Association of chest tube position with phrenic nerve palsy after neonatal and infant cardiac surgery

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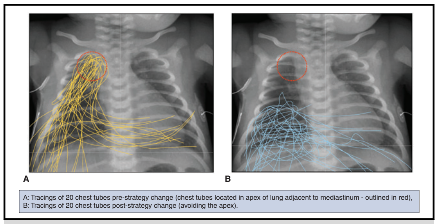
ABSTRACT

Background: Diaphragm paralysis (DP) complicates the postoperative course of neonates and infants undergoing cardiac surgery. Events causing DP remain poorly understood, and preventive strategies remain elusive. This retrospective cohort analysis aims to test the hypothesis that chest tubes in contact with the phrenic nerve in the pleural apex may cause pressure palsy.

Methods: In late 2018, the chest tube positioning strategy was changed so as to avoid a putative "danger zone" configuration, defined as (1) the chest tube looping apicomedially at the level of the second right intercostal space, and (2) wedging of chest tube tip against pericardium. A preintervention and postintervention analysis of 531 patients from 2012 to 2019 was performed to evaluate any association of chest tube position or duration in place with DP. Univariable and multivariable analyses were carried out, with significance set a priori at $P < .05$.

Results: The preintervention group comprised 488 patients, of whom 32 (6.6%) had RDP. The postintervention group comprised 43 patients, none of whom had DP. Multivariable analysis of the entire cohort revealed chest tube positioning in the danger zone as the only significant association with RDP (odds ratio, 4.22; 95% confidence interval, 1.57-11.33; $P < .05$).

Conclusions: Chest tubes that occupy the right superior pleural space are associated with increased risk of DP. (J Thorac Cardiovasc Surg 2021;161:1618-22)



Representative tracings of preprocess and postprocess change chest tube courses in the pleural space, with the danger zone (apex of lung adjacent to mediastinum) marked by a red circle.

CENTRAL MESSAGE

Chest tube positioning in the apex of the pleural space adjacent to the mediastinum is associated with diaphragm paralysis (DP). A change in chest tube placement strategy led to a significant reduction in DP.

PERSPECTIVE

Diaphragm paralysis after neonatal and infant cardiac surgery imparts significant morbidity, prolongation of postoperative length of stay, and increased mortality. Evidence supports the value of a simple modification of chest tube position in preventing this incompletely understood but important complication of surgery, and points to pressure palsy as a possible mechanism.

See Commentaries on pages 1623 and 1625.

The phrenic nerve is the longest branch of the cervical plexus and enters the thorax through the superior thoracic aperture, between the subclavian artery and vein.[1] The phrenic nerve descends, crossing the apex of the right or left pleural cavity, coursing between the mediastinal pleura and the pericardium.[2]

Phrenic nerve injury is a well-recognized complication of surgery. Proposed mechanisms of injury include hypothermia, retraction, and electrocautery, although data to support these mechanisms remain inconsistent[3-5] Nerves can also be

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Abbreviations and Acronyms
DP = diaphragm paralysis
RDP = right diaphragm paralysis

damaged by compression or stretching; Lundborg and colleagues[6] and Adachi and colleagues[7] performed nerve compression studies on rat sciatic and optic nerves and showed that ischemia from compression can lead to significant nerve damage. Compression injury of the radial nerve due to blood pressure cuff also has been reported.[8,9] The risk of phrenic nerve injury might not be limited to the intraoperative period of cardiothoracic surgery; compression damage from indwelling chest tubes may contribute risk of pressure palsy. In the present study, we aimed to test the hypothesis that chest tubes in contact with the phrenic nerve in the pleural apex may cause pressure palsy, contributing to clinical diaphragm paresis or diaphragm paralysis (DP).

METHODS

In late 2018, chest tube strategy at our institution was changed, and a preintervention and postintervention analysis of 531 patients between January 1, 2012, and June 22, 2019, was performed to evaluate any impact of positioning and duration of chest tubes. We included a single-surgeon series of all patients age <1 year undergoing congenital heart surgery with cardiopulmonary bypass who had right-sided 19 Fr Blake chest tube (Ethicon, Somerville, NJ) connected to a Pleur-evac system (Teleflex Medicine, Morrisville, NC) placed in the course of operation. Reoperations were excluded from the study. The intervention was a change in chest tube positioning to avoid the tube occupying a putative "danger zone," defined as the tube looping apicomedially into the second right intercostal space (Figure 1). Postoperative chest radiographs were examined by 3 independent readers to determine whether the chest tube was located in the danger zone. The examiner was blinded to right DP (RDP) outcome to avoid potential bias. All 3 examiners reported the same results for all 531 patients. Examiners also reviewed the chest radiograph immediately before chest tube removal to ensure that chest tubes had not significantly changed position. No chest tubes moved in or out of the danger zone between these time points.

