The advantage of early plication in children diagnosed with diaphragm paresis

Alejandro A. Floh, MD, MSc,[a] Intikhab Zafurallah, MD,[b] Cathy MacDonald, MD,[c] Osami Honjo, MD, PhD,[d] Chun-Po S. Fan, PhD, PStat,[e] and Peter C. Laussen, MB, BS[f]

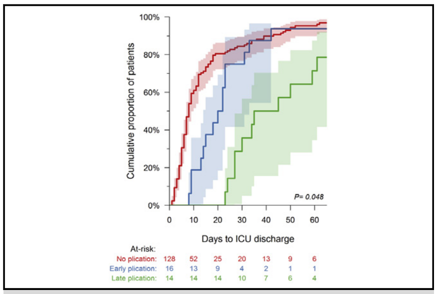
ABSTRACT

Background: In this single-center study, we sought to determine the frequency of phrenic nerve injury leading to diaphragm paresis (DP) in children following open cardiac surgery over the last 10 years, and to identify possible variables that predict the need for plication and associated clinical outcomes.

Methods: Patients diagnosed with DP were identified from departmental databases and a review of clinical diaphragm ultrasound images. A cohort was analyzed for predictors of diaphragm plication and associations with clinical outcomes. Cumulative proportion graphs modeled the association between plication and length of stay.

Results: DP was diagnosed in 161 of 6448 patients (2.5%) seen between January 2002 and December 2012. All diagnoses but 1 were confirmed by ultrasound. Plication of the diaphragm was performed in 30 patients (19%); compared with patients who did not undergo plication, these patients were younger (median age, 10 days vs 138 days; $P < .001$), more likely to have undergone deep hypothermic circulatory arrest (47% vs 18%; $P = .005$), had a longer duration of positive pressure ventilation (median, 15 days vs 7 days; $P < .001$), and had longer lengths of stay in both the intensive care unit (median, 23 days vs 8 days; $P < .0001$) and the hospital (median, 37 days vs 15 days; $P < .0001$). Early plication was associated with reduction in all intervals of care.

Conclusions: Early plication should be considered for patients with diaphragm paresis requiring prolonged respiratory support after cardiac bypass surgery. Longer follow-up evaluation is required to better define the long-term implications of plication. (J Thorac Cardiovasc Surg 2017;154:1715-21)



Cumulative proportion of intensive care unit discharge from index operation according to time to plication.

Central Message

Neonates with diaphragm paresis are at risk for requiring diaphragm plication. Early plication for those dependent on respiratory support facilitates weaning off ventilation and shortens intensive care unit and hospital lengths of stay.

Perspective

Diaphragm paresis (DP) occurs following pediatric cardiac surgery. Neonatal age and the use of deep hypothermic circulatory arrest are the strongest predictors of requiring plication to separate from respiratory support. Delays in plication result in prolonged intensive care unit and hospital stays. Routine follow-up is needed to define the natural history of DP and plication.

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Phrenic nerve injury resulting in diaphragmatic paresis (DP) has a reported frequency of 3% to 12.8% after pediatric cardiac surgery.[1-4] Associated perioperative morbidity includes increased duration of mechanical

From the [a]Department of Critical Care Medicine and Labatt Family Heart Centre, Departments of [c]Radiology and [f]Critical Care Medicine, [d]Division of Cardiovascular Surgery and Labatt Family Heart Centre, and [e]Cardiovascular Data Management Centre, The Hospital for Sick Children, Toronto, Ontario, Canada; and [b]Paediatric Intensive Care and KIDS Retrieval Service, Birmingham Children's Hospital, Birmingham, United Kingdom.

Received for publication Jan 25, 2017; revisions received April 25, 2017; accepted for publication May 31, 2017; available ahead of print July 13, 2017.

Address for reprints: Alejandro A. Floh, MD, MSc, The Hospital for Sick Children, 555 University Ave, Toronto, Ontario, Canada M5G 1X8 (E-mail: alejandro.floh@sickkids.ca).

0022-5223/$36.00

http://dx.doi.org/10.1016/j.jtcvs.2017.05.109

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CONG

Abbreviations and Acronyms
CPB = cardiopulmonary bypass
DHCA = deep hypothermic circulatory arrest
DP = diaphragm paresis
ICU = intensive care unit
IQR = interquartile range

ventilation, increased risk of atelectasis and pulmonary infection, prolonged postoperative recovery, increased length of stay in the intensive care unit (ICU), and increased hospitalization costs.[5,6]

The diagnosis of DP is suspected clinically in the context of increased work of breathing, persistently elevated hemidiaphragm (on roentgenogram), and failure to separate from positive-pressure ventilation. Diaphragmatic movement can be further evaluated using fluoroscopy and ultrasonography. Management strategies for DP range from supportive care with continued ventilator support while awaiting recovery of function to diaphragm plication to improve respiratory mechanics. Indications for surgical intervention are highly variable, with a tendency toward early plication seen in some centers, especially in infants.[7]

The purpose of this study was to identify the incidence of and risk factors for DP, and to examine the variability in management of DP following cardiac surgery. We also sought to describe the impact of diaphragm plication on intervals of care, including duration of ventilation and length of ICU and hospital stay.

