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Long-term results of the double purse-string plication technique in diaphragmatic eventration: Evaluation on chest radiography

Ayse Parlak[1] Arif Nuri Gurpinar[1]

1 Bursa Uludag University, Faculty of Medicine, Department of Pediatric Surgery, Bursa, Turkey

Abstract

Objective: We report the long-term effectiveness of the double purse-string plication technique by evaluating postoperative chest X-rays.

Materials and methods: We retrospectively reviewed 24 patients diagnosed with diaphragmatic eventration who underwent the double purse-string plication technique between April 2012 and December 2024. Postoperative outcomes and recurrence were evaluated using chest X-rays during a 5-year follow-up period. Postoperative chest radiographs were available for 20 patients and were included in the analysis. The diaphragmatic levels were evaluated by measuring the intercostal distances and the distance between the peaks of the hemidiaphragm and the apex on the chest X-rays, both pre- and postoperatively.

Results: In the 20 patients, the female-to-male ratio was 1:3, and the median age was 12.5 months (range, 6 months to 17 years). The mean duration of follow-up was 4.77± 2.35 years. A significant decrease of approximately 1.8 intercostal space levels was observed in the diaphragm level from the preoperative period to the postoperative 1st month. In the following years, no significant elevation was observed in the intercostal level of the corrected elevated diaphragm. The median percentage ratio between the normal and corrected diaphragmatic levels showed a progressive decrease over time: 42.26% preoperatively, 12.84% at postoperative 1st month, 7.99% at postoperative 1st year, and 4.71% at postoperative 5th year ($p<0.001$). A significant decrease in the percentage difference in diaphragm levels between the normal and elevated sides was observed in the 1st and 5th years compared to the preoperative measurement. One patient had a recurrence and underwent re-plication (5%). No significant long-term morbidity or mortality was observed.

Conclusion: The double purse-string plication technique offers an effective, durable, and minimally invasive option for the treatment of diaphragmatic eventration. Our long-term data show stable radiological correction and sustained symptomatic improvement.

Keywords: Double purse-string, Plication technique, Diaphragmatic eventration.

Correspondence:
Ayse Parlak, Bursa Uludag University, Faculty of Medicine, Department of Pediatric Surgery, 16059 Bursa, Turkey.
E-mail: ayseparlak@uludag.edu.tr

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ORCID ID of the author(s):
AP: 0000-0001-7686-2561
ANG: 0000-0002-7597-4825

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Introduction

Diaphragmatic eventration is characterized by abnormal elevation of the diaphragm due to muscular weakness or paralysis, which can lead to respiratory distress. This condition may be congenital or acquired (1). Eventration occurs in fewer than 0.05% of cases and is observed more frequently in males (2). Symptoms range from asymptomatic to severe respiratory difficulties, and treatment options vary from conservative management to surgical intervention, such as diaphragm plication to restore normal respiratory mechanics. Surgical intervention is generally reserved for patients who present with clinically significant symptoms (3).

Since the introduction of diaphragmatic plication as a surgical treatment for diaphragmatic eventration, numerous modifications have been described. These include minimally invasive video-assisted thoracoscopic and laparoscopic surgery, as well as different plication techniques such as multiple plications, reefing the mainsail technique, pleating technique, and invaginating the diaphragmatic dome technique (4-6). As part of these modifications, a new minimally invasive technique called the double purse-string plication technique was developed in our clinic and the preliminary results were published in 2020 (7).

This study aimed to assess the long-term effectiveness of the double purse-string plication technique and the five-year recurrence rate of diaphragmatic eventration by reviewing postoperative chest radiographs.

Materials and methods

A retrospective analysis of the clinical data of 24 patients diagnosed with diaphragmatic eventration who underwent the double purse-string plication technique at our institution between April 2012 and December 2024 was conducted. However, radiological data were unavailable for 4 patients, and one of these patients underwent the procedure via laparotomy. Consequently, the final analysis encompassed 20 patients who underwent thoracoscopic double purse-string plication (Figure 1). A comprehensive review of the clinical, radiological, surgical, and postoperative follow-up records was conducted. The Institutional Ethical Committee approved our study (Approval no: 2025/6-1).