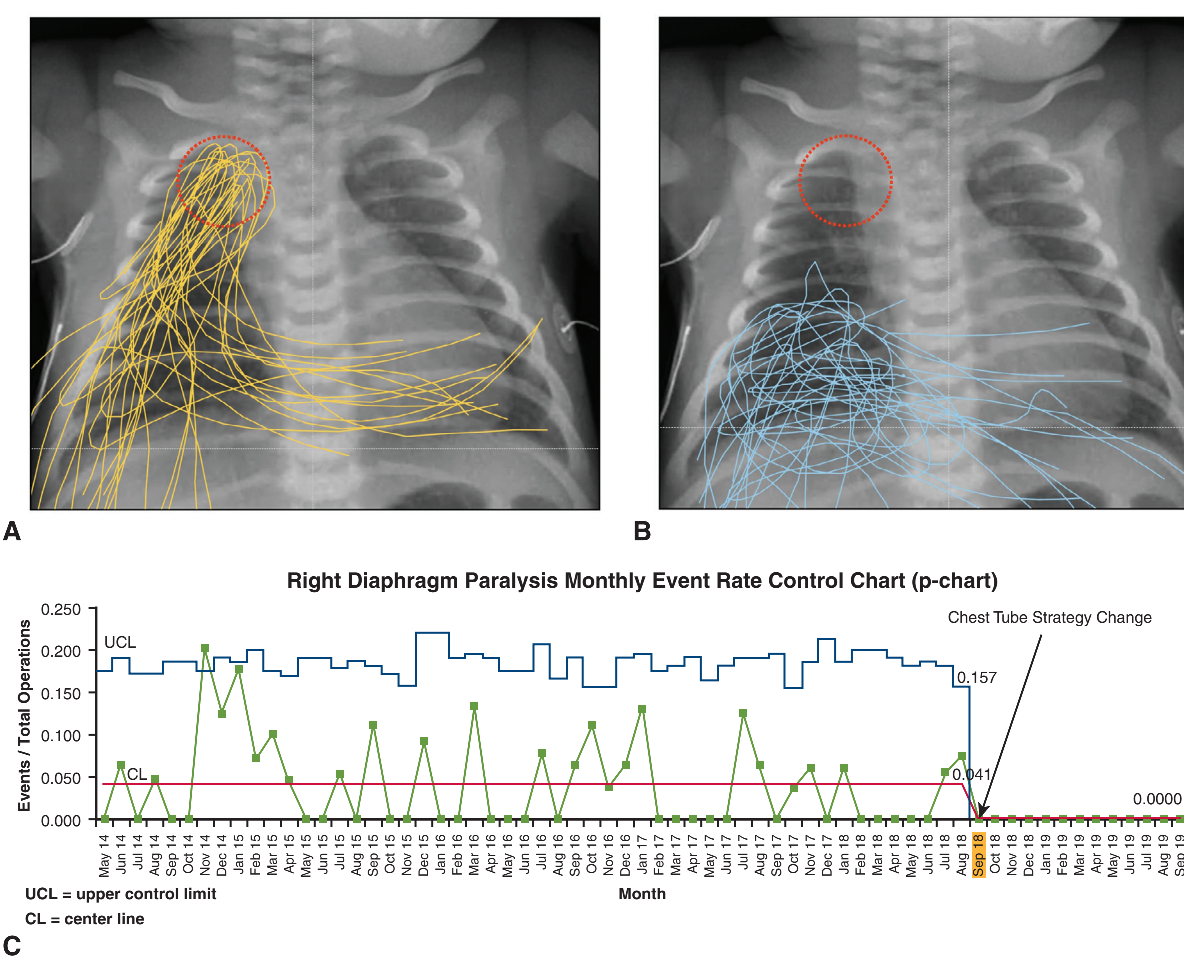

FIGURE 1. Representative tracings of (A) preprocess change and (B) postprocess change chest tube courses within the pleural space, with (C) control chart showing reduced incidence of diaphragm paralysis associated with the process change.

