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Diaphragmatic Flap: Technique of Preparation and Indications for Use

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Abstract

Background: The use of a vascularized pedicle flap of diaphragmatic muscle (DF) for reconstructive procedures in the chest has many advantages. Yet, despite the excellent reported results, the use of DF has not been widespread. Some factors for the less widespread use of DF have been, concern about diaphragmatic function, hesitation to use such a vital muscle for reconstructive purposes, and most importantly, the technical aspects for the preparation of the flap. **Methods:** Using a cadaveric model, the vascular anatomy of the diaphragm and the steps for the preparation of the DF was defined and illustrated for both the right and left hemidiaphragm. **Results:** No perioperative mortality with the use of DF has been recorded. Function of the native diaphragm has not been impaired. Bronchopleural fistulas and pericardial defects have healed in all instances. Excellent repair has been achieved in all patients with esophageal lesions. The disruption of the repaired native diaphragm and visceral herniation has been reported but it has been attributed to the learning curve and the technique of repair. **Conclusion:** With a better understanding of the vascular anatomy of the diaphragm and a formal methodical approach to harvesting the DF, more surgeons will be encouraged to use DF with excellent results.

Keywords

Diaphragmatic Flap, Diaphragmatic Pedicle Flap, Muscle Flap, Bronchial Stump Reinforcement, Esophageal Reinforcement, Vascularized Flap, Pedicle Flap

1. Introduction

Vascular pedicle flaps including serratus anterior muscle, latissimus dorsi muscle, intercostal muscle, omentum, pectoralis muscle, pleura, and pericardium have been used for intrathoracic transposition in several applications [1]. The first use of a diaphragmatic vascularized pedicle muscle flap (DF) was described by Petrovsky in 1948 [2]. Since then, several reports have documented the use of this flap in thoracic surgery [3]-[8]. Most commonly, DF is used to cover the bronchial stump, or to buttress the esophageal suture line after repair of spontaneous or iatrogenic perforation. However, despite the excellent reported results, unlike other vascular pedicle flaps, the use of DF has not been widespread. Some factors for the less widespread use of DF have been, concern about diaphragmatic function, hesitation to use such a vital muscle for reconstructive purposes, and most importantly, the technical aspects for the preparation of the flap. Mineo *et al.* have addressed the issue of diaphragmatic function by studies that have shown no effect on ventilatory dynamics or paradoxical motion in patients who underwent pneumonectomy and DF. Furthermore, in other studies, postoperative function tests have demonstrated normal and constant flow values (forced vital capacity and forced expiratory volume in 1 second) in those patients who had esophageal repair and reinforcement with a DF [5]. It appears that the lack of familiarity of surgeons with the safe preparation of the DF is the only remaining obstacle to a more widespread use of DF in thoracic surgical applications. This paper outlines the technical aspects of harvesting the DF for right and left side thoracic applications.

2. Material and Methods

Fresh human cadavers were dissected to determine the vascular anatomy of the right and left hemidiaphragm. The vascular anatomy of the diaphragm from a caudad view and the vantage point from the thoracic cavity was outlined. Diaphragmatic vascularized pedicle muscle flaps were prepared in excised specimens of the hemidiaphragm and *in situ*. A standardized surgical approach for the harvest of the DF based on the lateral phrenic artery was determined for the right and left hemidiaphragm.

Human Material and data were not used for the study.

The study used Human Cadavers and as the study was anatomic in nature, the lack of vital signs in the cadaveric model was not a determining factor.

