



Results of Open Transthoracic Plication of Diaphragm on the Respiratory, GI and Cardiovascular Systems, and Improvement of Life Quality

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Abstract

Objective: In this study, we carried out experiments on 30 patients, who had unilateral non-malignant diaphragmatic eventuation while focusing on their symptomatic status, especially degree of dyspnea, the pulmonary function, heart, GI-system, and their quality of life in a long-time follow-up.

Materials: From April 2004 to February 2018, we retrospectively investigated medical records of 30 patients (18 males and 12 females) which underwent surgical treatment with DE. The clinical data of the patients were collected. Furthermore, 16 patients (65%) were classified in idiopathic DE, eight patients in Trauma, and four patients in cardiac and mediastinal surgery. The two remaining patients had congenital origin.

Results: Out of thirty patients with DE, 18 patients were males and 12 were females. Mean age of the patients was 46 years (range: 18 to 64 years). Dyspnea was the most common complaint in 75% of patients. DE was idiopathic in sixteen of patients, trauma was the cause in eight patients, mediastinal surgery in four, and two patients had a congenital cause. Almost 21 patients experienced a feeling of tightness and light pain in the lower chest/upper abdominal a few days postoperative, which subsided with analgesics and carminative the follow-up was completed an average length of 36 to 62 months. Twenty-six patients were asymptomatic. There were four patients with chronic pain and another three patients with paresthesia in the thoracotomy area.

Conclusion: In summary, we inferred that Plication of diaphragm is a safe and effective procedure for respiratory, gastrointestinal, cardio-vascular systems, and significant improvement of life quality. We also concluded that pulmonary function tests (FEV1 and FVC) could increase post-operative. However, chronic chest wall pain still might remain a complaint by trans-thoracic approach.

Keywords: Diaphragm; Eventration; Plication; Thoracotomy

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Introduction

Diaphragm Eventration (DE) is defined as a permanent elevated hemidiaphragm without any defects in diaphragm. The muscular insertions to chest wall as well as all orifices of diaphragm are intact. Also, the interruption of the pleural or peritoneal layers is intact [1-3]. In DE, the atrophy of muscle and diaphragm progressively keep elevating [3]. There are four types of diaphragmatic abnormally: Posterolateral- Bochdalek hernia, Morgagni-Larrey parasternal hernia, peritoneal-pericardial diaphragmatic hernia, and diaphragmatic eventuation [1-3].

DE is also an acquired condition, which could appear due to phrenic nerve injury [2]. It could also involve the elevation of either one or both of hemidiaphragms, colon, stomach, omentum, and liver protrusion on the affected hemithorax [1-3]. During surgery and exploration, the involved diaphragm may appear either normally, mild tissue degeneration, or as a translucent membrane [4]. Sometimes, diaphragmatic hernia and eventration may be difficult to differentiate; however, in the eventuation, there is no true defect [2,3]. The incidence of DE is <0.05% [5]. Moreover, the aim of surgery is to decrease the elevated size, flatten the diaphragm, effectively restore the contraction of diaphragm, expands the collapsed lung, reduce the abdominal organs back to their normal places,