TABLE 1. Patient demographic and other characteristics

N	Characteristic	Right diaphragm paralysis Yes (N = 32)	Right diaphragm paralysis No (N = 499)	*P* value
481*	Birth weight, kg, median (95% CI)	3.18 (2.56-3.68)	3.13 (2.58-3.50)	.67†
531	Age at surgery, d, median (95% CI)	11.50 (6.00-85.50)	44.00 (8.00-158.00)	<.05†
531	Weight at surgery, kg, median (95% CI)	3.70 (2.80-4.95)	4.00 (3.30-6.00)	<.05†
529*	Height at surgery, cm, median (95% CI)	50.50 (47.50-55.88)	53.00 (49.50-61.00)	<.05†
529*	Body surface area, kg/m^2, median (95% CI)	0.23 (0.19-0.26)	0.24 (0.21-0.32)	<.05†
531	Sex, n (%)			.26‡
	Female	11 (34)	222 (44)	
	Male	21 (66)	277 (56)	
531	Postoperative length of stay, d, median (95% CI)	53.00 (29.00-100.75)	17.00 (9.00-17.00)	<.05†
513	Duration of intubation, d, median (95% CI)	20.50 (6.25-20.50)	3.0 (1.00-9.00)	<.05†
531	CPB time, min, median (95% CI)	158.50 (111.75-205.75)	135.00 (94.00-177.00)	.11†
531	Mortality, n (%)	5/32 (15.6)	33/499 (6.6)	.06‡
486*	30-d readmission, n (%)	7/28 (25.0)	102/458 (22)	.74‡

Percentages are expressed as column percentages. *CPB*, Cardiopulmonary bypass. *Missing data. †Continuous variables were analyzed using the Mann–Whitney *U* test. ‡Categorical variables were analyzed using the χ^2 test or Fisher's exact test as applicable.

The congenital heart surgery database was complemented with data from the electronic medical and radiologic records. This chart review study was approved by Vanderbilt University Medical Center's Institutional Review Board (IRB#151048), and patient consent was waived.

Definitions and Review of Electronic Medical Records

DP was defined as absent or paradoxical motion of the diaphragm on ultrasound and/or fluoroscopy during spontaneous respiration. Radiology reports were reviewed to ascertain the side of DP, and electronic medical records were reviewed. Reintubations were captured from the date of diagnosis to withdrawal of all respiratory support with subsequent placement on room air for at least 7 days. Respiratory support was defined as invasive or noninvasive ventilator support and high-flow oxygen via nasal cannula (Vapotherm, Exeter, NH). The danger zone was defined as the chest tube looping apicomedially into the second right intercostal space, and wedging of the chest tube tip against pericardium.

Statistical Analysis

Univariable and multivariable binary regression analyses were performed to determine associations between postoperative length of stay, cardiopulmonary bypass time, chest tube location, chest tube duration, age at surgery, and development of DP. Statistical analyses were performed using SPSS version 23 for Mac (IBM, Armonk, NY).

A process control chart (p-chart, QIMacros; https://qimacros.com) describing the monthly RDP rate (ie, events observed/operations performed) was constructed to illustrate the findings.[10,11]

RESULTS

Our total cohort comprised 531 patients, divided into an RDP group, with 32 patients (6%), and a non-RDP group, with 499 patients (94%) (Figure 2). Among demographic factors, the RPD and non-RDP groups differed significantly in days of age at surgery (11.50 [95% CI. 6.00-85.50] vs 44.00 [95% CI, 8.00-158.00]; $P < .05$) and body surface area in kg/m^2 (0.23 [95% CI, 0.19-0.26] vs 0.24 [95% CI, 0.21-0.32]; $P < .05$). There was no significant difference in birth weight ($P = .67$) or sex ($P = .26$) between the 2 groups. The RDP and non-RDP groups differed significantly in postoperative length of stay (53.00 days [95% CI, 29.00-100.75] vs 17.00 days [95% CI, 9.00-17.00]; $P < .05$) and duration of intubation (20.50 days [95% CI, 6.25-20.50] vs 3.0 days [95% CI, 1.00-9.00]; $P < .05$). There was no significant difference in cardiopulmonary bypass time ($P = .11$), mortality ($P = .06$), or 30-day readmissions ($P = .74$) between the 2 groups (Table 1).

Univariable analysis of chest tube location and duration revealed an odds ratio of 3.16 (95% CI, 1.27-7.82; $P < .05$) for RDP in patients with a chest tube in the danger zone compared with those without a chest tube in the danger zone. The RDP group had a significantly longer number of right chest tube days compared with the non-RDP group (11.00 days [95% CI, 7.25-15.70] vs 6.00 days [95% CI, 4.00-10.00]; $P < .05$). We also divided our population into preintervention and postintervention groups. The preintervention group comprised 488 patients, of whom 32 (6.6%) had RDP. The postintervention group had 43 patients, none of whom had RDP. The odds ratio for DP in the preintervention group versus postintervention group was 2.75 (95% CI, 0.365-20.674; $P = .1$) (Table 2).