In our clinic, posteroanterior and lateral chest radiographs were routinely obtained for each patient as part of the diagnostic evaluation for diaphragmatic eventration. However, only some patients underwent fluoroscopy, computed tomography, and pulmonary radioisotopic. The decision for thoracoscopic repair was made upon pulmonary radioisotopic examination of the lungs and the presence of recurrent lung infections and respiratory distress. In the thoracoscopic double purse-string suture technique, a 2/0 nonabsorbable polyester suture is applied to the weakest and loosest portion of the diaphragm, embedding the excessive diaphragmatic tissue into the abdominal cavity. The same procedure is repeated similarly, approximately 2 cm apart, to create the second or third layer. Diaphragmatic levels on chest radiographs, along with clinical symptoms, were assessed during follow-up outpatient visits conducted from 1 month to 1–5 years after surgery.

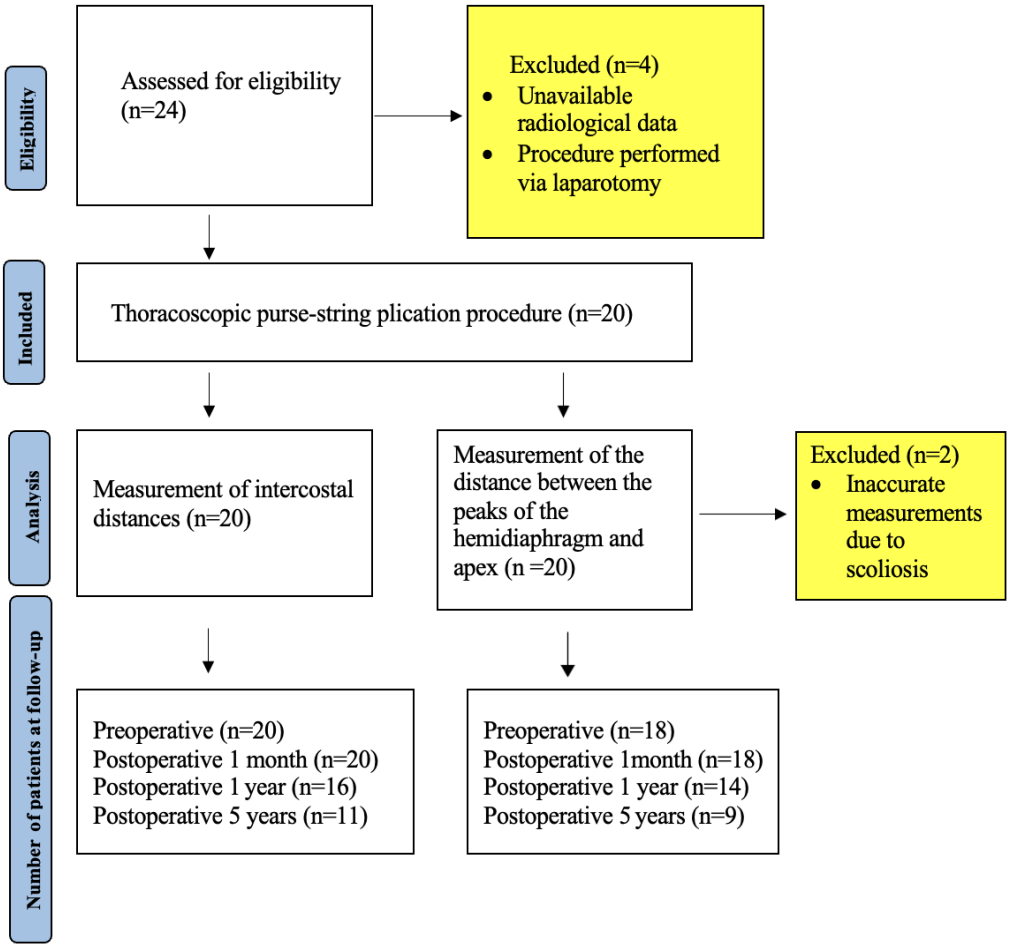

Figure 1: Flow diagram of patient selection, exclusion, and follow-up

Evaluation of eventration on chest radiographs

The evaluation of eventration on chest radiographs preoperatively and postoperatively was undertaken through the utilization of two distinct methodologies. In two cases, diaphragm measurements taken after the most recent operation were included in the calculations (Case 4: The patient had bilateral diaphragmatic eventration. Postoperative diaphragmatic levels were assessed after the second thoracoscopic surgery. Case 17: The patient had recurrent diaphragmatic eventration after surgery. Postoperative diaphragmatic levels were assessed after the second surgery).

