Journal of Pediatric Surgery 56 (2021) 938–943

Contents lists available at ScienceDirect

Journal of Pediatric Surgery

journal homepage: www.elsevier.com/locate/jpedsurg.org

The left-sided repair: An alternative approach for difficult esophageal atresia repair

Wendy Jo Svetanoff[a,b], Benjamin Zendejas[a], Peter Ngo[c], Michael Manfredi[c], Thomas E. Hamilton[a], Russell W. Jennings[a], C. Jason Smithers[a,d,*]

[a] Department of General Surgery, Boston Children's Hospital, 300 Longwood Ave, Boston, MA 02115, United States
[b] Department of Pediatric Surgery, Children's Mercy Hospital, 2401 Gillham Road, Kansas City, MO 64108, United States
[c] Division of Gastroenterology, Hepatology, and Nutrition, Boston Children's Hospital, 300 Longwood Ave, Boston, MA 02115, United States
[d] Department of Surgery, Johns Hopkins All Children's Hospital, 601 5th St S, Ste306, St. Petersburg, FL 33701, United States

ARTICLE INFO

Article history:
Received 28 May 2020
Revised 27 October 2020
Accepted 2 November 2020

Keywords:
Esophageal atresia
Long gap esophageal atresia
Left-sided approach
Foker procedure
Internal traction

ABSTRACT

Purpose: : We describe a left-sided approach for long gap esophageal atresia (LGEA) repair in patients who have a large leftward upper pouch and no significant tracheomalacia, or as a salvage strategy after prior failed right-sided repairs.
Methods: : Retrospective review of patients who underwent repair via traction induced growth (Foker procedure [FP]) from 2014 to 2019 was performed. Surgical technique and post-operative outcomes were evaluated.
Results: : Of 47 LGEA patients, 18 (38%) were approached via the left side – 94% had a left aortic arch, and 22% had prior attempts at a right-sided anastomosis. More left-sided patients underwent minimally invasive repair (39% vs 7%, $p = 0.007$) and internal traction (50% vs 10%, $p = 0.002$) compared to right-sided patients. On multivariate analysis, internal traction was associated with a decreased length of paralysis ($p<0.01$); length of intubation and hospital stay were similar between groups. Anastomotic leak (17% vs 20%, $p = 0.80$) and stricture resection (6% vs 24%, $p = 0.12$) rates were similar. No left-sided FP patient required additional surgery for tracheomalacia, while six right-sided patients required intervention.
Conclusion: : Left-sided FP can be considered for LGEA patients with a large leftward upper pouch or as a salvage pathway after a failed right chest approach, with similar outcomes to the right-sided approach.

1. Introduction

Esophageal atresia (EA) with or without a tracheoesophageal fistula (TEF) occurs in approximately 1 in 5000 births, with long-gap EA (LGEA) occurring in about 10% of these patients [1]. Many advances have occurred in the treatment of patients with LGEA, including the use of external traction for esophageal growth [2], a combination internal and external traction [3] and minimally invasive (MIS) approaches [4–9].

EA repair is generally performed through the right chest, with procedures through the left chest being reserved for cases with a right aortic arch (RAA). A RAA can obscure the view of the esophageal pouches and the TEF when repair is attempted through the right chest [10]. As a result, in patients where the RAA is not diagnosed until the time of surgery, either conversion to a left-sided approach is performed or dissection of the aortic arch is required for adequate exposure, increasing the risk of bleeding or injury to the vagus or recurrent laryngeal nerves [10–12].

However, in our experience, we have found that there are specific situations where an approach through the left chest, regardless of aortic arch position, may be beneficial. When trying to obtain esophageal continuity, the use of the patient's native esophagus is the preferable choice [13,14]; therefore, in infants with prior attempts at esophageal growth complicated by a leak or infection leading to dense adhesions, an approach through the left chest may allow for a clean operative field to attempt esophageal growth induction by either open or MIS techniques. This also can be especially helpful for infants with a left sided cervical esophagostomy following a failed repair.

The presence of tracheobronchomalacia (TBM) is also prevalent in the long gap esophageal atresia (LGEA) population, with a reported occurrence of up to 91% [15–17]. A large upper esophageal pouch is frequently located to the left side of the trachea, and in our experience, we have encountered that its mobilization and placement to the right of the trachea (as is the case in right sided repairs) may enhance posterior compression and worsen TBM that may already be present. We postulated that performing a left sided

* Corresponding author at: Department of Surgery, Johns Hopkins All Children's Hospital, 601 5th St S, Ste306, St. Petersburg, FL 33701, United States.
E-mail address: csmithe1@jhmi.edu (C.J. Smithers).

