Regression splines and multi-group propensity score weighting for the study of surgical volume-outcome relationships: neonatal esophageal atresia/tracheoesophageal fistula as an example

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ABSTRACT

Studies of associations between surgeon or hospital operative volumes and postoperative outcomes often simply select volume thresholds to ensure an equal number of patients across categories. Such studies also rarely define volume as time-varying and seldom evaluate the interaction between surgeon and hospital volumes. We demonstrate the combined use of regression splines to identify volume thresholds and multi-group propensity score weighting to estimate the effects of both surgeon and hospital volumes on surgical outcomes. We studied infants who underwent surgery for esophageal atresia/tracheoesophageal fistula (EA/TEF), a rare congenital anomaly, at US children's hospitals in 2000-2015. We defined surgeon and hospital operative volumes as the number of patients receiving this surgery from the provider in the previous 365 days. We identified no volume thresholds in the relationships between either surgeon or hospital volume and postsurgical outcomes among EA/TEF patients. Furthermore, outcomes did not differ across four groups defined by the intersection of surgeon and hospital volumes dichotomized at their upper tertiles.

Keywords: regression splines; inverse probability of treatment weighting using the propensity score; surgical volume-outcomes analysis

1. INTRODUCTION

Esophageal atresia with or without tracheoesophageal fistula (EA/TEF) is a rare congenital abnormality, with an annual incidence of approximately 2 to 4 per 10,000 live births [1]. Despite continued advances in medical and surgical techniques, in-hospital mortality for these patients has recently been reported to range from 5 to 9% [2-4]. Furthermore, patients who survive to discharge face many issues, with more than half being readmitted within two years of their surgery [4, 5] and many requiring additional procedures such as repeat TEF ligations, repeat esophageal reconstructions, and dilations [2, 4]. Due to the rarity of EA/TEF and previous success with the centralization of surgery for other rare pediatric surgical conditions such as biliary atresia [6], there has been surgeon subspecialization in EA/TEF in some countries [7, 8].

For most neonatal surgical procedures, pediatric surgeon subspecialization is not widespread in North America [9]. This stands in contrast to surgery in adults. Studies of surgeon operative volumes and patient outcomes in adult surgery have found a significant relationship across a variety of complex procedures; this has contributed to the formation of Centers of Excellence and highly focused surgeon training programs [10, 11]. Pediatric surgeons typically do not subspecialize and are frequently called upon to operate on a wide variety of rare congenital abnormalities [9]. The total number of such cases is also fewer than similar complex procedures in adults, which limits the statistical power of volume-outcome analyses in pediatric surgery. The rarity of these cases also means that greater centralization or surgeon subspecialization could limit patients' access to care and surgical trainees' exposure to these procedures. Studies of surgeon volume-outcome relationships in children's surgery are few, and the methodologic rigor has generally been limited [12, 13]. Regardless, efforts from credentialing bodies in surgery are moving toward benchmarking outcomes in pediatric surgery and stratifying children's surgery centers by the quality of their care and extent of their resources. Specifically, the American College of Surgeons (ACS) launched the Children's Surgery Verification Quality Improvement Program in 2015 with a goal of "optimizing outcomes for patients based on matching an individual child's needs and institutional resources" [14].

EA/TEF repair is one example of a rare and technically challenging procedure in pediatric surgery that, not unlike esophagectomy in adults, could potentially benefit from being performed at higher-volume centers and by higher-volume surgeons [15, 16]. However, no studies to date have examined the relationship between surgeon volume and patient outcomes after surgical repair of EA/TEF. While one previous study found no relationship between hospital EA/TEF operative volume and patient outcomes [4], it remains possible that surgeon and hospital volumes may moderate each other's effects on patient outcomes after EA/TEF repair. The aim of our study was to determine whether higher surgeon and hospital volumes are associated with better outcomes after EA/TEF repair.

2. METHODS

2.1 Cohort Identification

We performed a multi-institutional, retrospective cohort study of neonates who were diagnosed with EA/TEF and underwent operative repair prior to death or hospital discharge. We used the Pediatric Health Information System (PHIS), a hospital discharge database containing inpatient, observation, ambulatory surgery, and emergency department encounters to 49 tertiary children's hospitals across the US. We included EA/TEF patients treated at one of 44 different hospitals who were discharged in January 2000 to September 2015. We have previously described and validated our method of identification of these patients.[4, 17] Briefly, we identified patients who had an International Classification of Diseases, 9th edition, Clinical Modification (ICD-9-CM)

diagnosis code of EA/TEF (750.3) or acquired TEF (530.84) and were less than 30 days old at admission to the children's hospital. We then included only patients who had also undergone at least one surgical procedure for esophageal atresia or tracheoesophageal fistula repair (ICD-9 procedure codes 31.73, 42.85, 42.51, 42.84, 42.89, 42.61, 42.52-9, 42.62-9, or 42.87). We limited our study cohort to those patients who were discharged at least one year after their hospital began contributing clinical and financial data to PHIS. From this cohort we excluded patients who were operated on by a surgeon with a missing physician identifier, by more than one attending surgeon, or by a surgeon who did not have evidence of having operated continuously at the patient's hospital during the entire year (at least 11 of 12 months) before the patient's EA/TEF repair.