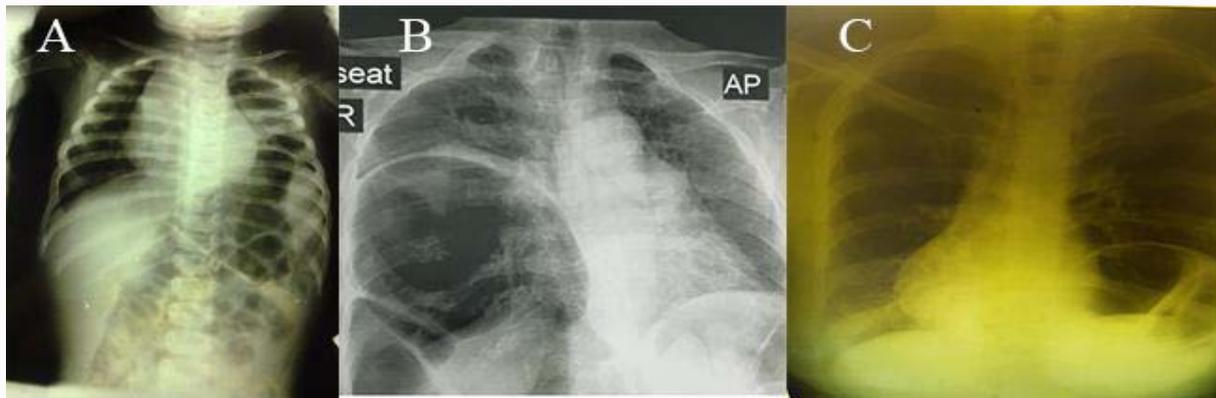


Figure 1: A: CXR show congenital (DE); B: CXR show right side (DE); C: show left side (DE) with shift of heart.

and improve the respiratory, Gastrointestinal (GI) and heart activities [1,2]. For correction of this abnormality, diaphragmatic plication can be performed via thorotomy or using a minimally invasive laparoscopic or thoroscopic procedure, with or without a mesh material [6,7]. Generally, the Etiology of DE is either trauma, surgery, neuropathies, inflammatory disorder, compression effect, congenital, or even idiopathic [3,8,9]. On the other hand, dyspnea, dry cough, chest pain tracho-bronchial spasms, palpitation, abdominal pain, and gastrointestinal discomfort are the most common symptoms of this medical condition [8,9]. In the related literature, repeated attack of bronchial asthma has been also reported. If chest X-ray shows unilateral elevation of diaphragmatic, it can be a highly sensitive DE in (85%) of cases [5,10]. Sniff test, during the Fluoroscopy of diaphragm, can identify motion or confirm paralysis [5,10]. In 88% of patients, Fluoroscopy can diagnose unilateral diaphragm paralysis [10]. Moreover, ultrasound can help the physician diagnose diaphragm dysfunction. Under ultrasound a paralyzed diaphragm fails to increase in thickness during inspiration; it can also determine degree of atrophy [11]. Chest X-ray, CT-scan and MRI are other method used for diagnosis of DE. Diaphragm plication was first reported in the 1920s [2,3]. The aim of plication is to decrease the elevated size and flatten the diaphragm. However, it is only applicable in symptomatic patients [12-14]. Contraindications to plication include obesity and neuromuscular disease [2,3]. Nowadays, several approaches, such as open thorotomy, thoroscopic and laparoscopic are being used. Open transthoracic plication is the traditional one [2,15-17]. Plication is performed via a posterolateral or anterolateral thoracotomy in the 6th, 7th, or 8th intercostal space with one lung ventilation (double-lumen endotracheal tube) [1,3]. The diaphragm is plicated from medial to lateral with a series of sutures until it becomes taut and flat. Complications for all the above approaches include pneumonia, pleural effusions, abdominal compartment syndrome, conversion to open (for minimally invasive approaches), abdominal viscous injury, deep vein thrombosis, stroke, upper GI, hemorrhage, pulmonary emboli, arrhythmia, and acute myocardial infarction [1,3]. Video-Assisted Thoracoscopic Surgery (VATS) is an alternative approach, which can be performed using two to four ports. Similar to the open thoracotomy, plication can be done using sutures and/ or laparoscopic stapling devices [1,3,13,17]. In this study, we carried out experiments on 30 patients, who had unilateral non-malignant diaphragmatic eventuation while focusing on their symptomatic status, especially degree of dyspnea, the pulmonary function, heart, GI-system, and their quality of life in a long-time follow-up.

Materials and Methods

From April 2004 to February 2018, we retrospectively investigated medical records of 30 patients (18 males and 12 females) which underwent surgical treatment with DE. In this study, Inclusion criteria were all patients, who were diagnosed with DE according to radiologist and surgical reports from medical records of the patients. Also, all patients with malignant DE were excluded from this study. The clinical data of the patients were collected including: Age, gender, clinical history, etiology, symptoms, side of disease, medical history of other diseases, spirometry, procedures of surgery, duration of chest drainage, pre- and post-operative complications, and duration of hospital stay. Preoperative roentgenograms such as (Chest X-ray, U&S, Thoracic and upper abdominal Computed Tomographic (CT) scan, as well as Magnetic Resonance Imaging (MRI)) were reviewed (Figure 1, 2).