https://doi.org/10.1016/j.jpedsurg.2020.11.003
0022-3468/

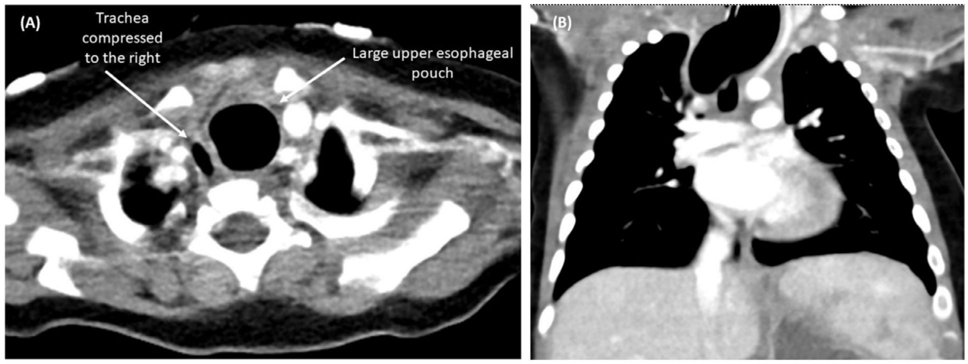

Fig. 1. A-B. Computed Tomography scan identifying the position of the upper esophageal pouch. (A) A large esophageal pouch can cause tracheal compression even before an esophageal anastomosis is attempted., compressing the trachea as it moves into the right chest. Moving the upper pouch to the right chest for anastomosis may lead to tracheal compression and subsequent development of symptoms of tracheomalacia (B).

repair may not only avoid this worsening of posterior airway compression but improve it. We present our left-sided approach, as an alternative to the right-sided repair, for primary and salvage esophageal anastomosis in select infants who do not require simultaneous intrathoracic tracheopexy and either do not have a distal TEF or had their TEF repaired previously.

2. Methods

2.1. Study design

A retrospective review of infants who underwent EA repair via traction induced growth (Foker procedure [FP]) from 2014 to 2019 was performed. Patients were considered for FP if they met the International Network of Esophageal Atresia (INoEA) Working Group's definition of having a long gap, which included patients with Gross type A or B EA and those with inability to perform a primary repair due to the length of the gap (which includes Gross type C EA) [14]. Patients were categorized based on whether the Foker procedure was performed in either the right chest or the left chest. Pre-operative assessment included an echocardiogram with or without computed tomography (CT) angiography to assess for structural heart disease, orientation of the aortic arch, presence of great vessel anomalies and location of the upper esophageal pouch (Fig. 1A-B); contrast studies of the upper and lower esophageal pouches to assess the character and length of the two esophageal segments and measure the gap between the two ends; and a 3-phase rigid bronchoscopy to identify the location of any fistula, specifically an upper pouch fistula, and to determine the extent and location of tracheobronchomalacia [18,19]. Left sided repairs were considered for infants with a large pouch located primarily in the left neck or chest, as seen in Fig. 1A-B, with minimal to no tracheomalacia of the intrathoracic trachea and no distal TEF at the time of evaluation. Patients with posterior intrusion type of tracheomalacia located only in the cervical trachea were considered for left-sided repair, with or without the performance of additional airway procedures from the left side, including left cervical posterior tracheopexy and/or posterior descending aortopexy specifically to improve left mainstem bronchomalacia. A history of prior esophageal surgery at a referring institution with or without associated infection in the right chest was also taken into consideration when considering a left sided approach for the FP. Patients were included if their esophagus was in discontinuity at the time of evaluation at our institution; patients with a previous repair who were referred for a severe esophageal stricture were excluded.

2.2. Surgical technique

Our technique for external traction has been previously described [2,18]. We have modified the internal traction procedure with the use of MIS in some cases to decrease the required duration of paralysis and intubation. For a left sided MIS approach, the patient is placed in the right lateral semi-prone position. The initial incision for the camera port is placed near the tip of the scapula with additional ports placed around the axilla and lower chest as needed. The two ends of the esophagus are dissected free and traction sutures with pledgets are placed on both ends. In the MIS approach, the sutures are secured either around a rib or one pouch is secured to the other; sutures are tied with a one-way slip knot [Fig. 2A-B]. This knot allows for traction to be maintained on the esophageal ends, while at subsequent procedures, these knots can be further tightened instead of redoing the entire traction system. With the internal traction system, suture tightening occurs only during weekly return trips to the operating room; therefore, no paralysis is used in the interim, and patients are extubated and transferred to the general care floor when appropriate. In the open approach, the traction sutures are brought through the skin as previously reported [2,18]. When the esophageal segments are found to be overlapping, the anastomosis is then performed either via MIS or thoracotomy based on the discretion of the surgeon.

The techniques of direct posterior tracheopexy and descending aortopexy have been previously described [17,20]. In the left-sided approach group, cases with more severe posterior intrusion type tracheomalacia of the cervical region (often correlating with larger size of the proximal pouch), and/or the presence of a proximal TEF, will include a left neck dissection for TEF repair and/or posterior tracheopexy. Select patients with severe left mainstem bronchomalacia underwent posterior descending aortopexy to decrease airway compression in that location. As mentioned above, the left-sided approach does not afford access to perform a posterior tracheopexy of the thoracic trachea in cases with a normal left aortic arch, but it does for patients with a right-sided arch.