2.2 Definitions of hospital and surgeon volumes

The primary exposures of interest in this study were hospital and surgeon EA/TEF operative volumes. Surgeon volume was defined as the number of infants with EA/TEF on whom the surgeon had operated during the previous 365 days. Hospital volume was defined in the same way but at the hospital level. As such, both hospital and surgeon operative volumes temporally preceded the case under examination and could change over time. In addition, because some surgeons may have relocated or stopped practicing for a time, and also because surgeon identification numbers changed when there was a one-time change in file submission versions to PHIS, any patient treated by a surgeon without evidence of having performed at least one surgery of any type at the participating hospital in at least 11 of the preceding 12 months was excluded. As described above, patients operated on by a surgeon with a missing physician identification number or by more than one attending surgeon were also excluded. These excluded patients, however, still counted towards measures of hospital volume.

2.3 Patient characteristics and outcomes

Patient characteristics of interest at the time of surgery included both sociodemographic characteristics (age, sex, race, ethnicity, primary payer) and clinical characteristics. Clinical characteristics were defined using ICD-9 diagnosis codes and/or date-stamped ICD-9 procedure codes or Clinical Transaction Codes, the latter of which are unique to PHIS and provide standardized categories of medications and clinical services across all participating hospitals. Preoperative clinical characteristics of interest included birth weight, gestational age at birth, slow fetal growth/malnutrition, other congenital anomalies, respiratory failure, necrotizing enterocolitis, and use of mechanical ventilation, total parenteral nutrition, and extracorporeal membrane oxygenation (ECMO).

Postoperative outcomes examined included in-hospital mortality, readmission for any cause within 30 days of discharge, readmission for any cause within one year of discharge, readmission for pneumonia within one year of discharge, and the following procedures within one year of initial EA/TEF repair: reoperation for repeat TEF ligation or esophageal reconstruction, dilation, fundoplication, tracheostomy, and gastrostomy. Postoperative outcomes were identified using both ICD-9 and ICD-10 procedure and diagnosis codes.

2.4 Statistical analysis

All characteristics were reported as frequencies and percentages for categorical variables and medians and interquartile ranges for continuous variables. To assess associations between individual preoperative characteristics and outcomes, chi square and Fisher exact tests were used for categorical variables and Wilcoxon rank sum tests were used for continuous variables. A multivariable logistic regression model was then fit for

each outcome of interest, after performing multiple imputation to fill in missing data on birth weight and gestational age. The regression models included all preoperative characteristics present in at least 5 patients and associated with any outcome at $p<0.15$ in bivariate analyses. In addition to patient characteristics, models first included surgeon EA/TEF operative volume, then separate models included hospital EA/TEF operative volume. Each volume variable was evaluated using restricted cubic splines with knots at the quartiles. The relationship between surgeon or hospital volume and the adjusted risk of each outcome was evaluated visually to identify any inflection points that could be used to meaningfully categorize operative volumes. If an inflection point was seen, the area under the receiver operating characteristics curve (AUC) for the model with hospital or surgeon volume categorized at this cut point was calculated. The surgeon or hospital volume that resulted in the maximum AUC was selected as the cut point to categorize volume. If no inflection points were seen for any outcome, cut points at the top patient-level tertile were selected for both surgeon and hospital volumes. Furthermore, if surgeon and hospital volumes categorized at their apparent inflection points yielded models with lower AUCs than those of models in which surgeon and hospital volumes were dichotomized at their upper tertiles, the latter variables were used. Once cut points were selected for surgeon and hospital volumes, patients were then classified according to whether their surgery had been performed by a lower or higher volume surgeon and at a lower or higher volume hospital. This led to the creation of a four-level combined surgeon/hospital volume variable. Propensity score weighting (inverse probability of treatment weighting) was then used to estimate the effects of both surgeon and hospital volume on in-hospital mortality. Propensity scores were estimated using a multinomial logistic regression model in each imputed dataset. This model included all evaluated patient-level preoperative characteristics. After averaging patients' estimated propensity scores across all imputed datasets, weights were created such that each of the weighted comparison groups was similar to the overall study cohort. The estimated weights were then used in logistic regression models for the outcomes of interest. This analytic strategy yielded estimates of average treatment effects in the total study sample. In order to assess the balance in patient characteristics across groups before and after propensity score weighting, standardized differences were calculated, and any characteristics remaining unbalanced were included in the outcome regression models. Propensity score weights were also estimated separately in the subgroup of patients treated at a hospital that contributed outpatient surgery data to PHIS, and a logistic regression model was fit for the outcome of dilatation within one year in this subgroup.