Furthermore, 16 patients (65%) were classified in idiopathic DE, eight patients in Trauma, and four patients in cardiac and mediastinal surgery. The two remaining patients had congenital origin. The etiology assessment was performed by a pneumologist and a thoracic surgeon. Chronic obstructive pulmonary disease and arterial hypertension were identified in ten patients. Diabetes mellitus was diagnosed in three patients and one patient had coronary artery disease. Forced Vital Capacity (FVC) and Forced Expiratory Volume (FEV1) were measured in all patients. Assessment of dyspnea was also used by The American Thoracic Society Dyspnea Grading Method [11] (Table 1).

Surgery was performed by general anesthesia, single-lumen intubation, and postero-lateral or antero-lateral thoracotomy through sixth, seventh or eighth intercostal space. The structures of thoracic cavity and organs, such as lung, mediastinum, phrenic nerve, pericardium, and diaphragm were carefully examined for any other unsuspected pathology. The diaphragm was then plicated with six to eight rows of non-absorbed stitches until diaphragm becomes taut and firm (Figure 3B). We used nylons or vicryl stitch with simple separated sutures; the first row starts at the posterior portion of the diaphragm to the costal side. Then, another suture was used to complete the shortening of the central portion from posterior to anterior of diaphragm. The third suture was further used at the pericardium side. Next, for termination of plicaton between the three former sutures, and another four suture was used. Redundant tissue of diaphragm, between the first rows of sutures, was flattened by using second row of running sutures. Extreme care was needed to avoid

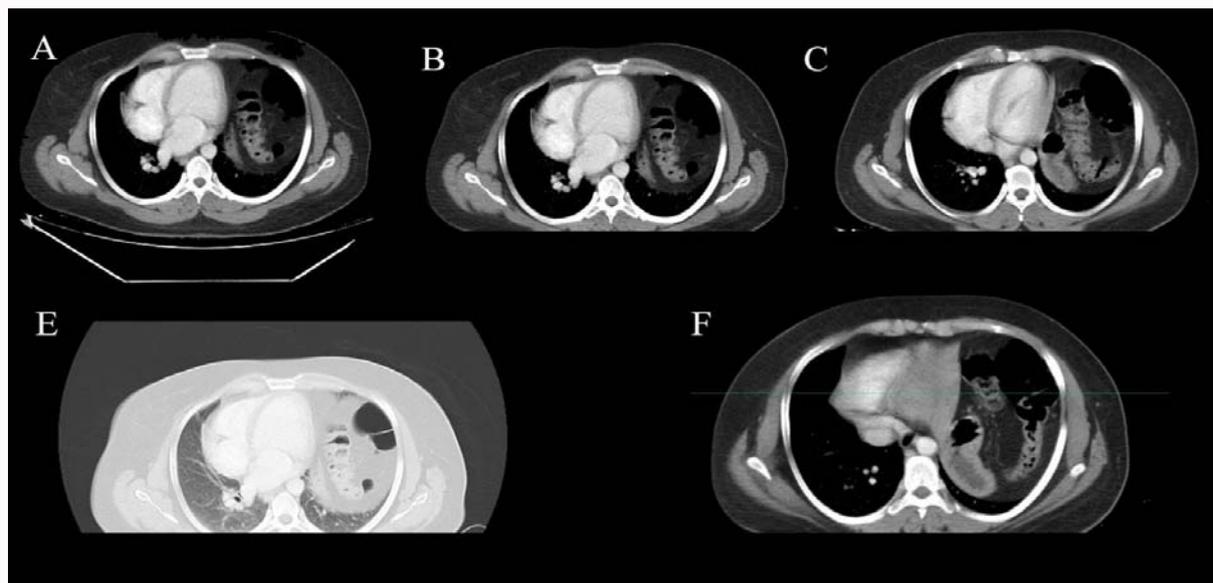


Figure 2: CT-scan of the chest with IV and oral contrast show colon and omentum. Small intestine in the chest.

Table 1: American Thoracic Society Dyspnea Grading Method.