Multivariable analysis was performed to ascertain the effects of age at surgery, postoperative length of stay, cardiopulmonary bypass time, chest tube positioning in the danger zone, and chest tube duration on DP in the entire cohort (531 patients). The logistic regression model was statistically significant [$\chi^2(4) = 29.091$; $P < .0005$; Hosmer–Lemeshow test, $\chi^2 = 3.843$, $P = .871$]. The model explained 15.3% (Nagelkerke's R^2) of the variance in heart

TABLE 2. Univariable analysis of chest tube location and duration

N	Variable	Right diaphragm paralysis Yes (N = 32)	No (N = 499)	Odds ratio (95% CI)	*P* value
531	Right chest tube in danger zone, n (%)	27 (84)	276 (55)	4.34 (1.63-11.36)	<.05*
	Yes	5 (16)	220 (45)		
	No				
531	Right chest tube duration, d, median (95% CI)	11.0 (7.25-15.70)	6.00 (4.00-10.00)		<.05†
531	Change in chest tube strategy, n (%)	32 (6.6)	456 (93.4)		.1*
	Prechange	0 (0)	43 (100)		
	Postchange				

*Categorical variables were analyzed using the χ^2 test or Fisher's exact test as applicable. †Continuous variables were analyzed using the Mann-Whitney *U* test.

disease and correctly classified 93.5% of cases. The area under the receiver operating characteristic curve (c-index) was 0.78 (95% CI, 0.69-0.87) (Appendix E1). Of the 5 predictive variables, only chest tube positioning in the danger zone was significantly associated with DP. Chest tube position in the space defined as danger zone was associated with 4.05-fold higher odds (95% CI, 1.5-10.9; $P = .006$) of DP compared with chest tube position outside of the danger zone (Table 3).

A RDP monthly event rate control chart (p-chart) shows a center line shift following the process change in September 2018, with mean monthly event rate shifting from 4.1% to 0%, which was sustained for 12 consecutive months.

DISCUSSION

DP after infant cardiac surgery is an uncommon but consequential event, elusive in etiology and often presumed to be from direct phrenic nerve injury during the performance of surgery. Prompted by an observed increase in the incidence of postoperative DP at our center, we studied procedural associations with phrenic nerve injury in a large cohort of patients and found no significant associations except neonatal age status and prolonged length of postoperative stay (unpublished data). Seeking other potential culprits, we analyzed pleural drains, which was not considered among the procedural elements in our previous study. Nerve compression injuries have been described in animal models.[6,7] but no previous study examined whether chest tube position and duration in that position may exert sufficient pressure over time to cause diaphragm paresis or DP.

Our routine historical practice has been to place a single right-sided 19 Fr Blake drain (Ethicon, Somerville NJ) in a majority of infants at operation, looped into the pleural apex and wedged in the pericardium, to drain both the pleural space and the pericardium after cardiac surgery. An observed preponderance of right-sided phrenic palsies, a preponderance of chest tube placement on the right side, and the absence of other demonstrable procedural associations led us to hypothesize that chest tube position may cause compression injury and an increased incidence of RDP. Based on our observations, a practice change was instituted in which chest drains are now routinely placed laterally and inferiorly in the pleural space, away from the pleural apex and the phrenic nerve (Figure 1).

In light of a preponderance of right-sided palsies observed, and for analytic consistency, we considered RDP our main outcome variable and included only thosepatients with right chest tube placement.

Our univariable analysis showed that both chest tube duration and position were associated with an increased likelihood of DP. Multivariable analysis showed significance only with chest tube position. Our results are graphically demonstrated by a monthly event rate control chart (p-chart), showing the monthly rate (events/number of operations) of RDP between May 2014 and September 2019. The RDP event rate declined to zero for 12 consecutive months, representing a significant association

TABLE 3. Multivariable analysis

Variables in the equation	B	SE	Wald	df	Sig.	Exp(B)	95% CI for EXP(B) Lower	Upper
Postoperative LOS	.005	.003	3.594	1	.058	1.005	1.000	1.010
CPB time	.001	.003	.051	1	.822	1.001	.995	1.006
Right CT duration, d	.013	.016	.644	1	.422	1.013	.982	1.044
Right CT in danger triangle*	1.399	.505	7.660	1	.006	4.051	1.504	10.909
Age at surgery	−.004	.003	1.768	1	.184	.996	.991	1.002
Constant	−3.986	.680	34.369	1	.000	.019		

LOS, Length of stay; *CPB*, cardiopulmonary bypass; *CT*, chest tube. *Significant.