Finally, because surgeon and hospital operative volumes, particularly for rare diseases such as EA/TEF, can vary substantially from year to year, a sensitivity analysis was run in which surgeon and hospital EA/TEF volumes were defined as their averages over the previous three years, rather than one year, before a patient's initial EA/TEF repair. In both the primary and the sensitivity analyses, a Bonferroni correction was used to account for the nine outcomes evaluated, such that $P<0.0056$ was considered statistically significant. SAS Enterprise Guide version 7.11 (SAS Institute Inc., Cary, NC) was used for the statistical analyses.

3. RESULTS

3.1 Cohort identification and characteristics

A total of 3,085 patients treated across 44 tertiary children's hospitals were identified. Baseline characteristics and associated congenital anomalies are listed in Table 1. Of note, 2,644 (85.7%) patients had another congenital anomaly and 2,213 (71.7%) had a congenital cardiac anomaly. Preoperative mechanical ventilation was required in 1,481 (48%) patients, and preoperative TPN was given to 1,440 patients (46%).

Sixty percent of patients were treated by a surgeon who had performed zero or one EA/TEF repair in the preceding 365 days; 50% of patients were treated at a hospital that had performed less than 9 EA/TEF repairs in the preceding 365 days. When relationships between surgeon or hospital volume and patient outcomes were examined in multivariable models including patient-level risk factors, no significant associations were detected ($p>0.20$ for all). Figure 1 shows the risk-adjusted relationships between surgeon or hospital volume and the outcomes of in-hospital mortality and reoperation within 1 year. Though a weak inflection point was visually detected for the association between surgeon or hospital volume and some outcomes, no volume threshold examined generated an AUC that was significantly higher than that of a model with the volume cut point set at its top tertile. Therefore, for ease of interpretation and consistency across outcomes, both surgeon and hospital volume were dichotomized at their top tertiles of 2 and 9 procedures in the preceding year respectively.

Patients were then classified into four groups based on their surgeon's and hospital's EA/TEF volume in the preceding year: low-volume surgeon in a high-volume hospital (LVS in HVH), low-volume surgeon in a low-volume hospital (LVS in LVH), high-volume surgeon in a high-volume hospital (HVS in HVH), and high-volume surgeon in a low-volume hospital (HVS in LVH). In propensity score weighted analyses, there was no significant association between surgeon or hospital EA/TEF volume and any clinical outcome examined (Table 2). In a sensitivity analysis in which volumes were defined as their averages over the preceding 3 years rather than 1 year, all results were similar, with no significant differences in outcomes detected across surgeon/hospital volume groups (data not shown).

4. DISCUSSION

This study of over 3000 neonates with EA/TEF found no association between either surgeon or hospital volume and outcomes after repair of EA/TEF. After accounting for patient baseline characteristics, there were no significant associations between any of the measured postoperative outcomes and either surgeon or hospital EA/TEF volume. This implies that the previously demonstrated volume-outcome relationship appreciated in adult specialty surgery may not translate to EA/TEF repair.

Efforts are underway to identify pediatric surgical procedures that would benefit from greater centralization and/or surgeon subspecialization in the United States. In 2015 the American College of Surgeons published the first version of the Optimal Resources for Children's Surgical Care as a part of the Children's Surgery Verification Quality Improvement Program. This program seeks to improve the care of children with surgical needs by identifying the resources required to provide specific surgical treatments to children, with verification and designation of various levels of pediatric surgical centers. Similar to the trauma system, there will be levels of pediatric surgical centers, which will define the scope of practice of each center. Complexity and volume of surgical needs are the main impetus behind level delineation. The verification committee recommends that "certain needs that occur infrequently should be concentrated in [Level 1] centers to ensure these patients are properly treated" [14]. As these centers evolve, it will be critical to define what procedures are classified as complex enough to warrant treatment at a Level 1 facility only. High quality volume-outcomes studies will likely play an important role in the decision-making process of what procedures can be recommended to be performed by all general pediatric surgeons versus subspecialized teams at Level 1 centers.