Grade	Severity	Explanation
Grade 0	None	No trouble with breathing except with strenuous exercise
Grade 1	Mild	Trouble with shortness of breath when hurrying on level or walking up a slight hill
Grade 2	Moderate	Walks slower than people of same age on the level or has to stop for breath walking at own pace on the level
Grade 3	Severe	I stop for breath after walking 100 yards or after a few minutes on the level.
Grade 4	Very severe	Too breathless to leave the house or breathless when dressing or undressing

hurting abdominal viscera, such as colon, spleen, liver, and stomach with the sutures. A single chest tube was put in the pleural space and the thoracotomy was closed in layers. Additionally, all patients were extubated in the operating room after completion of procedures. If chest-X-ray showed air under diaphragm postoperatively, there would be no problem because air could have escaped from stitch site to the abdominal cavity. Eventually, patients were contacted by telephone or invited to come to the clinic for evaluation of the dyspnea score, chronic chest wall or abdominal pain. In follow-up period, Spirometry and chest X-ray was performed two to eight months postoperatively (Figure 3A).

Results

The demographic of patients are shown in Table 2. Out of thirty patients with DE, 18 patients were males and 12 were females. Mean age of the patients was 46 years (range: 18 to 64 years). Dyspnea was the most common complaint in 75% of patients; chest wall pain was present in 25%, palpitation in 18%, and epigastric pain in 12% of them. DE was idiopathic in sixteen of patients, trauma was the cause in eight patients, mediastina surgery in four, and two patients had a congenital cause. Chronic obstructive pulmonary disease and arterial hypertension were further present in 10% of patients, while diabetes mellitus was observed in six of them. The mean Forced Expiratory Volume in 1 (FEV1) and Forced Vital Capacity (FVC) were 64 and 68% of the predicted values, respectively. Diagnostic tools included Chest radiography in all 30 of patients, CT-scan used in 20 individuals, MRI in 10 patients, and U&S in eight patients. Preoperative and postoperative diagnosis matched with these tools.

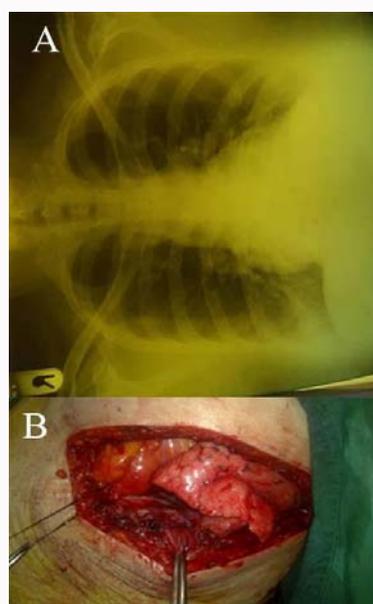


Figure 3: A: CXR show 2 months postoperative, B: Picture show repair of diaphragm during surgery).

The side of eventration in 20 of patients was in left side and 10 in right side. Moreover, the postero-lateral thoracotomy and antero-lateral thoracotomy were used in 20 and 10 patients, respectively. Radical correction was also performed in all patients. There was no mortality in hospital or within 30 days following the study procedure. Average

Table 2: Demographic of surgically patients in this study.

Variable	Result
Age [mean (range)]	60 (36-66) years
Male/female (n)	18/12
Progressive dyspnea (n)	22
Chest wall pain(n)	
Respiratory and digestive symptoms (n)	6
Epigastric pain(n)	2
Mean duration of symptom [mean (range)]	(32-72) months
Etiology (n)	
Idiopathic	16
Congenital	2
Cardiac by-pass, mediastinal surgery	4
Trauma	8
Operation side (n)	
Right	10
Left	20
Diagnosis(n)	
CXR	30
CT-scan	24
MRI	6
U&S	8
Postero-lateral thoracotomy	20
Antero-lateral thoracotomy	10