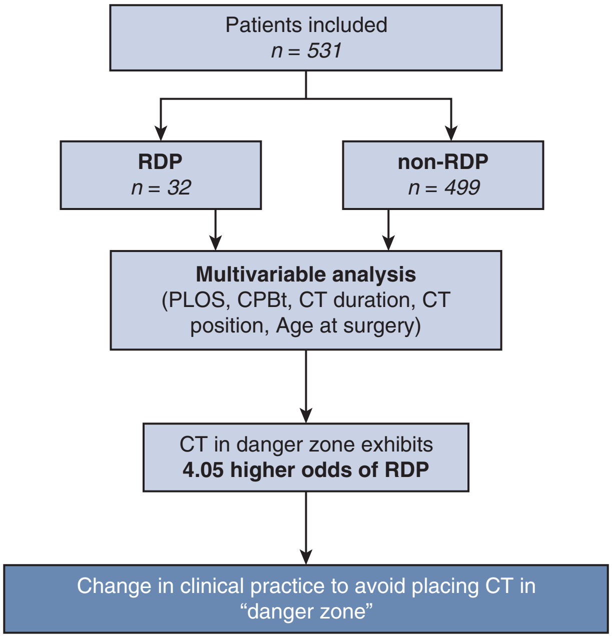

FIGURE 2. Flow chart of 531 patients who underwent univariable and multivariable analysis to determine the risk factors for diaphragm paralysis. *RDP*, Right diaphragm paralysis; *PLOS*, postoperative length of stay; *CPBt*, cardiopulmonary bypass time; *CT*, chest tube.

with the practice change that directed chest tubes away from the pleural apex and mediastinum.[10,11] These results support the hypothesis that the mechanism of injury in DP may be pressure palsy of the phrenic nerve when chest tubes are pushed into the apex of the pleural space, where they may exert pressure on the course of the phrenic nerve.

Study limitations include those inherent in a retrospective study examining rare events, including missing data, incomplete accounting for potential confounders, and subjectivity of the judgment of chest tube position. The hypothesized pressure palsy of the phrenic nerve can only be inferred indirectly and cannot be proven by these data. Any potential association of early chest tube removal with phrenic nerve recovery is beyond the scope of this study, and phrenic nerve recovery is the subject of further study.

DP following cardiac surgery is rare but important, contributing to morbidity and mortality. Causes contributing to DP may be multifactorial, institution-dependent, and individual-dependent. Although we demonstrate a compelling association of chest tube position with DP at our center, our findings might not be broadly translatable. Our results call attention to chest tube position as one possible, easily modifiable contributing factor.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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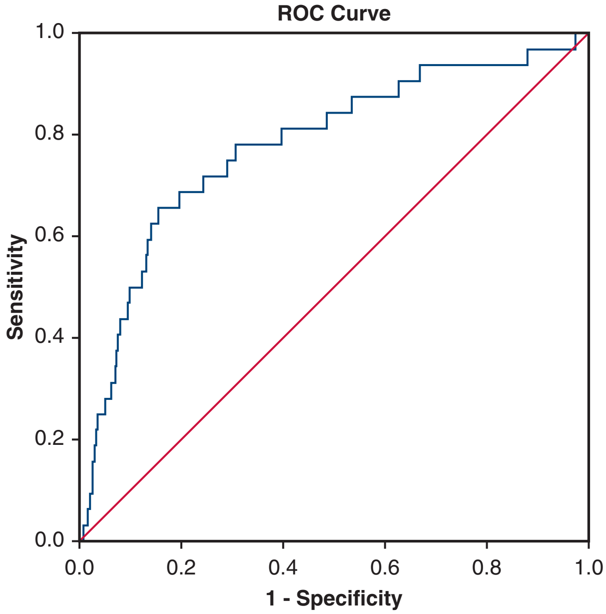
Key Words: congenital heart surgery, diaphragm paralysis, phrenic nerve, neonatal cardiac surgery

Coefficients*		
	Collinearity statistics	
Model	Tolerance	VIF
1 Postoperative LOS	.944	1.059
CPB time	.894	1.118
Age at surgery	.892	1.121
Right chest tube in danger triangle?	.968	1.033

VIF, Variance inflation factor. *Dependent variable: right chest tube duration (d).



Area under the curve				
Test result variable(s): predicted probability				
		Asymptotic	Asymptotic 95% CI	
Area	SE*	significance†	Lower bound	Upper bound
.779	.046	.000	.688	.869

*Under the nonparametric assumption. †Null hypothesis: true area = 0.5.