2.1. Blood Supply of the Diaphragm

Figure 1, shows the blood supply to the diaphragm. The blood supply is provided by the phrenic artery (PA), which visible along the inferior surface of the muscle. The phrenic artery is not easily visualized from the thoracic side of the diaphragm. Therefore, a comprehensive knowledge of the arterial anatomy is paramount for the ability to prepare a reliable vascularized pedicle of diaphragmatic muscle. The branching pattern of the phrenic artery is different between the right and left hemidiaphragm and shows significant variability in its course. Since the vessels are not visible from the thoracic vantage point, the surgeon needs to follow an organized and standardized approach in order to identify the

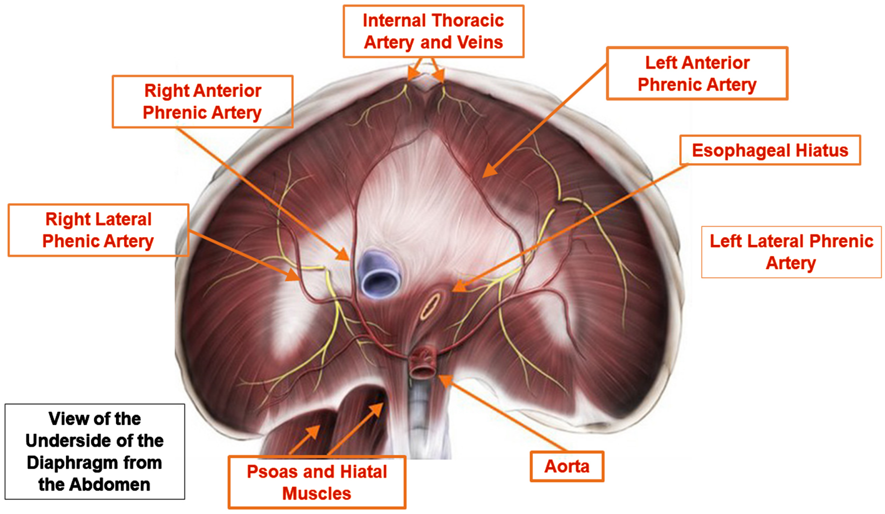

Figure 1. Peritoneal view from underside of the diaphragm showing the blood supply of the diaphragm. The Phrenic Artery (PA) pierces trough the diaphragmatic muscle and supplies the diaphragm from the underside. The branches of the PA are not easily seen from the thoracic vantage point but are visible from underside of the diaphragm.

branches of the PA and to preserve the arterial branches as well as the phrenic nerve.

2.2. Right Hemidiaphragm (RHD)

The PA accompanies the Phrenic Nerve (PN) and pierces through the diaphragm on the medial aspect of the RHD. Shortly after piercing the RHD, the PA becomes infra-diaphragmatic and divides into the Anterior and lateral branches. The Anterior branch of the PA accompanies the major branch of the PN and takes an anterolateral course. The Lateral branch of the PA courses in a lateral direction just Posterior to the tendonous portion of the RHD. The vascularized pedicle of diaphragm (DP) is based on the lateral branch of the PA. Figure 2 shows the arterial anatomy of the RHD from the above and from the thoracic vantage point.

2.3. Left Hemidiaphragm (LHD)

Figure 3 shows the arterial anatomy of the RHD from the above and from the thoracic vantage point. The anatomy on the LHD is similar to the right, except the Lateral branch of the PA courses in a lateral direction just Anterior to the tendonous portion of the RHD.

2.4. Technique for Preparation of the Flap

Right Hemidiaphragm: An incision is made on the **posterior** border of the tendonous portion of the RHD (Figure 4). Care is taken to preserve the common PA and the PN. A 5 mm videoendoscope is introduced through the incision and used to transilluminate the diaphragm and identify the lateral branch of the Right PA (LPA). The incision is carried laterally parallel to the LPA. The length