2.3. Data collection

Demographic information including esophageal-related variables (type of EA, history of prior attempt at repair and gap length) and intra-operative variables were collected. Post-procedure outcomes, anastomotic and in-hospital complications, need for surgical airway intervention due to symptomatic tracheomalacia, date of last follow-up and one year post-FP feeding outcomes were obtained. Possible surgical airway interventions to address TBM included posterior or anterior cervical and/or thoracic tracheopexy [15,18,21,22]. Feeding status was captured in four groups using

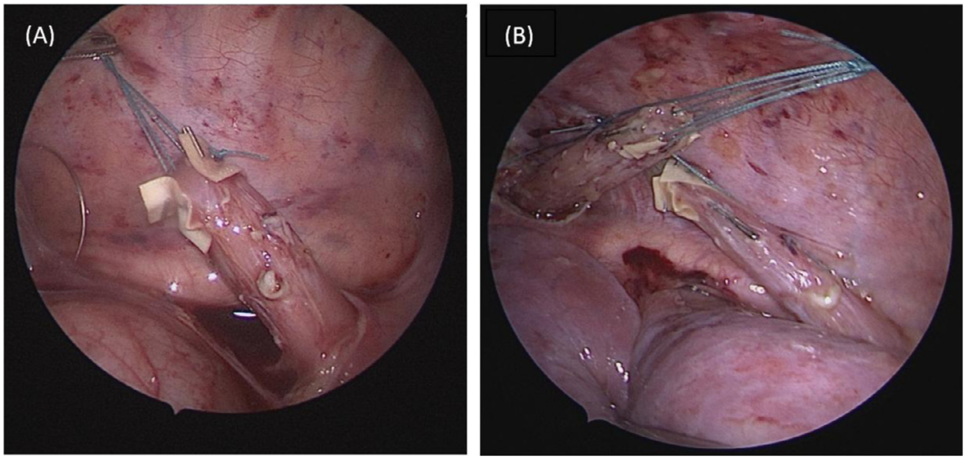

Fig. 2. A-B. Internal Traction Technique. Pledgeted sutures are placed on each end of the esophagus, incorporating the muscular and submucosa layer (A). The sutures are then secured around the rib using Roeder's knots, which are tightened weekly (B).

the modified Functional Oral Intake Scale (mFOIS): full oral intake, consistent oral intake with some feeding tube supplementation, predominantly tube fed, and exclusively tube fed [23].

2.4. Statistical analysis

Descriptive and summary statistics are provided when applicable. Fisher's exact and Mann-Whitney U test was used to compare demographic variables, acute post-operative outcomes, esophageal anastomotic complications and feeding outcomes between the right and left-sided FP cohorts. We hypothesized that the side of Foker procedure, use of an open or MIS surgical technique and type of Foker procedure (external or internal) would be colinear variables. To address such potential confounding, multivariate regression was performed for all univariate outcomes that were found to be statistically significantly associated with patient outcomes of interest. For the multivariate regression, patients who had one part of their Foker procedure performed using internal traction and another part using external traction were placed in the external traction category. Statistical analysis was carried out using STATA 15.2 (StataCorp 2017, College Station, TX); a p-value < 0.05 was considered statistically significant.

3. Results

From May 2014 to January 2019, 47 patients underwent LGEA repair using the FP and were included in the study, with 18 patients in the left-sided group. Twenty-nine patients had their repair performed on the right side and were used as a comparison cohort. Eleven Gross Type C patients had their distal tracheoesophageal fistula ligated at a referring facility with or without attempt at primary anastomosis prior to transfer but ultimately were not amenable to primary EA repair; thus, all patients analyzed had LGEA and required an esophageal growth process to achieve anastomosis. Of note, during the time frame of this study, there were another seven type C EA patients, transferred with their TEF previously repaired and had been deemed LGEA at the referring institution, in whom we were able to perform a primary repair without a FP, and thus were excluded from our analysis for this study. Also excluded were seven type A and four type B cases that were able to have a primary anastomosis without the Foker procedure for esophageal growth. Of these 18 excluded cases, all but one were repaired from the right, and five were repaired using minimally invasive techniques.

Of included patients, 55% were male, and 30 (64%) were born prematurely; nine patients had a genetic anomaly ($n = 8$ Trisomy 21, $n = 1$ CHARGE syndrome), and 40 (85%) had at least one other anomaly associated with the VACTERL syndrome. Only one patient in the left sided group had a right aortic arch, and four were considered as part of our salvage strategy for a prior failed right sided EA repair (Table 1). Patients in both groups had similar gap lengths and percentage of patients experiencing an attempt at esophageal anastomosis at a referring facility. Patients in the left-sided FP group more frequently underwent internal traction (single or serial events) for the entirety of the growth procedure (50% vs 10%, $p = 0.002$) and had all their operations done through a minimally invasive (MIS) approach (39% vs 7%, $p = 0.007$) when compared to their right-sided counterparts. This related to surgeon preference to perform thoracic tracheopexy by open thoracotomy methods (Table 2). Ten patients also had a left neck approach combined with an open or MIS approach for the left chest, in order to better dissect the upper pouch ($n = 4$), close the cervical esophagostomy ($n = 2$), repair an upper pouch TEF ($n = 2$), resect a cervical

Table 1
Demographic comparison between patients who underwent Foker Procedure from either a right-sided or left-sided approach. There was no difference in gap length, previous attempts at esophageal repair, age, or weight at the time of surgery.

