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Early versus late repair of diaphragmatic palsy after congenital heart surgery: A comparative study

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***Abstract*---Background:** Diaphragmatic palsy (DP) following pediatric cardiac surgery is a known complication because of phrenic nerve injury, which can significantly impact respiratory function and overall recovery. The aim is to evaluate the effect of early diaphragm plication on clinical outcomes in pediatric patients who have undergone cardiac surgery and to compare it with late diaphragm plication. **Methods:** This retrospective study carried out on 46 cases with DP; 26 underwent early diaphragmatic plication, while 20 patients subjected to late Plication. Diagnosis of DP was primarily based on clinical signs, confirmed with bedside ultrasonography and fluoroscope. The early plication being defined as surgery performed in 7 days of DP diagnosis and late plication as surgery performed after 7 days. All plications were done through standard thoracotomy using non absorbable sutures to flatten the diaphragm. **Results:** Patients who underwent early diaphragmatic plication were significantly younger (P value = 0.02), and had fewer complications including the need for noninvasive ventilation (P value = 0.031), ventilator acquired pneumonia (P value = 0.011), and recurrent lung collapse (P value = 0.040). Also, cases in the early plication group had significantly shorter duration of mechanical ventilation (P value = 0.029), ICU (P value = 0.043), and hospital stay (P value <0.001). **Conclusions:** Early diaphragm plication proves to be a crucial intervention for enhancing recovery, improving clinical outcomes, and minimizing complications,

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which subsequently leads to decreased duration of ICU and hospital stay.

***Keywords*---**Diaphragmatic Palsy, Diaphragmatic Plication, Mechanical Ventilation, Continuous Positive Airway Pressure, Recurrent Lung Collapse, Congenital Heart Surgery.

Introduction

Diaphragmatic palsy (DP) following pediatric cardiac surgery is a known complication, particularly because of phrenic nerve injury, which can significantly impact respiratory function and overall recovery. The occurrence rate of DP after cardiac surgery varies widely, from 0.3% to 12.8%, with neonates and infants being highly prone [1-2]. The complications associated with DP include prolonged mechanical ventilation (MV), respiratory distress, recurrent lung infections, atelectasis, and increased hospital stays [3].

Management strategies for DP include both conservative measures and surgical intervention through diaphragmatic plication which involves surgical repositioning of the diaphragm to improve its function and alleviate lung compression [4]. Diaphragmatic plication is often required when conservative measures fail. Plication of the diaphragm for DP has been associated with improved outcomes, including reduced MV duration, decreased ICU stay, and fewer respiratory complications [5]. Previous researches have shown the benefits of diaphragm plication, but these studies highlight significant variability in practices, including the timing of plication and the approach (minimally invasive vs. thoracotomy) [6,7].o

The aim is to evaluate the effect of early diaphragmatic plication on clinical outcomes and to compare these outcomes with late plication in pediatric cases who have undergone cardiac surgery and developed DP.

Patients and Methods

This retrospective study was performed over a period of three years, from January 2018 to December 2020 at Tanta University Hospitals and Misr Children Hospital, and included patients diagnosed with diaphragmatic paralysis and subjected to diaphragmatic plication post congenital cardiac surgery.
A total of 1459 cases who had congenital cardiac surgery during the study period were identified. 57 patients were diagnosed with diaphragmatic palsy (DP). Out of those 57 patients, 26 patients underwent early diaphragmatic plication, 20 patients underwent late plication, while 11 patients managed conservatively and excluded from the study.

Inclusion Criteria:

- Patients diagnosed with diaphragmatic palsy post congenital heart surgery during the period of hospitalization and subjected to diaphragmatic plication.

Exclusion Criteria:

- Preoperative elevated hemidiaphragm.
- Preoperative neuromuscular disease.
- Any patient who was ventilator-dependent prior to surgery.
- Patients developed DP after congenital cardiac surgery and managed conservatively.