Much of adult surgery has subspecialized into focused clinical and anatomic categories with the continued concentration of expertise in particular surgical conditions into Centers of Excellence at many institutions. These trends have resulted, in part, from

research demonstrating that patients treated by the highest-volume hospitals and surgeons have better outcomes after major, complex surgeries [10, 11, 18]. Although evidence of association between surgeon and/or hospital volume and patient outcomes has been demonstrated for some pediatric procedures [6, 19-22], the majority of such studies have significant limitations. Key methodological shortcomings were identified in a recent systematic review of volume-outcomes relationships in pediatric surgery, namely a lack of case mix adjustment , no accounting for the clustering of patients within surgeons or hospitals, and a lack of simultaneous consideration of both hospital and surgeon characteristics [12]. The present study has attempted to account for these shortcomings. In addition, the present study defined hospital and surgeon volume as temporally preceding the outcomes of interest, an important consideration given that both can change over time, particularly for uncommon procedures.

In this study, we found the majority of patients were treated by a surgeon who had performed less than two EA/TEF repairs in the preceding year and at a hospital that had treated less than nine neonates with EA/TEF in the preceding year. These findings are consistent with previously reported case volumes. A recent multi-site retrospective cohort study identified an average of seven cases per year among tertiary children's hospitals in the Midwestern US [2]. A survey distributed at the Canadian Association of Pediatric Surgeons in 2012 found an average institutional volume of 8-10 cases per year [23]. Another survey administered at the International Pediatric Endosurgery Group 2012 meeting found that most (67%) surgeons performed between one and three EA/TEF repairs per year [7, 9, 24]. Not only is esophageal atresia a rare disease, but patients often have concurrent congenital anomalies that may affect their outcomes and require coordinated care amongst specialists. In our study, more than 85% of patients were found to have an associated congenital anomaly. This is slightly higher than numbers reported by a recent multi-institutional medical record review that found an associated anomaly rate of 68% [2]. This difference appears to primarily result from our inclusion of all cases of patent ductus arteriosus or patent foramen ovale (PDA or PFO) documented on the billing record, many of which may have been clinically insignificant. However, after accounting for a wide variety of sociodemographic and clinical characteristics that may impact patient outcomes, including concurrent congenital anomalies, we found no associations between surgeon or hospital volumes and outcomes after EA/TEF repair.

While there has been evidence of improved outcomes with increased volume and centralization of some pediatric surgical procedures such as the portoenterostomy for biliary atresia [6, 25], there has been little evidence regarding volume-outcomes relationships in EA/TEF repair. In the United Kingdom, an effort to move toward subspecialization of EA/TEF repair was documented in a study from 2010 by Jawaid et al. [8]. They analyzed outcomes before and after the implementation of subspecialist repair of EA/TEF at a single institution. After nearly complete subspecialization of surgeons performing EA/TEF repair, they found significant reductions in intensive care length of stay and neonatal mortality. However, many other outcomes were unchanged and trainee experience in EA/TEF repair decreased dramatically. They concluded that subspecialization for EA may have limited benefit clinically. Consistent with this report, the lack of any significant associations between surgeon or hospital volumes and outcomes after EA/TEF repair suggests that there would be minimal benefit to centralization or subspecialization of EA/TEF care in the U.S.

One reason that hospital volume may not have had an effect on patient outcomes in our study is that the hospitals participating in the PHIS are tertiary children's hospitals accustomed to treating neonates with complex medical issues. In addition, the majority of hospitals in our study are moderate to large sized children's hospitals with an average of 306 inpatient beds and 62 NICU beds in 2015. Therefore, EA/TEF patients treated at

small children's hospitals are underrepresented, and the small percentage of EA/TEF repairs not performed at a children's hospital are absent from this study [3, 26]. With regards to surgeon volume, one potential reason we found no effect on patient outcomes may be that it was not possible in PHIS to account for subtle operating room staffing changes. While we excluded patients in whom two attending surgeons were listed as having performed distinct concurrent procedures at the time of initial surgery for EA/TEF, it is also possible that a second attending may have been present for part or all of the case but was not required to be identified for billing purposes. Finally, in a rare disease with variable severity such as EA/TEF, there are many other provider-level factors that contribute to patient outcomes besides surgeon and hospital volumes. While patient characteristics associated with outcomes have been well-described in other articles [3, 4], other factors such as perioperative care and surgical approach are important contributors to outcomes but are unable to be assessed in the PHIS database [27, 28]. While our study demonstrates that surgeon volume is not associated with outcomes for patients undergoing EA/TEF repair, further investigation into other provider-level factors that influence patient outcomes is warranted, such as provider experience with a specific approach with technically similar procedures.