Demographics*	Right-Sided FP ($n = 29$)	Left-Sided FP ($n = 18$)	P-value
Male (%)	14 (48%)	12 (67%)	0.21
Birth Weight (kg)	2.0 (1.7, 2.6)	2.3 (1.8, 2.6)	0.72
Prematurity (%)	20 (69%)	10 (56%)	0.37
Genetic Anomaly (%)	3 (10%)	6 (33%)	***0.05***
Type of Esophageal Atresia			
-Type A (%)	13 (45%)	11 (61%)	0.29
-Type B (%)	7 (24%)	5 (28%)	0.76
-Type C (%)	9 (31%)	2 (11%)[a]	0.12
Gap Length			
-Pressure (cm)	3.5 cm (2.3, 3.5)	2.0 cm (1.5, 3)	0.14
-Static/Contrast (cm)	4.4 cm (3.5, 5.0)	5.25 cm (4, 6)	0.17
Vertebral Bodies	5.25 (4, 6.5)	6.0 (5, 6)	0.91
Previous Attempt at Esophageal Anastomosis[b]	6 (21%)	4 (22%)	0.94
Age at Surgery (months)	5 months (3, 6)	3 months (2, 7)	0.36
Weight at Surgery (kg)	5.7 kg (4.0, 7.0)	5.5 kg (4.3, 6.4)	0.83

*All continuous variables are in medians with interquartile range.

[a] We do not recommend left-sided repairs for patients with Type C EA due to the fistula being right-sided in orientation. These two patients had repair of the fistula with an initial attempt at anastomosis through the right chest at the referring institution.

[b] These patients included Type A, B, and C EA patients who underwent previous anastomotic attempts performed in the right chest. This did not include patients who had a tracheo-esophageal fistula ligation without an attempt at primary repair.

Table 2
Comparison of Intra-Operative Characteristics between right-sided and left-sided Foker patients. Patients undergoing left-sided repair were more likely to have both a minimally invasive approach and undergo internal traction for their Foker procedure.

Intra-operative Variables	Right-Sided FP ($n = 29$)	Left-sided FP ($n = 18$)	P-value
Operative Approach			
-Open Thoracotomy	26 (90%)	6 (33%)	***<0.001***
-Minimally Invasive	2 (7%)	7 (39%)	***0.007***
-Part MIS, Part Open	1 (3%)	5 (28%)	***0.01***
Type of Traction			
-External Foker Procedure	24 (83%)	5 (28%)	***<0.001***
-Internal Foker Procedure	3 (10%)	9 (50%)	***0.002***
-Part Internal, Part External	2 (7%)	4 (22%)	0.14

Table 3
Univariate Analysis of Early Post-Operative Outcomes. Initial univariate analysis was performed comparing outcomes of patients who underwent either a right-sided Foker procedure or a left-sided Foker procedure. Outcomes that were found to be significant were then analyzed using multivariate regression to control for minimally invasive versus open approach and internal versus external Foker technique. (ICU = intensive care unit).

	Right-Sided FP ($n = 29$)	Left-sided FP ($n = 18$)	P-value
Unplanned Return to the OR for Leak or Suture Pull	10 (34%)	3 (17%)	0.21
Time on Traction (days)	14 (10, 21)	12.5 (9, 20)	0.92
Length of Paralysis (days)	19 (12, 22)	9 (1, 13)	***0.003***
Length of Intubation (days)	26 (15, 38)	16 (9, 22)	***0.008***
ICU Length of Stay	50 (24, 75)	34 (22, 38)	*0.06*
Hospital Length of Stay	74 (52, 134)	67 (46, 74)	*0.09*

tracheal diverticulum ($n = 3$), and/or perform a cervical posterior tracheopexy ($n = 3$).

Patients undergoing right side repairs underwent more surgical airway interventions (either concurrently with the FP and/or subsequently) for symptomatic TBM than those undergoing left sided repairs (83% vs 50%, $p = 0.02$). Right-sided patients were much more likely to undergo concurrent posterior thoracic tracheopexy ($p<0.001$) . Six patients in the right-sided group required either an additional anterior tracheopexy or redo posterior tracheopexy after having initial posterior airway work performed at the time of EA repair to address TBM, while no patients in the left-sided group had more than one operation for correction of TBM. Three patients in the left-sided group had a concurrent posterior descending thoracic aortopexy to help improve left mainstem bronchomalacia, and three had a posterior tracheopexy at the cervical level.