1) The diaphragmatic levels were evaluated by measuring the intercostal distances on the chest X-rays preoperatively, and postoperatively at the 1st month, 1st and 5th years (Figure 2a). The degree of diaphragmatic descent was quantified by measuring intercostal distances on the elevated side, comparing preoperative and postoperative posteroanterior chest radiographs. The calculation formula was: Difference between the normal side's diaphragmatic level and the corrected diaphragmatic level over the

years (intercostal space): normal side diaphragmatic level- corrected diaphragm level.

2) The degree of eventrations was measured by using a different method that has been previously documented in the literature (8,9). In this method, the distance between the peaks of the hemidiaphragm and the apex of the ipsilateral thorax was measured. The left and right distances between the peaks of the hemidiaphragm and apex were also measured (Figure 2b). The eventration level was calculated as a percentage by using the B/A ratio, where A was the distance between the peaks of the normal hemidiaphragm and apex, and B was the distance between the peaks of the eventrated hemidiaphragm and apex. The calculation formula was: 100 - (B/A*100). The postoperative assessments at 1 month, 1 year, and 5 years were performed using the same measurement formula and chest radiographic evaluation.
   A total of 18 patients were evaluated for eventration on chest radiographs by this measure (cases 8 and 19 had scoliosis, and thus were excluded due to abnormal calculations).

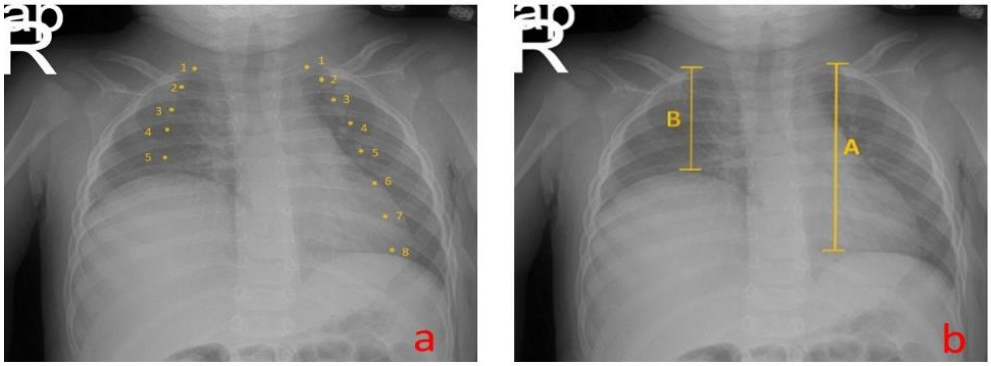

Figure 2: Evaluation of eventration level on chest radiographs. a) Measuring the intercostal distances b) Measuring the distance between the peaks of the hemidiaphragm and apex.

Statistical analysis

The data were evaluated using the Shapiro–Wilk test to determine whether they exhibited a normal distribution. The results were presented as median (with minimum and maximum values), or frequency and percentage. The Friedman tests were used to assess the variables' overall change over time. The Bonferroni correction was applied for multiple comparisons, and significant differences were identified between the time points. Statistically, the significance level was set at $\alpha = 0.05$. Statistical analyses were performed with IBM SPSS 29.0.2.0 (IBM Corp. Released 2023. IBM SPSS Statistics for Windows, Version 29.0.2.0 Armonk, NY: IBM Corp.).

Results

Double purse-string suturing technique in diaphragmatic eventration was performed on 20 cases. The female/male ratio was 1/3 and the median age was 12.5 months (6 months-17 years). The main causes of admission were recurrent respiratory system infections (n:14), respiratory distress with effort (n=7), ventilator dependence (n=3), gastrointestinal complaints such as nutritional problems (n=1), and incidental (n=1). Concomitant situations were extralobar bronchopulmonary sequestration (n=1), congenital diaphragmatic hernia (n=2), congenital myopathy (n=2), difficult birth history, brachial plexus injury (n=1), immunodeficiency (n=1), trauma (n=1), operated congenital cardiac defect (n=1), scoliosis (n=2), and neuromotor developmental disorders (n=2).