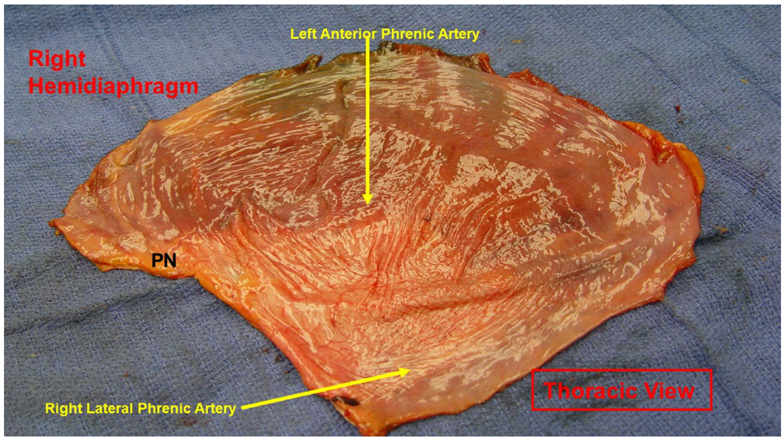

Figure 2. Thoracic view of the right hemidiaphragm excised from a cadaver. The anterior and lateral phrenic arteries are identified. The vessels are not easily seen from the thoracic vantage point. Phrenic Nerve (PN).

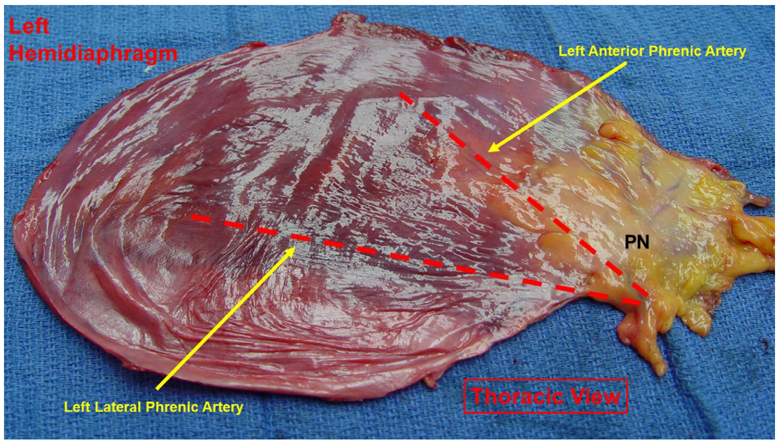

Figure 3. Thoracic view of the Left hemidiaphragm excised from a cadaver. The anterior and lateral phrenic arteries are identified. The vessels are not easily seen from the thoracic vantage point. Phrenic Nerve (PN).

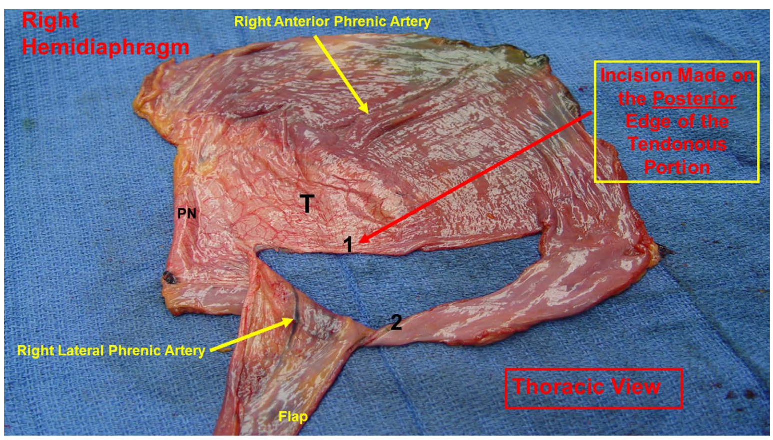

Figure 4. Thoracic view of the right hemidiaphragm excised from a cadaver. in order to prepare the diaphragmatic flap (df) an incision is made at the **posterior** edge of the tendonous portion. This incision is parallel to the lateral phrenic artery and prevents damaging the vessel.