Diagnosis of DP was primarily based on clinical signs. Phrenic nerve injury was suspected primarily in cases of failure of weaning from mechanical ventilator (MV), and in patients reported signs of respiratory distress after weaning (which could not be described by other reasons such as chest infection or residual cardiac pathology). Elevation of diaphragmatic copula in the chest X-ray in absence of lung atelectasis or abdominal distension raises the possibility of DP. Suspicion of left DP raised when there is elevation of the left hemidiaphragm than the right one. Regarding the right side, two or more ribs elevation than the left copula, suggesting right DP. Diagnosis of DP was confirmed by bedside chest ultrasound to assess diaphragmatic motion and fluoroscopy used when US was inconclusive. DP was characterized by minimal, absent, or paradoxical movement of the diaphragm as identified through confirmatory testing. Absent or reduced diaphragm movement in the correct direction was characterized as paresis; diaphragms exhibiting paradoxical motion were classified as paralyzed (1). The Risk Adjustment for Congenital Heart surgery (RACHS) score was used to verify surgical complexity (8).

Plication was evaluated in cases who experienced multiple unsuccessful extubation attempts, reintubation after extubation, persistent respiratory distress, and oxygen dependency, while other patients managed conservatively. The timing of plication was determined based on clinical indications, with early plication being defined as surgery performed within 7 days of DP diagnosis, and late plication as surgery performed after 7 days from diagnosis.

All surgical plications were performed utilizing a standardized technique. Thoracotomy was performed at the fifth or sixth intercostal space to mobilize the ipsilateral lung, and multiple polypropylene sutures with Teflon pledgets were applied to plicate the diaphragm into a flattened position with slight tension.

Data were obtained from the medical records, including demographic data, surgical details (cardiopulmonary bypass use, cross clamp time, and duration of bypass), and clinical outcomes (duration of mechanical ventilation, ICU stay, hospital stay, and postoperative complications). The primary outcomes were the duration of mechanical ventilation, ICU stay, and hospital stay. The secondary outcomes included the need for nasal CPAP, any respiratory complications such as recurrent lung collapse or pneumonia, sepsis, and mortality.

Statistical Analysis

Statistical analysis was done by SPSS v26 (IBM Inc., Armonk, NY, USA). Shapiro-Wilks test and histograms were used to evaluate the normality of the distribution of data. Quantitative parametric data were presented as mean and standard deviation (SD) and were analyzed by unpaired student t-test. Quantitative non-

parametric data were presented as median and interquartile range (IQR) and were analyzed by Mann Whitney-test. Qualitative data were presented as frequency and percentage (%) and were analyzed by the Chi-square test or Fisher's exact test when appropriate. A two tailed P value ≤ 0.05 was considered statistically significant.

Results

Diaphragmatic palsy was identified in 57 patients out of 1459 underwent congenital cardiac operation during the time interval of the study, with incidence 3.9%. From those 57 patients, 11 patients managed conservatively and were excluded from the study. Regarding the clinical characteristics of cases required diaphragmatic plication, the median age was 146 days (median 1-1550 days) (Diaphragmatic plication distribution according to the patient's age is illustrated in **figure 1**), there was predominant male sex (65.2%), the diaphragmatic lesion was mainly paralysis (91.3%), and the majority of the patients underwent open heart surgery on CPB (91.3%). **Table 1**

Table 1: Clinical characteristics of cases required diaphragmatic plication

Clinical characteristics	**Total (n=46), n (%)**
Age (Days)	146 (1-1550)
Male (%)	30 (65.2%)
Ventricular physiology (%)	
Univentricular	9 (19.6%)
Biventricular	37 (80.4%)
Diaphragmatic activity (%)	
Paresis	42 (91.3%)
paralysis	4 (8.7%)
Closed heart surgery (%)	4 (8.7%)
CPB (%)	42 (91.3%)
RACHS score (%)	
1	3 (6.5%)
2	20 (43.5%)
3	10 (21.7%)
4	12 (26.1%)
5	1 (2.2%)
Comorbidities (%)	
None	33 (71.8%)
Genetic syndrome	3 (6.5%)
Prematurity	6 (13%)
Both	4 (8.7%)

Data presented as median (IQR), or number (percentage %), RACHS: risk adjustment for congenital heart surgery, CPB: cardiopulmonary bypass.