Both immediate post-operative and long-term complications were analyzed. While more patients in the right-sided group (34%) required an unplanned return to the operating room due to a leak from one of the esophageal pouches or because of a traction suture pull-out compared to the left-sided group (17%), this was not statistically significant ($p = 0.21$). Although the median number of days on traction were similar between groups, the length of paralysis (9 days vs 19 days, $p = 0.003$) and intubation (16 days vs 26 days, $p = 0.008$) were significantly less in the left-sided FP group (Table 3). However, on multivariate analysis, it was the use of internal traction that was significantly associated with a shorter length of paralysis ($p<0.01$), while neither side of Foker procedure ($p = 0.29$) or use of MIS technique ($p = 0.68$) was found to be significant. Likewise, use of internal traction was found to be trending toward a significantly shorter length of intubation ($p = 0.08$), while neither side of Foker ($p = 0.56$) and MIS technique ($p = 0.62$) were significant. No significant association was found in length of ICU stay or hospital stay on multivariate regression.

There were no significant differences in rates of anastomotic leak requiring intervention (17% vs 20%, $p = 0.80$) or need for stricture resection (6% vs 24%, $p = 0.12$) between left and right-sided cohorts, respectively. More patients in the right-sided group required eight or more anastomotic dilations (a proxy for refractory stricture) compared to the left-sided group (31% vs 6%, $p = 0.04$) (Table 4); however, the length of follow-up in the right-sided group was longer (median 498 days [IQR 221, 989] vs 297 days [IQR 76, 460], $p = 0.04$), which is expected considering the more recent implementation of the left-sided approach. One year post-FP feeding outcomes were similar between groups (Fig. 3). Overall, 13 (28%) patients were fully orally fed, while another 14 (30%) had consistent oral intake but still required feeding tube for supplementation. Twenty (43%) patients were still dependent on a feeding tube for adequate nutrition.

Table 4
Long-term Complications between Right-Sided and Left-Sided Foker Patients.

	Right-Sided FP ($n = 29$)	Left-sided FP ($n = 18$)	P-value
Anastomotic Leak[a]	6 (20%)	3 (17%)	0.80
Anastomotic Dilations			
-None	3 (10%)	3 (17%)	0.49
−1 to 3	7 (24%)	7 (39%)	0.28
−4 to 7	10 (34%)	7 (39%)	0.73
−8 or More	9 (31%)	1 (6%)	***0.04***
Stricture Resection	7 (24%)	1 (6%)	0.12
Venous Thromboembolism	3 (10%)	2 (11%)	0.91
Chyle Leak	1 (3%)	2 (11%)	0.27
Long Bone Fractures	1 (3%)	1 (6%)	0.62
Length of Follow-up	498 days (IQR 221, 989)	297 days (IQR 76, 460)	***0.04***

[a] Leak that required either operative intervention, stent, or VAC placement.

4. Discussion

Performing a LGEA repair through the left chest, regardless of aortic arch position, leads to similar outcomes as the standard right sided approach in appropriately selected patients who have either a failed EA repair through the right chest or have a large leftward-situated upper esophageal pouch or esophagostomy. Outcomes such as anastomotic leak rate, need for stricture resection and feeding status at one year post-FP were similar between the two groups, supporting the effectiveness of the left-sided approach.

The left-sided approach has been reserved historically for patients who were found to have a right aortic arch because TEF division or other airway work is generally much easier from the side opposite of the aortic arch. A systematic review performed by Parolini and colleagues found that all patients with a LGEA and a RAA required a left-sided approach (either primarily or conversion from a right-sided approach) in order to achieve an esophageal anastomosis [11]. Likewise, a survey of members of the International Pediatric Endosurgery Group (IPEG) and the European Society of Paediatric Endoscopic Surgeons (ESPES) found that while 50% would primarily perform an esophageal anastomosis in the left chest if a RAA was identified pre-operatively, 76% would switch from the right to the left side if difficulties arose intra-operatively [12]. Of physicians surveyed, 51% would convert to the left side rather than converting from a minimally invasive to an open approach on the right side, and overall, it was felt that the left-sided approach resulted in the best chance of a successful anastomosis [12].

In a retrospective review by the Midwest Consortium looking at 396 infants, 17 patients underwent EA repair with a RAA: 12 occurring on the right side and 5 on the left [24]. Interestingly, those who had their repair performed through the right chest had a greater incidence of anastomotic strictures (requiring at least one dilation). There was no difference in the rate of successful