of the flap is estimated by using a cloth tape (premeasured to extend to the level of the bronchus or the esophagus in need of reinforcement) which is extended from the base of the flap laterally toward the lateral insertion of the diaphragm. As soon as the length of the flap is deemed suitable for the surgical purpose, the direction of the incision is inverted ventrally to draw an arch of variable angulation. We normally mark the *tip* of the flap with a radiopaque clip to facilitate radiographic localization. The width of the base should be approximately one quarter of the entire length. The flap is tailored to be rotated inside the chest cavity, avoiding torsion on the pedicle and allowing sufficient mobility and low tension of the remaining diaphragm (**Figure 5** and **Figure 6**). The flap can reach any are below the hilum. On the right the DF is usually used to reinforce the bronchial stump (**Figure 7** and **Figure 8**). An additional 2 cm of length

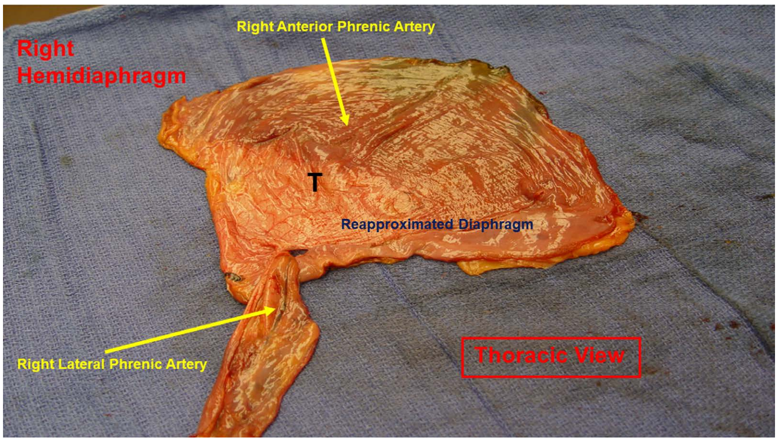

Figure 5. Thoracic view of the right hemidiaphragm excised from a cadaver. the diaphragmatic flap is shown. The remaining edges of the native diaphragm are reapproximated using interrupted horizontal mattress sutures with absorbable pledgets.

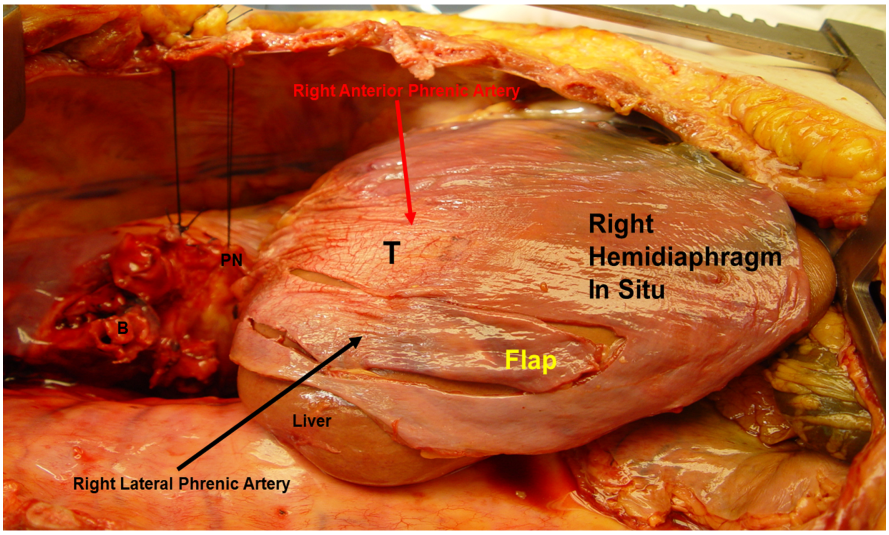

Figure 6. Thoracic view of the right hemidiaphragm *in situ* in a cadaver. the diaphragmatic flap can be seen. Right mainstem bronchus (B), Phrenic Nerve (PN).