Eventration was located on the right side in 18 patients, on the left side in 1 patient, and was bilateral in 1 patient. Plication was completed thoracoscopically in all patients except 2. One of those patients underwent conversion to thoracotomy due to adhesions resulting from thoracotomy due to previous cardiac surgery, and the other patient had ipsilateral recurrence of eventration, and the second surgery was started with thoracotomy. The patient with bilateral eventration underwent right-sided repair first, followed by left-sided repair one month later. In 6 cases, a third layer of suturing was required for plication. The median duration of the thoracic catheter was 4.5 days (2-11 days). Four patients developed postoperative pneumothorax, and in these cases, the duration of thoracic catheterization was prolonged. One patient with immunodeficiency and 1 patient with neuromotor developmental disorders had postoperative pneumonia, and their hospitalization was also prolonged. No other complications were observed. Recurrence was seen in 1 patient with congenital myopathy (5%). The median duration of hospital stay was 5 days (2-120 days).

Postoperatively, significant improvements in symptoms related to the respiratory tract and nutrition were observed in all patients who came to follow-up visits. One of the ventilator-dependent patients is being managed with a home-type ventilator and a tracheostomy due to myopathy. Additionally, two patients use nocturnal nasal intermittent positive pressure ventilation with bi-level positive airway pressure.

Table 1: Longitudinal changes in elevated diaphragm position across postoperative periods (intercostal space level)

	Preoperative	**Postoperative 1st month (n=20)**	**Postoperative 1st year (n=16)**	**Postoperative 5th year (n=11)**	**P-value**
Median	5.00	7.50	8.00	7.50	
Minimum	5.00	6.00	7.00	7.50	0.008
Maximum	6.00	8.00	9.00	8.00	

Eventration rate on chest radiographs

The mean duration of follow-up was 4.77±2.35 years. Preoperative intercostal space measurements were compared at postoperative 1st month, 1st, and 5th years to assess longitudinal changes in diaphragm level on the elevated side (Table 1). Accordingly,

a significant difference was found in the comparison of time-dependent measurements (p=0.008). A significant decrease of approximately 1.8 intercostal space levels was observed in the diaphragm level from the preoperative period to the postoperative 1st month. In the following years, no significant elevation was observed in the intercostal level of the corrected elevated diaphragm. The difference between the normal side diaphragmatic level and the corrected diaphragmatic level over the years (intercostal space) is shown in Table 2. Although significant differences were found in the overall comparison of repeated measurements using the Friedman test, no difference was found between measurement times in the pairwise comparison using the Bonferroni test.

Table 2: Longitudinal difference between the normal and corrected diaphragmatic levels over time (intercostal space level)

	Preoperative	**Postoperative 1st month (n=20)**	**Postoperative 1st year (n=16)**	**Postoperative 5th year (n=11)**	**P-value**
Median	2.25	1.00	0.50	0.00	
Minimum*	0.00	0.00	0.00	0.00	0.035
Maximum	4.00	2.00	2.50	2.00	

*The minimum value of zero reflects the case of a patient with bilateral diaphragmatic eventration, in whom the preoperative calculation assumed no intercostal level difference between the two hemidiaphragms.)

The percentage difference in the level of the diaphragm measured (the distance between the peaks of the hemidiaphragm and apex of the ipsilateral thorax) on the normal and elevated sides according to time is given in Table 3. The median percentage ratio between normal and corrected diaphragmatic levels showed a progressive decrease over time: 42.26% preoperatively, 12.84% at postoperative 1st month, 7.99% at postoperative 1st year, and 4.71% at postoperative 5th year (p<0.001). Also, significant differences were found between preoperative and postoperative 5th year, and between preoperative and postoperative 1st year in the pairwise comparison. A significant decrease in the percentage difference in diaphragm levels between the normal and elevated sides was observed in the 1st and 5th years compared to the preoperative measurement.

Table 3: The ratio between the normal and the corrected diaphragmatic levels over the years (percentage)

	Preoperative	**Postoperative 1st month (n=18)**	**Postoperative 1st year (n=14)**	**Postoperative 5th year (n=9)**	**P-value**
Median	42.26	12.84	7.99	4.71	
Minimum	11.11	1.31	0.00	0.71	<0.001
Maximum	58.80	38.28	35.74	18.45	

Discussion

In this study, we evaluated the long-term radiological outcomes of the thoracoscopic double purse-string plication technique, which was developed as a minimally invasive modification for the management of diaphragmatic eventration. Our results demonstrate that the double purse-string approach provides durable correction of diaphragmatic elevation and sustained symptomatic improvement.