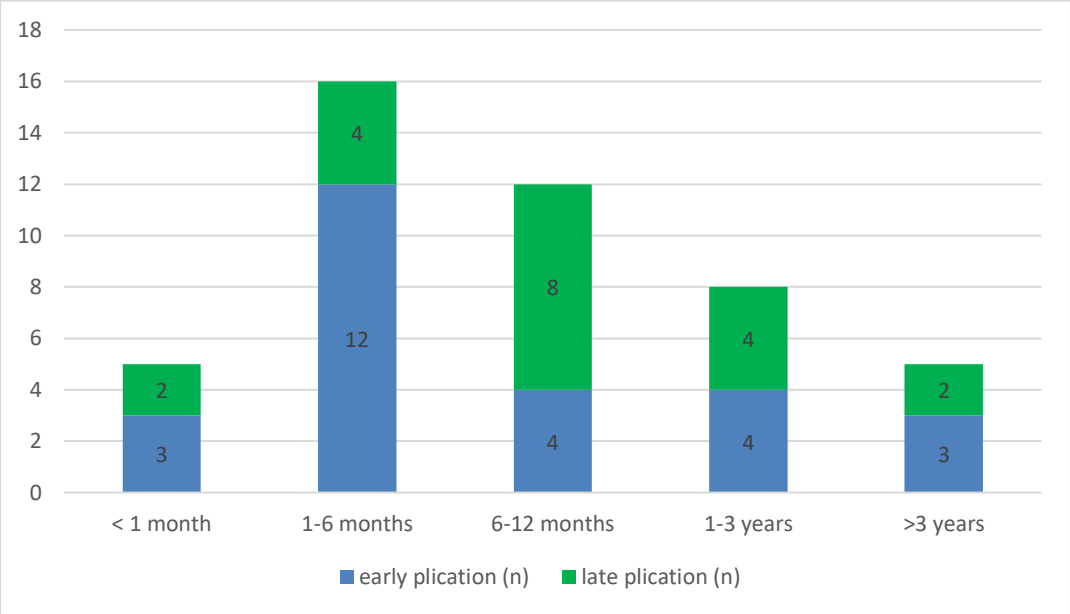

Figure 1: diaphragmatic plication distribution according to patient's age

Compared to patients had late plication, those underwent early plication were significantly younger (118 vs 172 days, P value = 0.02). There were insignificant differences in sex distribution, ventricular physiology, the use CPB, or diaphragm activity (paralysis vs. paresis) between early and late plication groups. Additionally, there was insignificant difference among both groups based on ischemic time (P value = 0.371) however, cases in the early plication group had significantly shorter CPB time (P value = 0.02). **Table 2**

Table 2: Comparison of patients' demographic and surgical data according to early and late plication

	Early plication (n=26)	**Late plication (n=20)**	**P value**
Age (days)	118 (1 - 1275)	172 (15 – 1550)	0.02*
Sex (%)			
Male	18 (69.2%%)	12 (60%)	0.752
Diaphragm activity (%)			
Paralysis	24 (92.3%)	18 (90%)	1.000
Paresis	2 (7.7%)	2 (10%)	
Affected side (%)			
Left	18 (69.2%)	13 (65%)	0.641
Right	8 (30.8%)	7 (35%)	
Ventricular physiology (%)			
Univentricular	6 (23.1%)	4 (20%)	0.350
Biventricular	20 (76.9%)	16 (80%)	
CPB	24 (92.3%)	18 (90%)	0.581
CPB time, min, mean ± SD	110 ± 35.06	142.9 ± 49.48	0.020*

	Early plication (n=26)	Late plication (n=20)	P value
Cross clamp time, min, mean ± SD	91.33 ± 21.6	105.26 ± 48.34	0.371

Data presented as mean ± SD, median (IQR), or number (percentage %), CPB: cardiopulmonary bypass, *: significant as P value ≤ 0.05.

In the majority of patients bed side chest ultrasound was the primary confirmatory image modality, with only one patient in the early plication group diagnosed by direct visualization, and one patient in the late plication group need fluoroscope to confirm the diagnosis. All surgical diaphragmatic plications were done through standard thoracotomy in the affected side. Failure of weaning from mechanical ventilator was the main indication for surgical plication in both early and late plication groups (42.3% and 50% respectively). **Table 3**

Table 3 : Comparison between the studied groups regarding diagnostic and intervention data

	Early plication (n = 26)	Late plication (n = 20)	P value
DP Diagnosis Mode			
Direct visualization	1 (3.8%)	0	0.641
Confirmatory chest US	25 (96.2%)	19 (95%)	
Need for fluoroscope	0	1 (5%)	
Surgical approach			
Standard thoracotomy	26 (100 %)	20 (100%)	1.0
Indications for plication			
Tachypnea with oxygen dependency	3 (11.5%)	1 (5%)	0.414
Failed weaning attempts	11 (42.3%)	10 (50%)	
Persistent respiratory distress	4 (15.4%)	2 (1%)	
Reintubation after extubating	8 (30.8%)	7 (35%)	