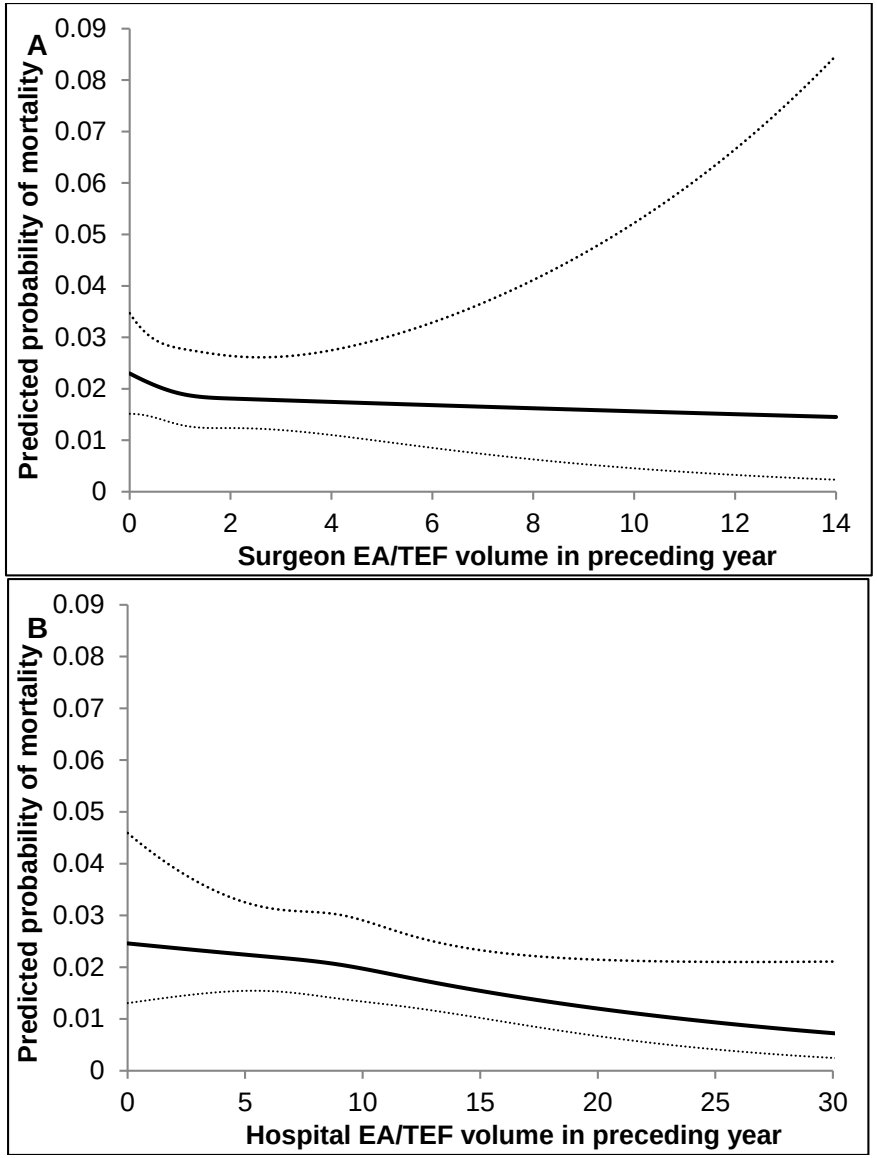
This study had several limitations. Due to the administrative nature of PHIS and the lack of specificity of ICD-9 diagnosis codes for EA/TEF, we lacked data on patients' type of EA/TEF. However, the recent retrospective analysis by Lal et al. did not demonstrate a difference in overall morbidity or anastomotic stricture rate across types of EA/TEF [2]. In addition to type of anomaly, we also lacked data on the gap length among patients with esophageal atresia, which has been shown to have an effect on patient outcomes [29]. With regard to the distribution of surgeon EA/TEF volumes, there were only 52 patients operated on by a surgeon who had performed more than five EA/TEF cases in the prior year. Unfortunately, this small sample did not allow for adequate statistical power to compare outcomes in this group of patients to patients treated by lower volume surgeons. However, this finding does demonstrate that there remains no trend toward surgeon subspecialization in EA/TEF repair in the United States. In conclusion, our analysis demonstrates that surgeon and hospital EA/TEF operative volumes are not significantly associated with patient outcomes. Therefore, this study does not provide evidence in support of selective referral or pediatric surgeon subspecialization in EA/TEF. Future analyses incorporating specific hospital resources relevant to this patient population are warranted.