drainage time was four days (range: 2 to 6 days). In addition, the main hospitalizations time was seven days. Appeared post-operation complications were: Respiratory failure in two patients, air leak in four patients. Two patients with COPD and diabetes had a right lower lobar pneumonia and were successfully treated with antibiotics and they were free from respiratory symptoms at the time of discharge. Pleural effusion was also discerned in four patients two day after removal of chest-tube, which managed with simple aspiration. Besides, moderate chest wall and abdominal pain continued in seven patients for three months. Also, Palpitation disappeared and there was no need for any medications. There were further mild abdominal pain, distention, belching, and gastrointestinal discomfort, which subsided with medications. Almost 21 patients experienced a feeling of tightness and light pain in the lower chest/upper abdominal a few days postoperative, which subsided with analgesics and carminative. At follow-up, FEV1 and FVC increased by 75% and 80%, respectively,

two months postoperative (the FEV1 was 75 ± 16 % and the VC was 80 ± 17 % ($p>0.1$)). The follow-up was completed an average length of 36 to 62 months. Twenty-six patients were asymptomatic. There were four patients with chronic pain and another three patients with paresthesia in the thoracotomy area. Recurrence of the eventration did not occur in 36 to 62 months after surgery follow-up was performed by chest X-ray and spirometry. At a long-time follow-up, grade of dyspnea completely improved in 22 patients. Eight patients had dyspnea score 1 after surgery plus feeling of fullness after their meals although the FVC and FEV1 mean values increased after surgery (Table 3).

Discussion

In this long-time follow-up study, we evaluated the outcome of unilateral diaphragm plication in 30 symptomatic patients. We found that plication for unilateral diaphragm eventration can re-expand the collapse of lung; improve respiratory, heart, digestive symptoms, and quality of life in a long duration of time. Symptomatic unilateral DE in all age groups is an uncommon but serious clinical problem. These symptoms are: dyspnea, chest pain, and GI discomfort [2,18]. Diagnosis of diaphragm eventration is suggested when the chest X-ray shows elevation of hemidiaphragm, which is then confirmed by fluoroscopy, ultrasonography, Spiral CT-scan of thorax, and MRI [1,2,18]. For differential diagnosis, spiral CT is used to roll-out particularly intrathoracic malignancies. Fiberoptic bronchoscopy is further used for diagnosis of endobronchial problem due to collapse of lung [1,2,18]. Chest and abdominal CT-scan is a valuable tool for evaluating sub diaphragmatic problem, diaphragm rupture and herniation of abdominal organ [19]. Unilateral diaphragm eventration might be not diagnosed in older patients [2]. In some patients, the identification of this problem is often delayed, unless it follows a trauma or cardiothoracic surgery. In some paper, ultrasound of diaphragm is recognized as sensitive, safe, and non-invasive method without radiation exposure and recommended to replace with the use of radioscopy and EMG [20].

The etiology of diaphragm eventration is usually defined based on the history and previous chest X-ray of the patients [14]. Before to surgical correction, careful evaluation of the eventration should be done to differentiate other possible reasons of respiratory symptoms such as parenchymal lung disease, chronic heart failure, and neoplastic etiology [2,18]. The most common indication for surgery is exertional dyspnea and difficulty with simple daily activities [17]. There is also controversy about time of surgery after diagnosis [2,14]. Some authors recommend that a period of 3 to 6 months is better for

Table 3: Spirometry results before and after plication at long-term follow-up.

Patient no.	FVC (%)			FEV1 (%)		
	Before plication	After plication	Improvement (% change)	Before plication	After plication	Improvement (% change)
2	52	80	58	64	74	21
5	58	85	62	70	85	23
3	59	81	59	65	78	26
3	68	102	56	68	103	53
2	77	95	34	88	99	28
5	78	81	42	65	85	45
4	56	78	58	60	76	38
3	57	67	38	57	76	46
1	54	77	76	65	81	45

plication [15] Summerhill et al. believed that the best time for surgery could vary from 5 to 25 months (mean time: 14.9 ± 6.1 months) [20]. Mouroux et al, recommend 18 to 24 months [16]. According to clinical experiments done in this study, surgery is necessary after diagnosis depending on the etiology of paralysis and the condition of patents.