Data are presented as frequency (%), US: ultrasound, DP: diaphragmatic palsy.

cases in the early plication group had significantly shorter MV duration (median 8 vs 15 days, P value = 0.029), ICU stay from the index operation (median 10 vs 17 days, P value = 0.043), and hospital stay from the index operation (median 19 vs 30 days, P value < 0.001) compared to late plication group. Additionally, there were significantly lower incidence for nasal CPAP requirement (P value = 0.031), ventilator Acquired pneumonia (VAP) (P value = 0.011), and the incidence of recurrent lung atelectasis (P value = 0.040) in early plication group when compared to late plication group.

There was insignificant difference among both groups regarding ICU and hospital stay after plication (P value = 0.436, and 0.631 respectively). Also, there was insignificant difference among both groups regarding the incidence of sepsis and mortality (P value = 0.137, and 0.821 respectively). **Table 4**

Table 4: Comparison of patients' related outcomes according to early and late plication

	Early plication (n=26)	**Late plication (n=20)**	**P value**
Total duration of MV (days)	8 (4 - 15)	15 (8 - 21)	0.029*
ICU stay from index operation (days)	10 (9 - 18)	17 (12 - 24)	0.043*
ICU stay after plication (days)	4 (2 - 7)	6 (3- 9)	0.436
Hospital stay from index operation (days)	19 (14 - 32)	30 (18 - 45)	< 0.001*
Hospital stay after plication (days)	9 (7 - 20)	13 (9 - 28)	0.631
Nasal CPAP requirement post plication	2 (7.7%)	5 (25%)	0.031*
Recurrent lung atelectasis	3 (11.5%)	6 (30%)	0.040*
VAP	1 (3.8%)	4 (20%)	0.011*
Sepsis	2 (7.7%)	3 (15%)	0.137
Mortality (%)	0	1 (5%)	0.821

Data presented as median (IQR), or number (percentage %), MV: mechanical ventilation, ICU: intensive care unit, VAP: ventilator acquired pneumonia, CPAP: Continuous positive airway pressure, *: significant as P value ≤ 0.05.

Discussion

Phrenic nerve damage during congenital cardiac surgery results in diaphragmatic palsy (DP), a well-documented postoperative complication that occurs through injury during cardiopulmonary bypass or direct surgical trauma during tissue dissection, thymectomy, or taking pericardial patch. This condition compromise's normal diaphragmatic function, resulting in breathing difficulties, prolonged ventilator dependence, extended stays in intensive care, and elevated patient morbidity rates. [5-7]. Historically, postoperative mortality has served as the principal metric of quality in congenital cardiac surgery. nevertheless, as surgical outcomes improve, mortality has become a less sensitive indicator, and postoperative duration of stay has emerged as a surrogate measure of quality of care [9]. Treatment approaches for DP typically include conservative strategies such as extended ventilator support with gradual weaning trials, or surgical intervention, primarily through diaphragmatic plication to restore normal respiratory mechanics [10].

The appropriate timing for surgical diaphragmatic plication remains a subject of clinical debate. Prompt early surgical repair may potentially decrease ventilator dependency duration and enhance respiratory function through immediate correction of diaphragmatic impairment however, it carries inherent operative risks in critically ill postoperative patients, necessitating careful evaluation of its effectiveness and safety [11]. On the other hand, delayed surgical intervention carries potential risk of prolonged ventilator requirements and related complications including ventilator-associated infections [6].

Our study was designed to assess the effect of early diaphragmatic plication on clinical outcomes in pediatric cases who have undergone cardiac surgery and developed DP and also to compare these outcomes with late diaphragmatic plication. The demographic analysis revealed that patients required early plication were significantly younger compared to those in the late plication group (mean age 118 vs 172 days, P value = 0.02). Our finding is in line with the results of Parmar et al. [11] who found that younger patients with diaphragmatic paralysis tend to have more severe respiratory compromise requiring earlier intervention. This is directly related to the role of the diaphragm as the main respiratory muscle in neonates and infants because of intercostal muscles weakness, in addition the mediastinum in this age group is more mobile, for these reasons elevation of the diaphragm lead to impairment of cardiorespiratory function [7]. In contrary, Lemmer et al [6]. found no significant age difference between early and late intervention groups, suggesting that age alone should not determine timing of surgical intervention.