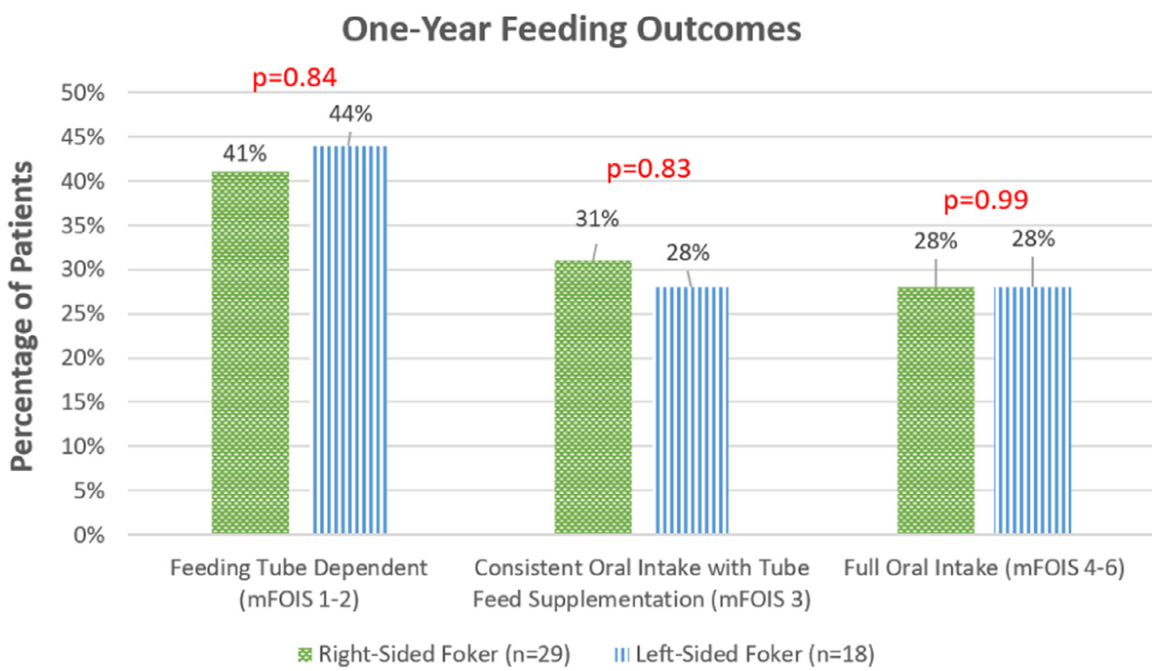

Fig. 3. One Year Feeding Outcomes of Patients using the modified Functional Oral Intake Scale. There was no difference between patients who underwent a right-sided or left-sided Foker in terms of one-year feeding outcomes.

establishment of esophageal continuity, anastomotic leak, recurrent TEF or chyle leak between groups [24]. The Midwest Consortium identified that repair through the left chest may be preferred in patients with a pre-operative diagnosis of RAA to decrease the risk of anastomotic stricture, which was consistent with the findings of the IPEG survey [12]. They found that a successful esophageal repair could be performed through the right chest in infants in whom the diagnosis of RAA was made at surgery [24]. While the left-sided approach has shown utility in patients with a RAA, alternative indications or descriptions of esophageal repair through the left chest in patients with a left aortic arch have not been described.

It is always best to use the patient's native esophagus for reconstruction [13,14]. Use of the left-sided approach in patients who have had multiple prior failed operations on the right side may facilitate preservation of the esophagus. We found it feasible to dissect the lower esophageal pouch in the posterior mediastinum from the left side, even with scar tissue of the lower pouch present in the right chest. This was true for both open and MIS approaches. Likewise, the upper esophageal pouch can be dissected in the left thoracic inlet superior to the arch and posterior to the left subclavian artery. This approach can be combined with a left neck exploration as needed for upper pouch mobilization, proximal TEF repair, and/or cervical level posterior tracheopexy. By this left-sided approach, we have achieved native esophageal continuity for several patients for whom it had been assumed esophageal replacement was the only feasible option.

In our practice, MIS techniques for esophageal growth and the internal traction method of the Foker procedure have evolved hand in hand. In this particular cohort, MIS techniques were utilized more often in the left sided group as stated above, but these techniques are clearly separate issues from side of approach, as MIS is very well established for right-sided thoracic esophageal procedures. Tainaka and colleagues and Bogusz and associates have both described an internal traction approach similar to ours [4,6]. The gap length was not measured in Bogusz's patients, while Tainaka used the technique on infants who had a gap ranging from 1 to 6 vertebral bodies. Tainaka described wrapping the sutures placed on the ends of the esophagus around the ribs [6], while Bogusz described placing the sutures between the two ends of the esophagus rather than using the ribs as internal pulleys [4]. Both Tainaka and Bogusz were able to show that the majority of patients (5/5 in Tainaka's cohort and 3/4 in Bogusz's cohort) achieved esophageal continuity at the second operation [4,6]. The 4th patient in Bogusz's cohort ultimately was able to achieve esophageal continuity after 6 attempts, most likely indicating a much longer gap than the other patients [4]. The long-term outcomes appear mixed in these two studies. The follow-up period was 7–67 months in Tainaka's study and 1–34 months in Bogusz's study [4,6]. While no patient in Tainaka's study developed a stricture requiring dilation, two patients (40%) developed an anastomotic leak [6]. In contrast, Bogusz reported that no patient had a leak, but two patients (50%) had strictures that required 3–4 dilations [4]. Our much larger cohort confirms these numbers, with under 20% in each group (which includes primary and rescue FP) developing a leak and about half (44–66%) of the cohort requiring at least 3 dilations. We also see the added benefit related to esophageal growth procedures for LGEA; with the addition of MIS and internal traction techniques, patients spent less time paralyzed and intubated. As the improvement reported in the univariate analysis of post-operative outcomes are likely due to a combination of technical changes, multivariate regression was performed of all outcomes that were found to be statistically significant in order to account for these colinear variables.

