diaphragm dysfunction, which can be due to eventration or an abnormally high-positioned diaphragm, can cause respiratory compromise. Eventration is most commonly due to unilateral diaphragm paralysis, which reduces ventilatory function in adults by about 25%. Since the 1920s, this condition has been treated with diaphragm plication, which itself has evolved to include the use of several different techniques and materials. This review explores the relevant literature on diaphragm plication using sutures or staples for the treatment of eventration to determine if either provides a clinical benefit over the other.

ABSTRACT
Diaphragm dysfunction, which can be due to eventration or an abnormally high-positioned diaphragm, can cause respiratory compromise. Eventration is most commonly due to unilateral diaphragm paralysis, which reduces ventilatory function in adults by about 25%. Since the 1920s, this condition has been treated with diaphragm plication, which itself has evolved to include the use of several different techniques and materials. This review explores the relevant literature on diaphragm plication using sutures or staples for the treatment of eventration to determine if either provides a clinical benefit over the other.

INTRODUCTION
The diaphragm is the primary muscle necessary for respiration. Normally, the diaphragm contracts during inspiration, which increases lung volumes, and relaxes during exhalation, which decreases lung volumes. It is innervated by the phrenic nerve with nerve roots from C3 to C5. If this nerve is damaged or if the diaphragm was formed abnormally, diaphragm paralysis can occur. Diaphragm paralysis is characterized by an abnormal partial or complete elevation of the diaphragm. Etiologies of diaphragm paralysis include intrathoracic, intra-abdominal, diaphragmatic and systemic conditions and diseases, such as pulmonary fibrosis, rib fractures, ascites, pregnancy, obesity, neuromuscular disorders and endocrine disorders. Another possible etiology is eventration. True eventration, or congenital eventration, is due to a muscular defect of the diaphragm, whereas acquired eventration, which is commonly referred to as diaphragm paralysis, is caused by trauma or tumor impingement on the phrenic nerve. Both forms result in an excessively relaxed diaphragm, causing it to be abnormally elevated, and the lungs and mediastinal structures become compressed, which produces difficulties in ventilation (Fig. 1). Although most cases are asymptomatic, when present, the most common symptoms in adults include dyspnea, palpitations, chest pain, pneumonia and dyspepsia, while infants present respiratory distress, cyanosis, pulmonary hypertension, vomiting and failure to thrive.

The most common treatment for symptomatic eventration is diaphragm plication, which involves folding the diaphragm upon itself, thus stabilizing and preventing it from paradoxical movement to improve pulmonary functions. Diaphragm plication was first used by Morrison in 1923 for patients with eventration due to unilateral...
phrenic nerve paralysis, and has since evolved to include different techniques using sutures or staples.1 This article aims to evaluate the current literature to review the indications and benefits of diaphragm plication and to compare the literature on suture and stapled diaphragm plication to assess whether one is superior for the management of diaphragm plication to assess whether one is superior for the management of eventration due to congenital or acquired diaphragm dysfunction.

### INDICATIONS

Eventration requires no intervention when asymptomatic. Only patients who are symptomatic are treated with diaphragm plication, and the only goal is to relieve symptoms, especially dyspnea.2 For infants, plication is generally only performed in those with inadequate nutritional intake or gastrointestinal complications, those who require ventilatory support, and/or those with recurrent or life-threatening pneumonia after failure of medical management for four weeks, whereas in adults, 6-12 months without resolution or even improvement of progressive dyspnea is the determinant of diaphragm plication.3,7 These time periods allow for adequate time for possible spontaneous recovery to occur. In patients who are symptomatic, other causes of dyspnea or orthopnea must be excluded, and pulmonary function tests (PFTs) and imaging must be performed. In assessing pulmonary function, PFTs are performed in the supine and upright positions. If the results are positive, the patient will exhibit a restrictive lung condition with a reduction in forced vital capacity (FVC) and forced expiratory volume in one second (FEV1).7 Normally, there is a decrease in FVC of about 20% from the supine to upright positions, whereas in patients with progressive dyspnea from diaphragm paralysis there is a greater reduction of FVC of about 20-50%.7 Sniff tests, which involve fluoroscopy to observe the movement of hemidiaphragms during inspiration, can also be used. However, patients with eventration can have little or no movement of their diaphragm, making sniff tests less effective in determining the severity of symptoms or the need for diaphragm plication.2 In addition to sniff tests, PFTs and imaging are also not dependable when used alone to determine if surgical intervention is indicated. Typically, a combination of factors must be considered along with an assessment of symptoms with a thorough history and physical exam.