Diaphragmatic plication remains the standard treatment for symptomatic diaphragmatic eventration, although various surgical techniques have been described, including thoracoscopic and laparoscopic approaches, multiple fold plications, reefing techniques, and dome-invagination suturing (4-6). The primary goal of plication is to reduce the paradoxical movement of the diaphragm and restore normal respiratory mechanics (5). In our series, the double purse-string technique offered the advantage of controlled inward imbrication of the loose diaphragm while preserving thoracoscopic feasibility. This is consistent with our previously published preliminary results, which demonstrated short-term efficacy (7). The present study extends those findings by confirming the long-term stability of the plicated diaphragm.

In this study, we used two distinct radiological assessment methods for diaphragmatic position. Measurement of intercostal distance demonstrated a marked initial descent of the eventrated hemidiaphragm (mean reduction of 1.8 intercostal spaces) within the first postoperative month, with no significant re-elevation observed during the subsequent follow-up period. Similarly, the percentage-based hemidiaphragm-to-apex distance ratio exhibited significant postoperative improvement, which was maintained up to the fifth year. These objective findings suggest that the structural correction achieved with double purse-string sutures is stable over time, and the technique is resistant to late recurrence. Large pediatric congenital diaphragmatic eventration cohorts report 0-7% recurrence after plication (10,11). In our study, only one patient with congenital myopathy had a recurrence and underwent re-plication.

Lung volume can be estimated using chest X-ray, ultrasound, tomography, and MRI (12). While these techniques are semi-objective, chest X-ray evaluation is a more convenient and accessible method. In adults, spirometry, dyspnea score, and chest X-ray evaluations are also performed in diaphragmatic eventration (13). Only a limited number of studies have investigated the long-term outcomes following diaphragmatic eventration in pediatric patients, and currently, no standardized guidelines exist for postoperative follow-up (9-11,14). Furthermore, the absence of a validated and fully compliant symptom scoring system for children, the inability to reliably perform spirometry before the age of five, and the challenges in conducting routine pre- and postoperative spirometry due to poor test compliance, along with the inherent difficulty of accurately assessing lung volumes, collectively limit the adequacy of postoperative evaluation. In adults, however, the clinical evaluation and chest X-ray are sufficient for the follow-up after diaphragmatic plications (13).

In our study, although the technique was successfully performed thoracoscopically in almost all cases, the requirement for conversion to thoracotomy in two patients

underscores the potential technical challenges in the presence of dense adhesions or recurrent eventration. These situations should be anticipated, particularly in patients with previous thoracic or cardiac surgeries.
Symptomatic patients require surgical correction for diaphragmatic eventration (9,11). However, there are no symptom scores that are fully adapted for children. In our study, all patients exhibited clinical improvement in respiratory symptoms, including a reduction in recurrent infections and decreased ventilatory support requirements. No significant long-term morbidity or mortality was observed.

Limitations

This study has several limitations. Its retrospective nature, relatively small sample size, and reliance on chest radiography rather than cross-sectional imaging for long-term follow-up may limit the generalizability of the findings. Additionally, pulmonary function tests could not be performed in most pediatric patients, which restricted our ability to quantify functional improvement objectively. However, the long-term follow-up and the use of two separate radiographic measurements strengthen the reliability of the outcomes.

Conclusions

In conclusion, the double purse-string plication technique offers an effective, durable, and minimally invasive option for the treatment of diaphragmatic eventration. Our long-term data show stable radiological correction and sustained symptomatic improvement. Based on our 12-year experience, the technique is a valuable alternative to traditional plication methods and may be particularly advantageous in pediatric patients.

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Ethical approval: All procedures performed on human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The Institutional Ethical Committee approved our study (Approval no: 2025/6-1).
Informed consent: Informed consent was obtained from parents of all patients before all procedures.
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Data availability: The datasets used and/or analyzed during the present study are available from the relevant author upon reasonable request.
Contributions:
Research concept and design: AP
Data analysis and interpretation: AP
Collection and/or assembly of data: AP

Writing the article: AP
Critical revision of the article: ANG
Final approval of the article: AP, ANG
All authors read and approved the final version of the manuscript.

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