METHODS

We conducted a retrospective review of all patients admitted to the cardiac intensive care unit of The Hospital for Sick Children, Toronto, after pediatric cardiac surgery between January 2002 and December 2012 who were diagnosed with DP. This study was approved by the hospital's Research Ethics Board, with a waiver of the requirement for consent. Subjects with DP and subjects who had undergone diaphragm plication were identified from the cardiology, cardiovascular surgery, and critical care databases. To ensure that potential subjects were not missed because of coding errors, charts of all patients who underwent ultrasound evaluation of diaphragm function and had previous cardiac surgery were identified from the radiology database and reviewed by a member of the research team (I.Z.). Subjects were included in the analysis if DP was diagnosed following the index surgery but within the index hospitalization. Subjects were excluded who had preoperative evidence of an elevated hemidiaphragm, known diagnosis of neuromuscular disease, or ventilator dependence (either invasive or noninvasive). No subjects were excluded for preoperative diaphragm elevation.

The management of patients identified with DP was left to the discretion of the responsible medical and surgical team. A standardized treatment protocol was not in place, but plication was generally considered for patients who failed multiple extubation attempts or were unable to wean from positive-pressure ventilation. All surgical plications were completed through a standardized approach. A thoracotomy at the level of the fifth or sixth intercostal space was used to mobilize the ipsilateral lung and divide the inferior pulmonary ligament. Several 4-0 polypropylene sutures (Polene; Ethicon, Somerville, NJ) with Teflon pledgets were placed to plicate the diaphragm into a flat position with some tension.

Demographic data, cardiac anatomy, cardiac surgery, additional interventions, and intervals of care were extracted from the electronic medical records. The time of DP diagnosis was defined as the time of confirmatory testing, including diaphragm ultrasound or fluoroscopy, or the time of index surgery if direct dissection of phrenic nerve was observed. DP was defined as minimal, absent, or paradoxical movement of the diaphragm as reported on confirmatory testing. Absent or diminished diaphragm movement in the proper direction was defined as paresis; diaphragms with paradoxical motion were considered paralyzed.

The primary outcome was total duration of positive pressure ventilation support, including all periods in which invasive and noninvasive support (continuous positive airway pressure/bilevel positive airway pressure) was provided. The durations of ICU stay and hospital stay were evaluated as secondary endpoints.

All continuous variables are expressed as mean $\pm$ standard deviation or median with interquartile range (IQR) according to their distribution. Categorical data are expressed as frequencies and proportions. The incidence of DP was defined as the number of identified cases by the total number of cardiac surgeries over the corresponding time period. Patients who underwent plication were categorized as early plication ($<$7 days after DP diagnosis) or late plication ($\geq$7 days after DP diagnosis). Seven days was chosen as the clinical limit by which time most of the other perioperative causes of ongoing respiratory support would have been resolved or addressed. Univariate linear regression was used to identify the direction and strength of associations between risk factors, surgical diaphragm plication, and outcomes. Owing to the competing event of postoperative mortality, the primary and secondary outcome variables were analyzed using competing-risk models. Cumulative incidence functions were used to model hospital discharge from the index operation, comparing patients who underwent diaphragm plication versus those who did not, and those who underwent earlier plication versus those who underwent later plication. Between-group differences were assessed using Gray's test. The competing-risk models were also used to summarize the median (IQR) of the time-to-event variables. Subgroup analysis included cumulative incidence functions to explore the association between the timing of plication and the time to discharge from plication surgery. All statistical analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC). A P value $\leq$.05 was considered statistically significant.

RESULTS

A diagnosis of DP was identified in 161 patients, 4 of whom were diagnosed after hospital discharge and thus were excluded from this analysis. A total of 6448 index open cardiac operations were completed during this time interval, corresponding to an overall incidence of DP of 2.4%. DP was diagnosed at a median of 7 days (IQR, 4-12 days) after surgery. Ultrasound was the primary confirmatory imaging modality in all but 1 case, with the diagnosis confirmed on visual inspection in only a single subject. Diaphragm plication was completed in 30 patients (19%).

Demographic Data

The study population was predominately male (63%), with a median age of 84 days (IQR, 9-310 days). The majority had undergone biventricular heart surgery (74%). Infants composed 76% (n = 12) of the cohort. The surgical approach was median sternotomy in 94% of the patients, and 88% of the surgeries used cardiopulmonary bypass (CPB). The most common surgical procedures included