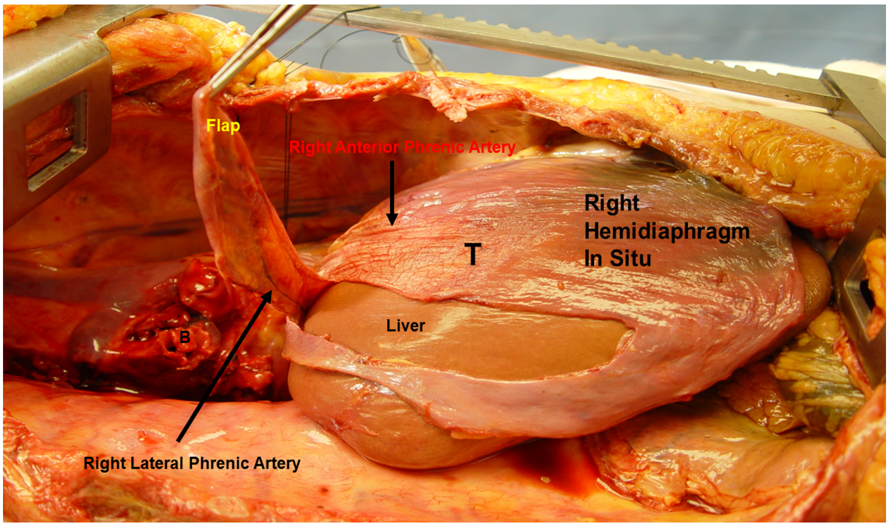

Figure 7. Thoracic view of the right hemidiaphragm *in situ* in a cadaver. The diaphragmatic flap is elevated and can easily reach cover any structure in the mediastinum. right mainstem bronchus (B), Phrenic Nerve (PN).

is required if the flap is to be used to wrap the bronchus. The diaphragmatic defect is closed by O Ethibond Suture (Ethicon Inc., New Jersey, USA) with 2 cm squared pledgets of vicryl mesh (Ethicon Inc., New Jersey, USA) in an interrupted horizontal mattress manner (Figure 9 and Figure 10). Peripheral vascularization can provide enough supply to the residual diaphragm, and its healing does not represent a problem. The DF is secured in place with interrupted OOOO polypropylene suture.

Left Hemidiaphragm (LHD): The technique on the left is similar to the right. However, on the LHD, the initial incision is made **anterior** border of the tendonous portion of the RHD. On the right, the PF is best used for reinforcement of esophageal suture lines (Figures 11-16).

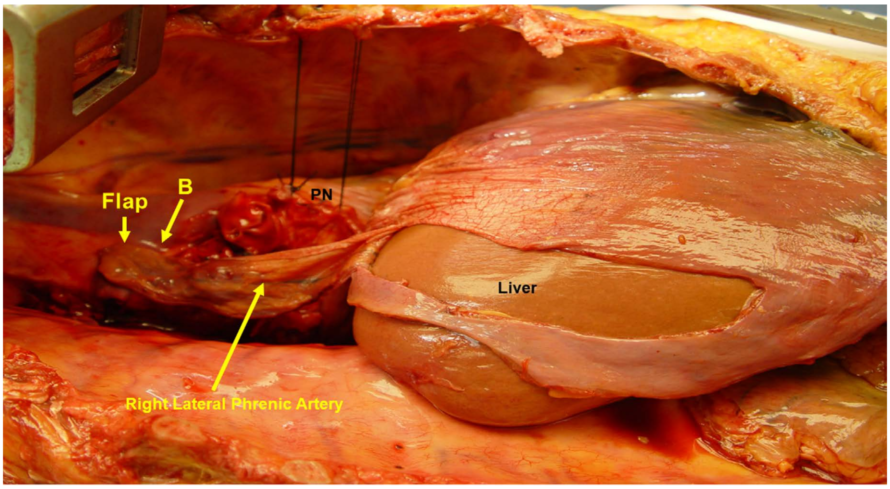

Figure 8. Thoracic view of the right hemidiaphragm *in situ* in a cadaver. The diaphragmatic flap has been rotated to cover the B. right mainstem bronchus (B), Phrenic Nerve (PN).