There are also some potential, but not absolute, contraindications to consider before patients undergo diaphragm plication. These include morbid obesity, calcified nonpliable diaphragms, and neuromuscular disorders, such as amyotrophic lateral sclerosis (ALS).7 For patients who are symptomatic with morbid obesity, it is recommended that they first undergo medical or surgical bariatric interventions, as their symptoms may diminish once they achieve adequate weight loss, and thus they may no longer require diaphragm plication as treatment.7

### BENEFITS

Although diaphragm plication can cause complications, such as pneumonia, pleural effusions, abdominal compartment syndrome, abdominal viscus injury, deep vein thrombosis, pulmonary embolism and myocardial infarction, its benefits are associated with its ability to increase the patient’s FEV1, improve their tidal volume, and reduce their ventilation rate.7

---

**Table I**

<table>
<thead>
<tr>
<th>Type of Plication</th>
<th>Author</th>
<th>Patient Population (No. of Patients)</th>
<th>Surgical Technique (Material Used)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suture</td>
<td>Demos et al.12</td>
<td>multiple indications (18)</td>
<td>single running suture w/ horizontal mattress sutures</td>
<td>Improved PFTs and DLCO</td>
</tr>
<tr>
<td></td>
<td>Mouroux et al.13</td>
<td>trauma-induced left diaphragm palsy (3)</td>
<td>2 running sutures</td>
<td>Improved PFTs, stabilized diaphragm positions on post-op CXR</td>
</tr>
<tr>
<td></td>
<td>Freeman et al.14</td>
<td>idiopathic, iatrogenic, and trauma-induced unilateral diaphragm palsy (41)</td>
<td>u-stitch sutures</td>
<td>Improved PFTs and MRC dyspnea scores</td>
</tr>
<tr>
<td>Stapled</td>
<td>Moon et al.15</td>
<td>surgical trauma-induced left diaphragm palsy (1)</td>
<td>endostaples</td>
<td>Improved PFTs and post-op CXR showed normalization of left diaphragm</td>
</tr>
<tr>
<td></td>
<td>Kim et al.16</td>
<td>idiopathic left diaphragm palsy (1)</td>
<td>endostaples w/ mesh</td>
<td>Improved dyspnea, improved PFTs and DLCO, post-op CXR showed improved and maintained position of left hemidiaphragm</td>
</tr>
<tr>
<td></td>
<td>Chang et al.17</td>
<td>trauma-induced right diaphragm palsy (1)</td>
<td>endostaples</td>
<td>Improved PFTs and post-op CXR showed reduced right diaphragm elevation</td>
</tr>
</tbody>
</table>

PFTs, Pulmonary Function Tests; DLCO, Diffusing Capacity of Lungs for Carbon Monoxide; CXR, Chest X-Ray; MRC, Medical Research Council
chenberger et al. reported a case series of 3 patients who underwent diaphragm plication for left diaphragm paralysis (mediastinal mass resection) and right diaphragm paralysis (lung transplantation and coronary artery bypass grafting). Preoperatively, these patients had a reduced FEV1 of 62%, 33% and 53%, respectively. Postoperatively, FEV1 had improved to 92% at 1-year follow-up, 41% at 8-month follow-up and 67% at 1-month follow-up, respectively. These changes allow patients to breathe better and improve their quality of life as a result. In addition, diaphragm plication decreases the hospital stay and the need for mechanical ventilation, which is commonly associated with several poor outcomes, including respiratory infections, speech difficulties, decreased life expectancy, loss of olfaction, and increased morbidity and mortality with prolonged use.

Since its initiation, diaphragm plication has been transformed in several different ways, such as in the variety of surgical techniques that are used during the procedure. These techniques are either suture-based, which includes mattress sutures, running sutures with or without pledges and U-stitches, or staple-based, which generally includes the use of endostaplers. Table I summarizes some postoperative results with these methods.