Our decision to initially try a left-sided approach in cases where the upper esophageal pouch was located more in the left chest was stimulated by several patients in the past with a large dilated leftward-situated upper esophageal pouch who developed significant symptoms of tracheal compression both during the esophageal growth process and after anastomosis. The resulting airway problems required additional operations in order to alleviate the compression that the upper part of the esophagus was placing on the posterior airway. Hence, another reason for performing a left-sided approach is to decrease the risk of airway distortion and subsequent symptomatic tracheomalacia in patients with a large leftward upper esophageal pouch. This study illustrates some of the differences related to airway disease and management that we have seen in patients with right-sided and left-sided approaches. Clearly, these differences were largely driven by selection bias in our decision to use a right-sided approach in those patients for whom a concurrent posterior thoracic tracheopexy was deemed necessary (which is not feasible from the left side with a left aortic arch). Use of the left approach therefore does not necessarily result in less tracheomalacia issues; rather, it is a useful alternative approach in select cases that have less severe **thoracic** tracheomalacia at baseline. And one of our primary exclusion criteria for using the left approach would be severe thoracic tracheomalacia that we believe deserves simultaneous repair (from the right side). This is not to say that we support the right-sided approach for cases that have tracheomalacia, and the left side for cases that do not; the issue is more nuanced than that. In fact, for the majority (78%) of patients in the left sided group, one of the main reasons for the left-sided approach related to airway optimization. It was to avoid creating or worsening posterior cervical tracheal intrusion by crossing a large proximal esophageal pouch behind the trachea in order to get it into the right chest.

Though our results are clearly impacted by selection bias, we did find that more patients in the right-sided group had concurrent and subsequent airway-related interventions to address TBM. These findings could be related to the severity of their underlying TBM or could be from worsening TBM from having pulled a large leftward upper pouch behind the trachea into the right chest. Because we did not use our selection criteria evenly during the entire study time-frame and because our use of a left-sided approach occurred toward the end of the study period, we can't make any cause and effect inferences from our data, but rather raise awareness of this potential issue so that we can study it in the future in a more controlled fashion with less selection bias. Nonetheless, it is interesting to note that no patient in the left-sided group required redo airway interventions to address TBM. Furthermore, the potential effect of a dilated upper esophagus, particularly in the setting of an anastomotic stricture, contributing to posterior intrusion type tracheomalacia should not be discounted. When the esophagus is repaired in the left chest (in patients with a normal left arch), it no longer occupies the space posterior to the trachea; therefore, this source of tracheal compression is avoided. So, rather than suggesting that a left-sided approach can allow the avoidance of evaluation or treatment for tracheomalacia, we think the option can become part of a comprehensive treatment strategy designed to optimize both esophageal and airway outcomes. We believe that all LGEA patients should have airway issues considered simultaneously with their esophageal management, and a left-sided repair offers another option to achieve the goal of esophageal continuity, while also considering best outcomes related to tracheomalacia, which itself has to be specifically delineated in terms of type and location and optimal strategy to repair it.

Additional limitations of this study include those inherent to a retrospective, single institution design. Our center is a specialized referral center for children with complex esophageal problems, which allows us to develop new approaches to tackle these challenging problems. We propose this approach for a specific population of patients and not to the general esophageal atresia population. As the thoracic trachea and carinal area cannot be easily approached from the left chest with a left sided aortic arch, infants with an intact TEF or those with a failed repair which is scarred at the level of the carina should not be approached from the left side. As our two groups were not equal in regard to the performance of thoracic TBM procedures, only descriptions of trends seen between airway work and side of Foker repair could be elucidated.

5. Conclusion

For LGEA patients, a left thoracic approach (regardless of aortic arch position) can be employed for patients with a large leftward upper esophageal pouch or multiple prior right sided operations without symptomatic thoracic tracheobronchomalacia and without a distal TEF. In these circumstances, outcomes are similar to the standard right-sided approach and could potentially yield less airway compression issues.

References

[1] Rothenberg SS. Thoracoscopic repair of esophageal atresia and tracheo-esophageal fistula in neonates: evolution of a technique. J Laparoendosc Adv Surg Tech A 2012;22(2):195–9.

[2] Foker JE, Linden BE, Boyle EM Jr, Marquardt C. Development of a true primary repair for the full spectrum of esophageal atresia. Ann Surg 1997;226(4):533–43.