On the other hand, the most frequently used surgical technique for Plication is standard thoracotomy. It carries low morbidity and no mortality [1,2]. Graham et al. report in which 17 patients underwent thoracotomy and functional improvement of diaphragm was made at a long-term follow-up [21]. Higgs et al. also reported that diaphragm plication is an effective treatment for unilateral diaphragmatic paralysis and shows improvement in spirometry findings within a long-term period [22]. Similar results were also reported by Ribet et al. and Linder et al. [22]. In this study, the surgical technique displayed several advantages because, the paralyzed diaphragm is very thin, thus take care to avoid injury of abdominal organs especially colon which is just below this thin structure. We took and elevated the flaccid eventration portion to prevent the organ under diaphragm from damaging. With this method we did not hurt any organs the second way for prevention of injury to organ could be placing extra tight and tense sutures in the lowest border of flaccid diaphragm [2]. Furthermore, in a standard thoracotomy, the surgeon is able to control the diaphragm completely by touching and feeling [2]. Another way to avoid damaging is phrenotomy and exploration of underlying organs with direct vision. The suturing procedure also becomes easier in this approach [1,2,18]. We never employed this method in present study. A highly important factor for providing a favorable long-term surgical outcome is that plication must be strong and tense on the diaphragm [2,12,14,18]. Some experiments reported serosanguineous drainage from chest-tube and announced that mean time for removal of chest-tube is at three-day after plication [23,24]. We did not see this complication in our study. This complication may be due to an impaired lymphatic circulation after plication [4,12,14,18]. In a report, Freeman showed that in all patients who had undergone plication by Video-Assisted Thoracoscopic Surgery (VATS), dyspnea and spirometric values improved in long-term period, however, there is still controversy on advantages and disadvantages of VATS technique [1,15,18,25]. In the present study, we did not perform plication with VATS. Similarly, a recent work showed that obtaining a sufficiently tense diaphragm with VATS technique is difficult [26]. During plication, diaphragm must not be over-tightened because lower chest wall would be restrained and it would prevent limiting inspiration [12-14,26]. Moreover, incidence of phrenic nerve dysfunction in adults after coronary artery bypass grafting is reported to be 10% to 60% Katz et al. [29,30] showed that 80% of patients spontaneously recovered within one year. However, Kuniyoshi et al. [27,28] suggested that one of the indications of plication for patients with diaphragm paralysis, who have undergone coronary artery bypass surgery is that they are difficult to be weaned from mechanical ventilation.

Kuniyoshi et al. [27] also reported that plication is an effective and safe procedure for diaphragm paralysis due to open cardiac surgery in adults similar to children. In this study, plication was performed in three patients with diaphragm paralysis due to coronary artery bypass surgery. In these three patients, the internal mammary artery had been used for bypass surgery and duration of dyspnea was over 15 months. Diaphragmatic paralysis after coronary artery bypass grafting in adult patients is due to topical cooling [15,16,27].

In addition to surgical technique, diabetes and aging have been considered potential risk factors for diaphragm paralysis [22,31]. In the present study, MRC/ATS dyspnea scale was used to evaluate the subjective effect of diaphragm plication on symptoms [5]. This system is based on the assessment of apparent dyspnea by five different severity statements. While Simansky et al. [25] used ATS dyspnea scoring system, Freeman et al. applied MRC system; both studies reported that dyspnea improves long-term after plication surgery and most of patients could return to their work [25]. However, they used baseline dyspnea index in preoperative and postoperative periods as described by Witek and Mahler [32]. Diaphragm eventration patients with chronic obstructive lung disease and obesity have high risk of morbidity and mortality [2,5,18]. This experience showed us that plication must not be applied in the patients with moderate-to-severe chronic obstructive lung disease and in the patients with a body-mass index of 30 kg/m^2 or above. If plication is performed in these patients, long intense bronchodilator treatment, respiration physiotherapy needs to be carried out and patients should try to lose weight. Three deaths happened out of 22 patients who had undergone plication in Versteegh report [32]. These deaths were due to heart problem, pulmonary thromboembolism, renal failure, and right heart failure [8]. Pathak and Page also reported splenic injury due to plication [33]. Besides, Phadnis reported abdominal compartment syndrome after right-side diaphragm plication surgery [26]. They suggested that their patients had developed abdominal compartment syndrome because of downward hepatic shift and a reduced intra-abdominal volume. Mortality related to this surgical procedure has not yet been reported. In this study, we caused no injury to colon, spleen, abdominal compartment syndrome, hepatic, and stomach duo to the suturing for plication of diaphragm.