The main lesion in patients required diaphragmatic plication in our study was diaphragmatic paralysis (91.3%), while patients with paresis represented only (8.7%). Our results are in line with Langer et al. [13] who found in their study that the majority of patients indicated for plication have diaphragmatic paralysis rather than paresis. This can be explained by the lower position of the diaphragmatic copula in patients with paresis compared to patients with paralysis, this lower position maintains better respiratory function, in addition there is a higher possibility of recovery and so the majority of those patients managed conservatively.

For diagnosis of DP the main confirmatory procedure was chest ultrasound using bedside echo machine. Chest US was sufficient and accurate for diagnosis of the majority of cases (95.6%). Our results are in line with Langer et al. [13] who documented that using chest US was equal to using fluoroscope in diagnosis of DP with a sensitivity 100%. We believe that using chest US provides a safe and effective alternative for evaluating DP, as it decreases the necessity of transporting the patient for fluoroscopy, thus reducing transport-associated risks and enhancing overall patient safety especially for intubated patient.

Our findings confirm that early plication leads to better clinical outcomes, including reduced MV duration compared to late plication (median 8 vs 15 days, P value = 0.029), ICU stay from the index operation (median 10 vs 17 days, P value = 0.043), and hospital stay from the index operation (median 19 vs 30 days, P value <0.001).

Parmar et al. [11] found that early plication was linked to a reduction in the duration of mechanical ventilation, ICU stay, and hospital stay, a pattern that aligns with our findings. Floh et al. [7] also emphasized the benefits of early plication, reporting that early intervention was associated with reduced durations of MV and shorter ICU stay.

Simansky et al. [14] and Tonz et al. [12] also concluded that early diaphragm plication is associated with improved recovery, including faster extubation, shorter ICU and hospital stays. These studies align with our findings, reinforcing the importance of early intervention to mitigate the complications of diaphragm paralysis and shorten recovery times. Akay et al. [15] further supports this by noting that early plication helps in faster recovery and reduced ICU dependency. In our research, we observed that cases who underwent early diaphragm plication had a significantly lower requirement for CPAP, similar to the results of Parmar et al. [11], who observed that early plication reduced the need for CPAP. Floh et al. [7] also discussed the advantage of early plication in reducing CPAP dependency showing that earlier intervention reduces respiratory support needs. These studies emphasize that early plication not only improves respiratory mechanics but also minimizes the reliance on CPAP, enhancing recovery.

Similarly, Simansky et al. [14] observed a similar trend where early diaphragm plication reduced the need for non-invasive ventilation techniques, including CPAP, reinforcing that plication is beneficial in decreasing ventilation dependency. Our study found a significantly lower incidence of recurrent lung collapse, and ventilator acquired pneumonia in the early plication group, which is consistent with the findings of Floh et al. [7]. They observed that early diaphragm plication helps maintain lung expansion and prevents atelectasis. Similarly, Parmar et al. [11] documented a lowered incidence of recurrent lung collapse, following early diaphragmatic plication, highlighting the role of early plication in improving diaphragm function and lung expansion.

Tonz et al. [12] found that early diaphragm plication significantly decreased the incidence of recurrent lung collapse by improving diaphragm function and allowing better lung expansion. Additionally, Lemmer et al. [6] emphasized that the re-expansion of the diaphragm following plication aids in reducing the likelihood of lung collapse supporting that diaphragm repositioning plays a key role in preventing pulmonary complications.

In our study, we found insignificant difference in the incidence of sepsis and mortality among early and late plication groups. This aligns with Parmar et al. [11] who observed insignificant difference in sepsis rates among early and late plication groups. Similarly, Gibson et al. [16] did not observe a direct link between diaphragm plication and sepsis incidence, suggesting that while plication improves ventilation and respiratory function, it does not significantly impact sepsis rate. These studies suggest that sepsis is likely influenced by other factors such as underlying comorbidities or postoperative complications, rather than diaphragm function alone.

Limitation of our study was its relatively small sample size and retrospective design. Another limitation was the lack of standardized protocols for diagnosing

diaphragm paralysis and performing plication, which could result in variability in treatment approaches. We recommend future research focuses on standardizing diagnostic criteria and treatment protocols for diaphragm paralysis in pediatric cardiac surgery with larger multi-center prospective nature.