Table 1. Characteristics of EA/TEF patients at the time of surgery

Characteristic	N (%) or Median (IQR) (N=3085)
Age in days	2 (1, 4)
Birth weight in grams (N=2952)	2590 (2010, 3045)
Gestational age in weeks (N=2199)	37 (35, 39)
Gender	
Female	1396 (45.3)
Male	1688 (54.7)
Race	
Black	295 (9.6)
White	2139 (69.3)
Other or Unknown	651 (21.1)
Primary Payer	
Government	1378 (44.7)
Private	1342 (43.5)
Other	365 (11.8)
Premature	1150 (37.3)
Slow fetal growth/malnutrition	310 (10.0)
Associated congenital anomalies	
Any other congenital anomaly	2644 (85.7)
Congenital heart disease[a]	2213 (71.7)
RACHS Score	
None	2847 (92.3)
1	2 (0.1)
2	69 (2.2)
3	93 (3.0)
4	68 (2.2)
5	0 (0)
6	6 (0.2)
Other gastrointestinal anomaly	645 (20.9)
Eye anomaly	109 (3.5)
Coloboma	45 (1.5)
Hepatobiliary anomaly	51 (1.7)
Neurologic anomaly	282 (9.1)
Auditory anomaly	163 (5.3)
Head or neck anomaly	25 (0.8)
Respiratory anomaly	524 (17.0)
Palate anomaly	78 (2.5)
Renal anomaly	650 (21.1)
Genital anomaly	303 (9.8)
Musculoskeletal anomaly	871 (28.2)
Genetic anomaly	200 (6.5)
Respiratory failure	807 (26.2)
Necrotizing enterocolitis	61 (2.0)
Preoperative mechanical ventilation	1481 (48.0)
Preoperative TPN	1440 (46.7)
Preoperative ECMO	3 (0.1)

Characteristic	N (%) or Median (IQR) (N=3085)
Surgeon EA/TEF operative volume in the previous 365 days	1 (0, 2)
Hospital EA/TEF operative volume in the previous 365 days	9 (6, 12)

[a]Includes all congenital cardiac anomalies, including those that did not require an invasive corrective procedure at birth [b]Classification system for risk adjustment for in-hospital mortality among children after surgery for congenital heart disease; this system does not consider catheter-based interventions. IQR=interquartile range, RACHS=Risk Adjustment for Congenital Heart Surgery, TPN=Total parenteral nutrition, ECMO=Extracorporeal Membrane Oxygenation, EA/TEF= esophageal atresia/tracheoesophageal fistula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Predicted probability of mortality
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Surgeon EA/TEF volume in preceding year
B
Predicted probability of mortality
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Hospital EA/TEF volume in preceding year