Conclusion

In this study, we inferred that Plication of diaphragm is a safe and effective procedure for respiratory, gastrointestinal, cardiovascular systems, and significant improvement of life quality. We also concluded that pulmonary function tests (FEV1 and FVC) could increase post-operative. However, chronic chest wall pain still might remain a complaint by trans-thoracic approach. Therefore, after diagnosis of DE with either Chest radiography or CT-scan of the chest, plication is recommended.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Guilan University of Medical Sciences and is in compliance with the declaration of Helsinki; however, there was no need to taking informed consent since only leftovers from medical record were used.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author's contributions

MTA, AAL and MA: conceived and design of the study. MA, AAF and AT interpreted the data. MA: obtained ethical clearance and permission for study. HH, AAF and AAL: Supervised data collectors. AAL, AT and MTA and MTA: Drafting the article or revisiting it critically for important intellectual content. MA, HH and MTA: were project leaders and primary investigators of the study. All authors read and approved the final manuscript.

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References

- Celik S, Celik M, Aydemir B, Tuncakaya C, Okay T, Dogusoy I. Long-term results of diaphragmatic plication in adults with unilateral diaphragm paralysis. *J Cardiothorac Surg.* 2010;5:111.
- Cordeiro JdA, Almeida AK, Júnior SADO, Fernandes BM, Rego ACM, Araújo-Filho I. Diaphragmatic eventration: Review of current knowledge, diagnostic, and management options. *IJMRHS.* 2016;5(3):62-5.
- Joseph LIII, Richard FH, Yolonda CL, Gaetano R. *Shields' general thoracic surgery*: Lippincott Williams & Wilkins. 2018.
- Anraku M, Shargall Y. Surgical conditions of the diaphragm: Anatomy and physiology. *Thorac Surg Clin.* 2009;19(4):419-29.
- Nason LK, Walker CM, McNeeley MF, Burivong W, Fligner CL, Godwin JD. Imaging of the diaphragm: Anatomy and function. *Radiographics.* 2012;32(2):E51-70.
- Levine S, Nguyen T, Taylor N, Friscia ME, Budak MT, Rothenberg P, et al. Rapid disuse atrophy of diaphragm fibers in mechanically ventilated humans. *N Engl J Med.* 2008;358(13):1327-35.
- Newton K, Malik V, Chiong LT. Sleep and breathing. *Clin Chest Med.* 2014;35(3):451-6.
- Maish MS. The diaphragm. *Surg Clin North Am.* 2010;90(5):955-68.
- McCool FD, Tzelepis GE. Dysfunction of the diaphragm. *N Engl J Med.* 2012;366(10):932-42.
- Kharma N. Dysfunction of the diaphragm: Imaging as a diagnostic tool. *Curr Opin Pulm Med.* 2013;19(4):394-8.
- Merino-Ramirez MA, Bolton CF, Boon AJ, Sorenson EJ, Strommen JA, Watson JC. Sensitivity and specificity of diagnostic ultrasound in the diagnosis of phrenic neuropathy. *Neurology.* 2015;84(21):2200.
- Welvaart WN, Ong KH, Paul MA, Vonk-Noordegraaf A, Ottenheijm CA. Laparoscopic diaphragmatic plication in patients with unilateral diaphragm paralysis with thoracoscopic verification. *Open J Thorac Surg.* 2012;2(4):104-7.
- Tsakiridis K, Visouli AN, Zarogoulidis P, Machairiotis N, Christofis C, Stylianaki A, et al. Early hemi-diaphragmatic plication through a video assisted mini-thoracotomy in postcardiotomy phrenic nerve paresis. *J Thorac Dis.* 2012;4(Suppl 1):56-68.