Conclusions

Our study highlights the significant benefits of early diaphragmatic plication in improving clinical outcome in pediatric patients following cardiac surgery. Also, early diaphragmatic plication, was associated with reduced need for noninvasive ventilation, reduced mechanical ventilation duration, shorter ICU, and hospital stay when compared with late plication.

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Conflict of Interest: Nil

References:

1. Fraser CD, 3rd, Ravekes W, Thibault D, Scully B, Chiswell K, Giuliano K, et al. Diaphragm Paralysis After Pediatric Cardiac Surgery: An STS Congenital Heart Surgery Database Study. Ann Thorac Surg. 2021; 112:139-46.
2. Zhang YB, Wang X, Li SJ, Yang KM, Sheng XD, Yan J. Postoperative diaphragmatic paralysis after cardiac surgery in children: incidence, diagnosis and surgical management. Chin Med J (Engl). 2013; 21:4083–7.
3. Talwar S, Agarwala S, Mittal CM, Choudhary SK, Airan B. Diaphragmatic palsy after cardiac surgical procedures in patients with congenital heart. Ann Pediatr Cardiol. 2010;3:50-7.
4. El Tantawy AE, Imam S, Shawky H, Salah T. Diaphragmatic nerve palsy after cardiac surgery in children in Egypt: outcome and debate in management. World J Pediatr Congenit Heart Surg 2013; 4: 19-23.
5. Georgiev S, Konstantinov G, Latcheva A, Mitev P, Mitev I, Lazarov S. Phrenic nerve injury after paediatric heart surgery: is aggressive plication of the diaphragm beneficial? Eur J Cardiothorac Surg. 2013;44:808-12.
6. Lemmer J, Stiller B, Heise G, Hübler M, Alexi-Meskishvili V, Weng Y, et al. Postoperative phrenic nerve palsy: early clinical implications and management. Intensive Care Med. 2006;32:1227-33.
7. Floh AA, Zafurallah I, MacDonald C, Honjo O, Fan C-PS, Laussen PC. The advantage of early plication in children diagnosed with diaphragm paresis. The Journal of Thoracic and Cardiovascular Surgery. 2017;154:1715-21.
8. Jenkins JK, Gauvreau K, Newburger JW, Spray TL, Moller JH, Lezzoni LI. Consensus- based method for risk adjustment for surgery for congenital heart disease. The Journal of Thoracic and Cardiovascular Surgery.2002;123(1);110-118.
9. Akbariasbagh P, Mirzaghayan MR, Akbariasbagh N, Shariat M, Ebrahim B. Risk Factors for post-Cardiac Surgery Diaphragmatic Paralysis in Children with Congenital Heart Disease. J Tehran Heart Cent. 2015;10:134-9.
10. Johnson EA, Zubair MM, Armsby LR, Burch GH, Good MK, Lasarev MR, et al. Surgical Quality Predicts Length of Stay in Patients with Congenital Heart Disease. Pediatr Cardiol. 2016;37:593-600.

11. Parmar D, Panchal J, Parmar N, Garg P, Mishra A, Surti J, et al. Early diagnosis of diaphragm palsy after pediatric cardiac surgery and outcome after diaphragm plication - A single-center experience. Annals of Pediatric Cardiology. 2021;14 (2):178-186.
12. Tönz M, von Segesser LK, Mihaljevic T, Arbenz U, Stauffer UG, Turina MI. Clinical implications of phrenic nerve injury after pediatric cardiac surgery. J Pediatr Surg. 1996;31:1265-7.
13. Langer JC, Filler RM, Coles J, Edmonds JF. Plication of the diaphragm for infants and young children with phrenic nerve palsy. J Pediatr Surg 1988;23:749-51.
14. Simansky DA, Paley M, Refaely Y, Yellin A. Diaphragm plication following phrenic nerve injury: a comparison of paediatric and adult patients. Thorax. 2002;57:613-6.
15. Akay TH, Ozkan S, Gultekin B, et al. Diaphragmatic paralysis after cardiac surgery in children: incidence, risk factors, and management. J Cardiothorac Vasc Anesth. 2006;20(3):322-326.
16. Gibson GJ. Diaphragmatic paresis: pathophysiology, clinical features, and investigation. Thorax. 1989;44:960-70.