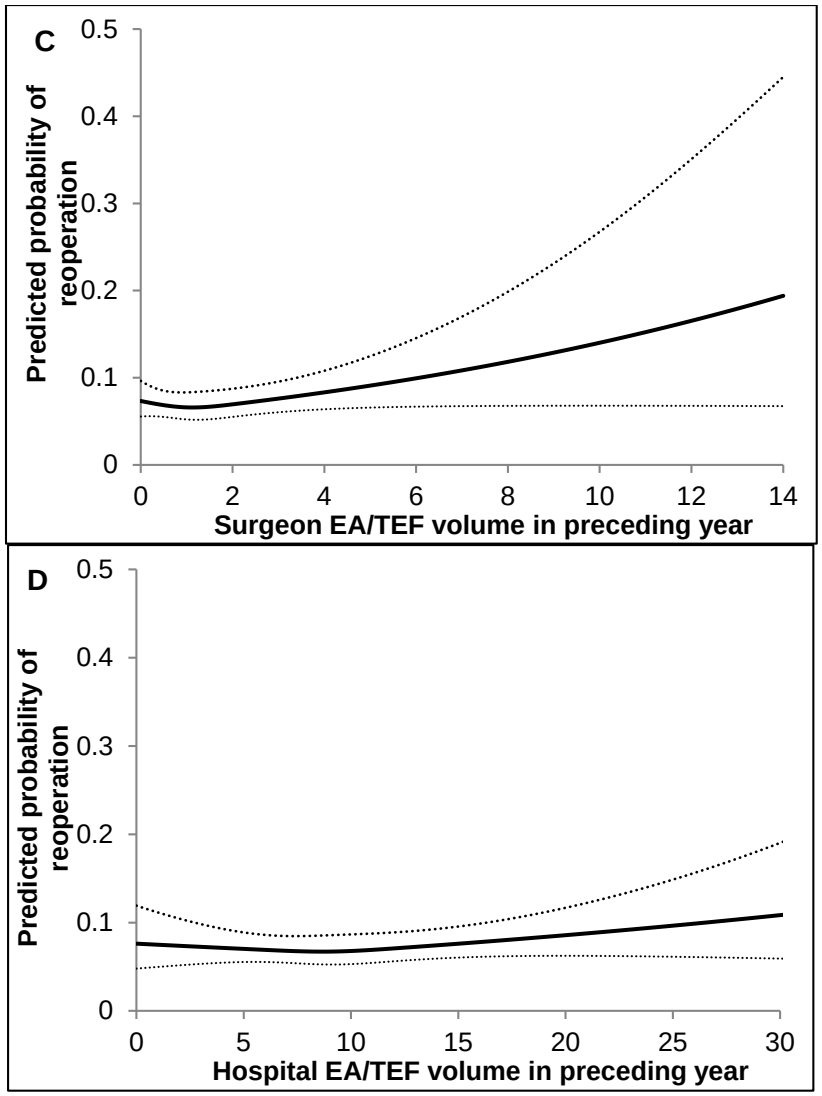

Figure 1. Risk-adjusted associations and 95% confidence intervals for relationships between (A) surgeon EA/TEF volume and in-hospital mortality (B) hospital EA/TEF volume and in-hospital mortality (C) surgeon EA/TEF volume and reoperation within 1 year (D) hospital EA/TEF volume and reoperation within 1 year. Associations are shown with patient-level characteristics in the model set equal to their sample means. P-values for all associations were > 0.15.

Table 2. Adjusted outcomes by surgeon and hospital volume category

	Outcomes								
Hospital and surgeon volume category	**In-hospital mortality (%)**	**30-day readmission (%)**	**1-year reoperation (%)**	**1-year dilation (%)[a]**	**1-year fundoplication (%)**	**1-year tracheostomy (%)**	**1-year g-tube placement (%)**	**1-year readmission (%)**	**1-year readmission with pneumonia (%)**
Hospital volume ≤ 10									
Surgeon volume < 2 (N=1352)	6.2	16.9	8.5	30.2	8.4	5.1	16.8	47.8	16.0
Surgeon volume ≥ 2 (N=668)	6.4	19.9	7.6	31.8	11.0	5.8	17.9	49.8	17.5
Hospital volume > 10									
Surgeon volume < 2 (N=486)	5.3	15.6	7.6	30.7	7.4	5.3	15.4	48.6	15.8
Surgeon volume ≥ 2 (N=579)	4.7	16.5	7.7	31.2	10.5	5.7	18.4	50.0	16.9

Estimates shown are risk-adjusted (propensity score weighted) estimates of the percentages of patients with the outcome. P values for all comparisons (comparisons across all four surgeon/hospital volume categories, comparisons between higher hospital and lower hospital volume categories, comparisons between higher and lower surgeon volume categories) were all ≥ 0.15

[a]N=2115 patients

References

[1] Sfeir R, Michaud L, Salleron J, Gottrand F. Epidemiology of esophageal atresia. Diseases of the esophagus : official journal of the International Society for Diseases of the Esophagus 2013;26(4):354-5.

[2] Lal DR, Gadepalli SK, Downard CD, Ostlie DJ, Minneci PC, Swedler RM, et al. Challenging surgical dogma in the management of proximal esophageal atresia with distal tracheoesophageal fistula: Outcomes from the Midwest Pediatric Surgery Consortium. Journal of pediatric surgery 2017.

[3] Wang B, Tashiro J, Allan BJ, Sola JE, Parikh PP, Hogan AR, et al. A nationwide analysis of clinical outcomes among newborns with esophageal atresia and tracheoesophageal fistulas in the United States. Journal of Surgical Research 2014;190(2):604-12.

[4] Sulkowski JP, Cooper JN, Lopez JJ, Jadcherla Y, Cuenot A, Mattei P, et al. Morbidity and mortality in patients with esophageal atresia. Surgery 2014;156(2):483-91.

[5] Dingemann C, Dietrich J, Zeidler J, Blaser J, Gosemann JH, Ure BM, et al. Early complications after esophageal atresia repair: analysis of a German health insurance database covering a population of 8 million. Diseases of the esophagus : official journal of the International Society for Diseases of the Esophagus 2016;29(7):780-6.

[6] McKiernan PJ, Baker AJ, Kelly DA. The frequency and outcome of biliary atresia in the UK and Ireland. The Lancet 2000;355(9197):25-9.

[7] Zani A, Eaton S, Hoellwarth ME, Puri P, Tovar J, Fasching G, et al. International Survey on the Management of Esophageal Atresia. Eur J Pediatr Surg 2014;24(01):003-8.

[8] Jawaid W, Chan B, Jesudason EC. Subspecialization may improve an esophageal atresia service but has not addressed declining trainee experience. Journal of pediatric surgery 2012;47(7):1363-8.

[9] Langer JC, Gordon JS, Chen LE. Subspecialization within pediatric surgical groups in North America. Journal of pediatric surgery 2016;51(1):143-8.

[10] Pieper D, Mathes T, Neugebauer E, Eikermann M. State of Evidence on the Relationship between High-Volume Hospitals and Outcomes in Surgery: A Systematic Review of Systematic Reviews. Journal of the American College of Surgeons 2013;216(5):1015-25.e18.