- Groth SS, Andrade RS. Diaphragm plication for eventration or paralysis: A review of the literature. *Ann Thorac Surg.* 2010;89(6):S2146-50.
- Shields T. Diaphragmatic function, diaphragmatic paralysis, and eventration of the diaphragm. *General Thoracic Surgery*. Shields TW, LoCicero J III, Ponn R, Rusch VW, editors. Philadelphia: Lippincott Williams&Wilkins; 2005.
- Mouroux J, Venissac N, Leo F, Alifano M, Guillot F. Surgical treatment of diaphragmatic eventration using video-assisted thoracic surgery: A prospective study. *Ann Thorac Surg.* 2005;79(1):308-12.
- Saroj SK, Kumar S, Afaque Y, Bhartia AK, Bhartia VK. Laparoscopic repair of congenital diaphragmatic hernia in adults. *Minim Invasive Surg.* 2016;2016:9032380.
- Onders P. Physiology of the diaphragm and surgical approaches to the paralyzed diaphragm. *Shields' General Thoracic Surgery*. 8th Ed Philadelphia: Wolters Kluwer. 2018. p. 664-672.
- Israel RS, Mayberry JC, Primack SL. Diaphragmatic rupture: Use of helical CT scanning with multiplanar reformations. *AJR Am J Roentgenol.* 1996;167(5):1201-3.
- Summerhill EM, El-Sameed YA, Glidden TJ, McCool FD. Monitoring recovery from diaphragm paralysis with ultrasound. *Chest.* 2008;133(3):737-43.
- Graham D, Kaplan D, Evans C, Hind C, Donnelly R. Diaphragmatic plication for unilateral diaphragmatic paralysis: A 10-year experience. *Ann Thorac Surg.* 1990;49(2):248-51.
- Ribet M, Linder J. Plication of the diaphragm for unilateral eventration or paralysis. *Eur J Cardiothorac Surg.* 1992;6(7):357-60.
- Mahler DA, Weinberg DH, Wells CK, Feinstein AR. The measurement of dyspnea. Contents, interobserver agreement, and physiologic correlates of two new clinical indexes. *Chest.* 1984;85(6):751-8.
- Tripp HF, Sees DW, Lisagor PG, Cohen DJ. Is phrenic nerve dysfunction after cardiac surgery related to internal mammary harvesting? *J Card Surg.* 2001;16(3):228-31.
- Freeman RK, Van Woerkom J, Vyverberg A, Ascoti AJ. Long-term follow-up of the functional and physiologic results of diaphragm plication in adults with unilateral diaphragm paralysis. *Ann Thorac Surg.* 2009;88(4):1112-7.
- Phadnis J, Pilling JE, Evans TW, Goldstraw P. Abdominal compartment syndrome: A rare complication of plication of the diaphragm. *Ann Thorac Surg.* 2006;82(1):334-6.
- Kuniyoshi Y, Yamashiro S, Miyagi K, Uezu T, Arakaki K, Koja K. Diaphragmatic plication in adult patients with diaphragm paralysis after cardiac surgery. *Ann Thorac Cardiovasc Surg.* 2004;10(3):160-8.
- Rajkumar JS, Ganesh D, Rajkumar A, Syed A, Guru V. Thoracoscopic diaphragmatic plication for eventration in pregnant woman: A case report. *J Clin Diagn Res.* 2017;11(7):QD03-4.
- Katz MG, Katz R, Schachner A, Cohen AJ. Phrenic nerve injury after coronary artery bypass grafting: Will it go away? *Ann Thorac Surg.* 1998;65(1):32-5.
- Tripp HF, Bolton JW. Phrenic nerve injury following cardiac surgery: A review. *J Card Surg.* 1998;13(3):218-23.
- Higgs SM, Hussain A, Jackson M, Donnelly RJ, Berrisford RG. Long term results of diaphragmatic plication for unilateral diaphragm paralysis. *Eur J Cardiothorac Surg.* 2002;21(2):294-7.
- Witek TJ, Jr, Mahler DA. Meaningful effect size and patterns of response of the transition dyspnea index. *J Clin Epidemiol.* 2003;56(3):248-55.
- Pathak S, Page RD. Splenic injury following diaphragmatic plication: An avoidable life-threatening complication. *Interact Cardiovasc Thorac Surg.* 2009;9(6):1045-6.