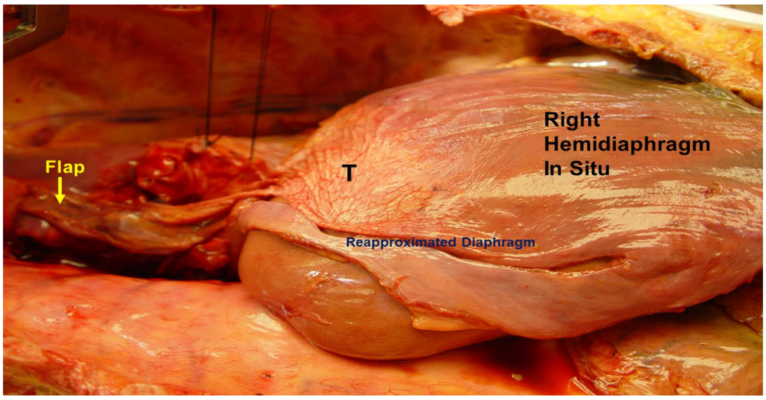

Figure 9. Thoracic view of the right hemidiaphragm *in situ* in a cadaver. The diaphragmatic flap has been rotated to cover the bronchus. The native hemidiaphragm can be reapproximated using interrupted horizontal mattress sutures with absorbable pledgets without tension.

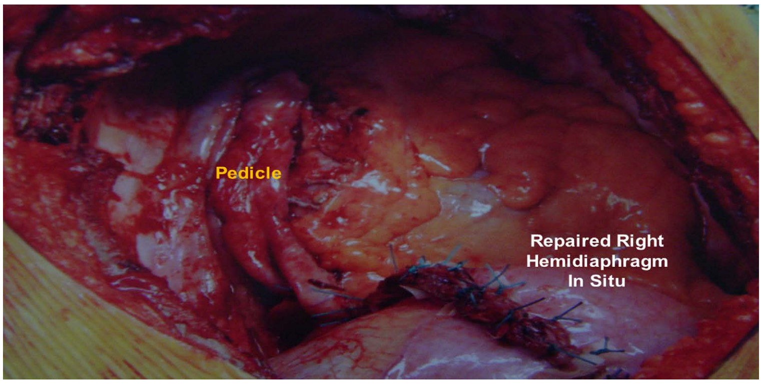

Figure 10. Thoracic view of the right hemidiaphragm *in situ* in a cadaver. The diaphragmatic flap has been rotated to cover the bronchus. The native hemidiaphragm has been reapproximated using interrupted horizontal mattress sutures with absorbable pledgets without tension.

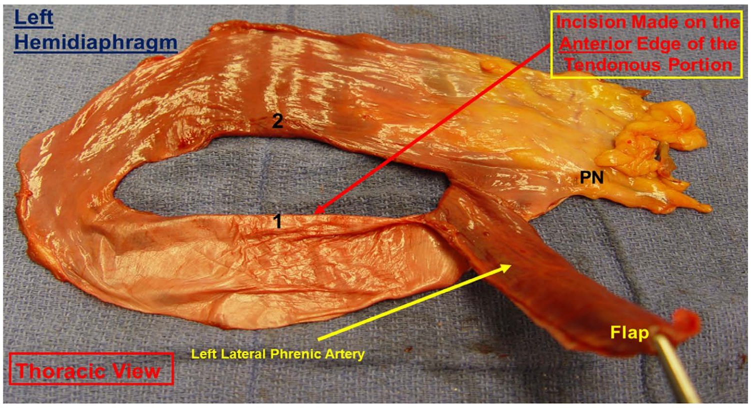

Figure 11. Thoracic view of the left hemidiaphragm excised from a cadaver. In order to prepare the Diaphragmatic Flap (DF) an incision is made at the Anterior edge of the tendonous portion (1). This incision is parallel to the Lateral Phrenic artery and prevents damaging the vessel. Next a second incision (2) is made anterior and parallel to the artery and a 4 cm wide flap is created.