[11] Finks JF, Osborne NH, Birkmeyer JD. Trends in Hospital Volume and Operative Mortality for High-Risk Surgery. New England Journal of Medicine 2011;364(22):2128-37.

[12] McAteer JP, LaRiviere CA, Drugas GT, Abdullah F, Oldham KT, Goldin AB. Influence of surgeon experience, hospital volume, and specialty designation on outcomes in pediatric surgery: A systematic review. JAMA Pediatrics 2013;167(5):468-75.

[13] LaRiviere CA, McAteer JP, Huaco JA, Garrison MM, Avansino JR, Koepsell TD, et al. Outcomes in pediatric surgery by hospital volume: a population-based comparison. Pediatric surgery international 2013;29(6):561-70.

[14] Optimal Resources for Children's Surgical Care. 1 American College of Surgeons; 2015.

[15] Finlayson EA, Goodney PP, Birkmeyer JD. Hospital volume and operative mortality in cancer surgery: A national study. Archives of Surgery 2003;138(7):721-5.

[16] Swisher SG, DeFord L, Merriman KW, Walsh GL, Smythe R, Vaporicyan A, et al. Effect of operative volume on morbidity, mortality, and hospital use after

esophagectomy for cancer. The Journal of Thoracic and Cardiovascular Surgery 2000;119(6):1126-34.

[17] Sulkowski JP, Deans KJ, Asti L, Mattei P, Minneci PC. Using the Pediatric Health Information System to study rare congenital pediatric surgical diseases: development of a cohort of esophageal atresia patients. Journal of pediatric surgery 2013;48(9):1850-5.

[18] Morche J, Mathes T, Pieper D. Relationship between surgeon volume and outcomes: a systematic review of systematic reviews. Systematic Reviews 2016;5:204.

[19] Baird R, Eeson G, Safavi A, Puligandla P, Laberge J-M, Skarsgard ED. Institutional practice and outcome variation in the management of congenital diaphragmatic hernia and gastroschisis in Canada: a report from the Canadian Pediatric Surgery Network. Journal of pediatric surgery 2011;46(5):801-7.

[20] Bucher BT, Guth RM, Saito JM, Najaf T, Warner BW. Impact of Hospital Volume on In-Hospital Mortality of Infants Undergoing Repair of Congenital Diaphragmatic Hernia. Annals of surgery 2010;252(4):635-42.

[21] Grushka JR, Laberge J-M, Puligandla P, Skarsgard ED. Effect of hospital case volume on outcome in congenital diaphragmatic hernia: the experience of the Canadian Pediatric Surgery Network. Journal of pediatric surgery 2009;44(5):873-6.

[22] Kane JM, Harbert J, Hohmann S, Pillai S, Behal R, Selip D, et al. Case Volume and Outcomes of Congenital Diaphragmatic Hernia Surgery in Academic Medical Centers. Amer J Perinatol 2015;32(09):845-52.

[23] Shawyer AC, Pemberton J, Flageole H. Post-operative management of esophageal atresia–tracheoesophageal fistula and gastroesophageal reflux: A Canadian Association of Pediatric Surgeons annual meeting survey. Journal of pediatric surgery 2014;49(5):716-9.

[24] Lal D, Miyano G, Juang D, Sharp NE, St Peter SD. Current patterns of practice and technique in the repair of esophageal atresia and tracheoesophageal fistua: an IPEG survey. Journal of laparoendoscopic & advanced surgical techniques Part A 2013;23(7):635-8.

[25] Durkin N, Davenport M. Centralization of Pediatric Surgical Procedures in the United Kingdom. Eur J Pediatr Surg 2017;27(05):416-21.

[26] Somme S, Bronsert M, Morrato E, Ziegler M. Frequency and variety of inpatient pediatric surgical procedures in the United States. Pediatrics 2013;132(6):e1466-72.

[27] Lal DR, Gadepalli SK, Downard CD, Ostlie DJ, Minneci PC, Swedler RM, et al. Perioperative management and outcomes of esophageal atresia and tracheoesophageal fistula. Journal of pediatric surgery 2017;52(8):1245-51.

[28] Yang YF, Dong R, Zheng C, Jin Z, Chen G, Huang YL, et al. Outcomes of thoracoscopy versus thoracotomy for esophageal atresia with tracheoesophageal fistula repair: A PRISMA-compliant systematic review and meta-analysis. Medicine 2016;95(30):e4428.

[29] Brown AK, Tam PK. Measurement of gap length in esophageal atresia: a simple predictor of outcome. Journal of the American College of Surgeons 1996;182(1):41-5.