[3] Till H, Muensterer O, Rolle U, Foker J. Staged esophageal lengthening with internal and subsequent external traction sutures leads to primary repair of an ultralong gap esophageal atresia with upper pouch tracheoesophageal fistula. J Pediatr Surg 2008;41:E33–5.

[4] Bogusz B, Patkowski D, Gerus S, Rasiewicz M, Górecki W. Staged thoracoscopic repair of long-gap esophageal atresia without temporary gastrostomy. J Laparoendosc Adv Surg Tech 2018;28(12):1510–12.

[5] Fraser JD, St Peter SD. The current thoracoscopic management of esophageal atresia. Eur J Pediatr Surg 2020 (in press).

[6] Tainaka T, Uchida H, Tanano A, et al. Two-stage thoracoscopic repair of long–gap esophageal atresia using internal traction is safe and feasible. J Laparoendosc Adv Surg Tech A 2017;27(1):71–5.

[7] van der Zee DC, Bax NMA. Thoracoscopic treatment of esophageal atresia with distal fistula and of tracheomalacia. Semin Pediatr Surg 2007;16:224–30.

[8] van der Zee DC, Vieirra-Travassos D, Kramer WLM, Tytgat SHAJ. Thoracoscopic elongation of the esophagus in long gap esophageal atresia. J Pediatr Surg 2007;42:1785–8.

[9] van der Zee DC, Gallo G, Tytgat SHA. Thoracoscopic traction technique in long gap esophageal atresia: entering a new era. Surg Endosc 2015;29:3324–30.

[10] Mentessidou A, Avgerinos I, Avgerinos N, et al. Right or left thoracotomy for esophageal atresia and right aortic arch? Systematic review and surgicoanatomic justification. J Pediatr Surg 2018;53:2128–35.

[11] Parolini F, Boroni G, Stefini S, et al. Role of preoperative tracheobronchoscopy in newborns with esophageal atresia: a review. World J Gastrointest Endosc Oct 2014;6(10):482–7.

[12] Aguilera-Pujabet M, Gaheter JAM, Guillén G, et al. Management of neonates with right-sided aortic arch and esophageal atresia: international survey on IPEG and ESPES members experience. J Pediatr Surg 2018;53:1923–7.

[13] Foker JE, Krosch TCK, Catton K, et al. Long-gap esophageal atresia treated by growth induction: the biological potential and early follow-up results. Semin Pediatr Surg 2009;18:23–9.

[14] van der Zee dc, Bagolan P, Faure C, et al. Position paper of INoEA working group on long-gap esophageal atresia: for better care. Front Pediatr 2017;5(63):1–3 March.

[15] Tytgat SHAJ, van Herwaarden-Lindeboom MYA, van Tuyll van Serooskerken ES, van der Zee DC. Thoracoscopic posterior tracheopexy during primary esophageal atresia repair: a new approach to prevent tracheomalacia complications. J Pediatr Surg 2018;53:1420–3.

[16] Briganti V, Oriolo L, Mangia G, Buffa V, Calisti A. Tracheomalacia in esophageal atresia. Usefulness in preoperative imaging evaluation for tailored surgical correction. J Pediatr Surg. 2006;41(9):1624–8.

[17] Bairdain S, Zurakowski D, Baird CW, Jennings RW. Surgical treatment of tracheobronchomalacia: a novel approach. Paediatr Respir Rev 2016;19:16–20.

[18] Bairdain S, Hamilton TE, Smithers CJ, et al. Foker process for the correction of long gap esophageal atresia: primary treatment versus secondary treatment after prior esophageal surgery. J Pediatr Surg 2015;50(6):933–7.

[19] Svetanoff WJ, Zendejas B, Smithers CJ, et al. Great vessel anomalies and their impact on the surgical treatment of tracheobronchomalacia. J Pediatr Surg 2019 Aug[Epub ahead of print]. doi:10.1016/j.pedsurg.2019.08.001.

[20] Hester HF, Smithers CJ, Hamilton TE, et al. Descending aortopexy and posterior tracheopexy for severe tracheomalacia and left mainstem bronchomalacia. Semin Thorac Cardiovasc Surg Autumn 2019;31(3):479–85.

[21] Morabito A, MacKinnon E, Alizai N, et al. The anterior mediastinal approach for management of tracheomalacia. J Pediatr Surg 2000;35(10):1456–8.

[22] Jennings RW, Hamilton TE, Smithers CJ, et al. Surgical approaches to aortopexy for severe tracheomalacia. J Pediatr Surg 2014;49:66–71.

[23] Crary MA, Dodrill P, Carnaby-Mann GD, Groher ME. FOIS – suckle feeds and transitional feeds. Dysphagia Clin Manag Adults Child 2014;876:1516–20.

[24] Lal DR, Gadepalli SK, Downard CD, et al. Infants with esophageal atresia and right aortic arch: characteristics and outcomes from the Midwest Pediatric Surgery Consortium. J Pediatr Surg 2019;54:688–92.