP had significantly longer hospital stays and higher cost of care. Despite controlling for multiple factors such as comorbidity and medical and surgical complications, other unmeasured factors, such as pre-operative VFP or dysphagia or the lung cancer stage, could also contribute to these adverse outcomes. However, our data suggest that VFP post-operatively identified is an indicator of poor swallowing-related outcomes, which may be particularly germane for patients undergoing thoracic procedures. In addition to impaired airway protection during swallowing, VFP also impairs the ability to cough and clear secretions. A previous population-based study found that VFP was an independent risk factor for pneumonia, consistent with our findings [16]. Oropharyngeal dysphagia has been linked to dramatically increased morbidity after lobectomy and lung transplantation [3, 17]. Methods for identifying patients with VFP, such as training care teams to recognize dysphonia and screen for clinical signs of dysphagia after thoracic surgery, may lead to earlier evaluation and treatment and are worthy of investigation. Zuniga et al. published data showing that Eating Assessment Tool-10 (EAT-10) scores > 9 in patients VFP suggest 5× greater risk of aspiration and this might be a useful instrument to help guide clinical decision-making [18].

ENT and SLP providers can evaluate and mitigate the risk of adverse outcomes of VFP-associated oropharyngeal dysphagia. Patients with VFP may benefit from SLP interventions to identify swallowing and airway protection deficits and provide non-invasive therapies to augment swallowing function such as alternative swallowing strategies (e.g., chin-tuck, head rotation) [19, 20]. ENT surgeons offer procedures bedside and operating room to mitigate dysphagia and dysphonia from VFP via surgical procedures to temporarily or permanently medialize the affected vocal fold (e.g., laryngoplasty) [21, 22]. Early medialization of VFP after thoracic procedures confers many benefits including decreased rates of pulmonary infections/aspiration pneumonia, decreased number of post-operative bronchoscopies, decreased length of stay, decreased dysphagia, quicker resumption of oral diet, and improved vocal quality [14, 23–25]. Yet, medialization procedures improve airway protection and dysphagia symptoms in many, but not all VFP patients; those who continue to demonstrate aspiration may demonstrate altered biomechanical swallowing features aside from reduced glottal closure that require compensatory and/or exercise-based treatments [6, 8, 26]. Thus, a team approach with SLP and ENT intervention is needed to optimize swallowing function [26, 27]. Shared decision-making strategies are needed to inform patients and family members about swallowing outcomes and determine best treatment options.

While the reasons for obtaining or not obtaining ENT/SLP evaluation and treatment cannot be discerned, varied utilization was noted. Approximately, only 1 in 6 cases with VFP had ENT/SLP evaluation and treatment. Discharges from a large bed-size hospital, northeast location, higher Elixhauser comorbidity scores, and pneumonectomy and lobectomy procedures were associated with an increased rate of ENT/SLP service utilization. The NIS database does not provide enough granularity to further explore the contexts underlying increased ENT/SLP utilization, but we can speculate that larger hospitals dealing with 'sicker' patients may have more robust ENT/SLP services available for consultation. Additionally, physician and nursing staff training and physician experience and practice pattern preferences could influence ENT/SLP utilization. These findings present avenues for future research to investigate the driving forces behind locoregional differences in ENT/SLP care as a means for identifying service gaps and opportunities for quality improvement.

In addition to the swallowing-related morbidity associated with VFP after general thoracic procedures, VFP was associated with increased hospital LOS and overall hospital costs (Table 4). To our knowledge, no prior analyses have reported VFP associated with increased LOS/hospital cost after general thoracic surgery. Increased hospital costs are likely a function of hospital LOS and interventions/procedures for the VFP and adverse swallowing outcomes.

Methodologic limitations standard to this type of research must be acknowledged. Our analyses rely upon an administrative dataset that is subject to coding and interpretation error. There is potential for misclassification bias regarding diagnostic and procedural codes. Potentially, VFP discharges could have been evaluated by ENT/SLP, but a billable encounter may not have occurred or a consult only without intervention (which could not be discerned in the dataset) may have occurred, leading to an underestimate of our utilization rate. Additionally, the NIS database does not include outpatient follow-up, during which time additional diagnoses of VFP not identified during the inpatient stay could be made. Lastly, the database does not provide variables that account for pre-operative VFP that existed prior to surgical intervention. Discharges underwent

invasive thoracic procedures could have had a pathologic process that impaired VFP function unrelated to iatrogenic injury. Moreover, the database does not distinguish upper versus lower lung lobectomy procedures that confer different risks of iatrogenic recurrent laryngeal nerve injury. Nonetheless, our investigation provides insights about VFP and adverse swallowing-related outcomes and practice patterns regarding ENT/SLP utilization.

Conclusion

VFP identified after general thoracic procedures is associated with increased odds of dysphagia, aspiration pneumonia, gastrostomy tubes, and tracheotomy. VFP discharges also had a longer median LOS and total hospital costs. Despite these adverse outcomes, ENT/SLP intervention occurred in 15.7% of VFP discharges. The low rate of ENT/SLP intervention in light of these outcomes is concerning as ENT/SLP providers may be able to offer effective treatments to mitigate the adverse swallowing outcomes associated with VFP. Future investigations focusing on the variability in ENT/SLP practice patterns and the development of multi-disciplinary care programs to identify and facilitate patient-focused treatment for VFP after thoracic procedures are needed.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflicts related to this manuscript.

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