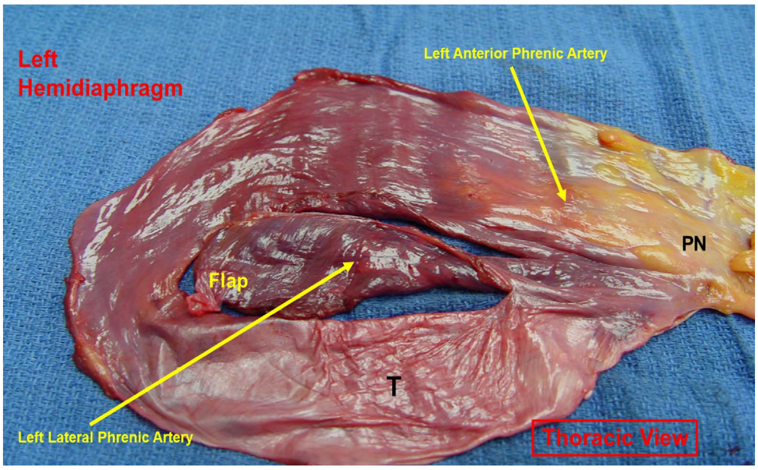

Figure 12. Thoracic view of the left hemidiaphragm excised from a cadaver. The diaphragmatic flap is shown. After the flap is rotated, the left lateral phrenic artery can be seen in the mid portion of the flap.

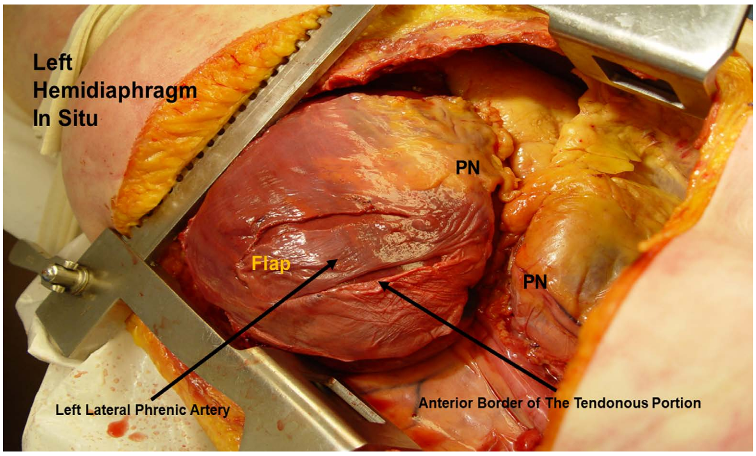

Figure 13. Thoracic view of the left hemidiaphragm *in situ* in a cadaver. The diaphragmatic flap can be seen. Phrenic Nerve (PN).

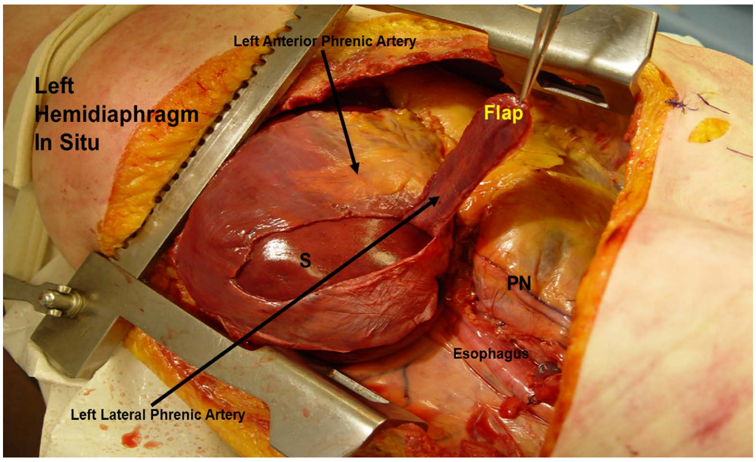

Figure 14. Thoracic view of the left hemidiaphragm *in situ* in a cadaver. The diaphragmatic flap is shown. After the flap is elevated, the left lateral phrenic artery can be seen in the mid portion of the flap. Phrenic Nerve (PN).