Suture diaphragm plication is the most commonly used method (Fig. 2). Demos et al. demonstrated the use of a single running suture with horizontal mattress sutures in a single-center, retrospective study of 18 patients undergoing video-assisted thoracoscopic surgical (VATS) diaphragm plication from 2008 to 2013 for a variety of indications. Postoperatively, for these 18 patients, there were two unrelated deaths (one from congestive heart failure and the other from progressive metastatic melanoma), two patients lost to follow-up, and complications, including atrial fibrillation in one patient, pneumonia in two, reintubation in one and an ileus in one; about 83% of patients experienced no complications. There were also significant increases in FEV1 (p=0.002) and FVC (p=0.002) from preoperative to postoperative measurements as well as a non-significant increase in the diffusing capacity of the lungs for carbon monoxide (DLCO).

They showed that running suture diaphragm plication is safe and effective for improving pulmonary function. However, their study was limited because it was a single-center, retrospective study with a small sample size.

Mouroux et al. conducted a similar study, but with two running sutures without reinforcement with horizontal mattress sutures. The use of two running sutures allows for proper tension distribution to avoid intrapertitoneal injury and provides appropriate reinforcement. This single-center study involved 3 patients (2 males and 1 female) who underwent thoracoscopic diaphragm plication for left diaphragm paralysis, all due to severe chest trauma, and only one patient presented pneumonia postoperatively. Follow-up revealed improved PFTs and no recurrence of eventration on imaging for 17, 20, and 30 months following the procedure in each patient.

In another study by Freeman et al., U-stitches with pledges were used in 41 patients who underwent diaphragm plication via thoracotomy, but mainly through VATS for idiopathic, iatrogenic or trauma-induced unilateral diaphragm paralysis. Postoperative complications included atrial fibrillation in 2 patients, pneumonia in 2, ileus in 1, and deep vein thrombosis in 1, with no mortality. All 41 patients showed objective improvements in PFTs, and 37 patients had a significant improvement in symptoms, specifically dyspnea, following the operation. Two of the 4 patients without significant improvements were morbidly obese and 3 of them experienced a delay of at least 4 years between diagnosis and treatment, suggesting that there may have been reasons for their poor functional outcome.

Staple-based diaphragm plication, on the other hand, is a growing technique. Chang et al. showed similar results. Their study also involved one participant, a female, who developed right diaphragm paralysis with right diaphragm eventration and progressive respiratory distress after a pair of garden shears accidentally pierced her neck while gardening. Her PFTs preoperatively displayed an FEV1 of 17%, and she subsequently underwent VATS diaphragm plication, without intraoperative or postoperative complications. At the 1-year follow-up, her postoperative FEV1 was 145%.

In our practice, we have replaced routine sutured diaphragm plication with stapled plication. Typically, with sutured diaphragm plication, because of the imbrication of the serosal areas, there is high chest tube output that prevents early discharge. Since, in our experience, stapled plication can decrease chest tube output, we hypothesize that there is less imbrication of serosal areas, which allows for patient discharge on postoperative day 1 or 2. One of the major concerns with staple diaphragm plication is a risk of anastomotic dehiscence. We typically oversew the diaphragm with 0-Ethibond to prevent any diaphragm dehiscence from the staple line. We have not encountered dehiscence of the diaphragm and this is mostly a hypothetical risk, as discussed in the literature.

Due to the short follow-up periods and small sample sizes, these studies are insufficient to form a definitive
conclusion about the safety and utility of this technique. However, these results can be used as a foundation for further investigations.

CONCLUSION

Although diaphragm plication has been shown to be effective for treating symptomatic unilateral diaphragm dysfunction, no previous studies have compared the postoperative outcomes, safety and efficacy in suture-based and staple-based diaphragm plication. This review of the relevant literature suggests that both stapled and suture diaphragm plication have therapeutic value. However, suture plication is supported by a greater body of evidence, whereas additional studies with larger sample sizes and longer follow-up periods are needed to obtain adequate information for proper interpretation of the utility of stapled plication. These techniques have primarily been used based on the surgeon’s preferences, and this trend will most likely continue until further research is completed.

AUTHORS’ DISCLOSURES

The authors declare that there are no conflicts of interest.

REFERENCES