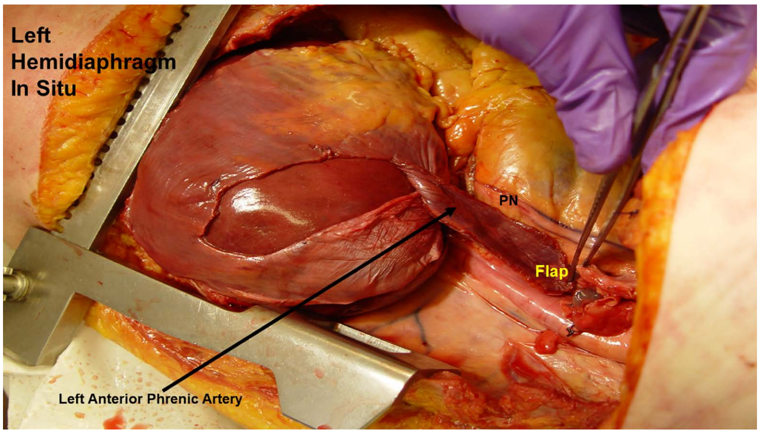

Figure 15. Thoracic view of the left hemidiaphragm *in situ* in a cadaver. The diaphragmatic flap has been rotated to cover the esophagus. Phrenic Nerve (PN).

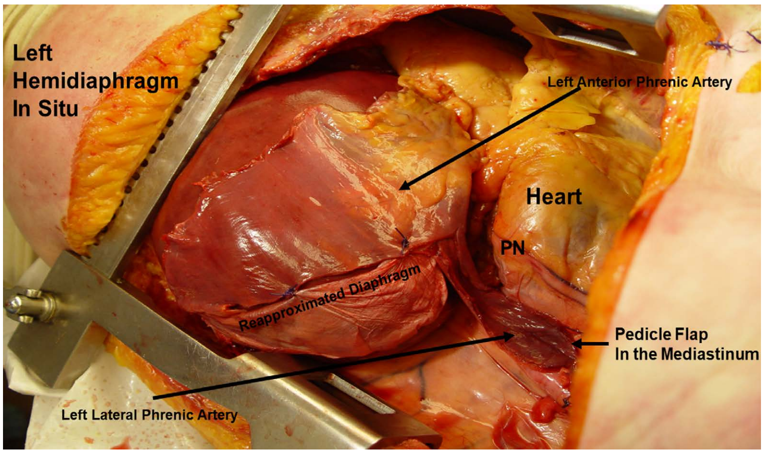

Figure 16. Thoracic view of the left hemidiaphragm *in situ* in a cadaver. The diaphragmatic flap has been rotated and can cover the esophagus and other mediastinal structures. The native hemidiaphragm can be reapproximated without tension. Phrenic Nerve (PN).

3. Discussion

Since the description of DF in the 1940's, DF has been used to reinforce repairs of iatrogenic or spontaneous perforations of the esophagus, prophylactic coverage of the bronchial stump at the time of pneumonectomy, repair of delayed bronchopleural fistula, reinforcement of the bronchial anastomosis after sleeve resections, and repair of the pericardium [5] [6]. Despite these favorable data, the "best evidence topic" study by Llewellyn-Bennett *et al.* demonstrated that the use of diaphragmatic muscle flaps for reconstructive procedures in the chest is not popular, and the surgeons mostly prefer tissue flaps or muscle flaps other than the diaphragm [9]. The main concerns have centered on the lack of widespread knowledge for the safe preparation of the DF, function of the remaining diaphragm following the harvest of DF, and the complication of visceral herniation.

The DF has been shown to be more effective than an intercostal flap [7]. If the DF is prepared using a proper technique with preservation of the blood supply for the flap, preservation of the phrenic nerve and the blood supply to the reaming diaphragm, and appropriate repair of the defect in the diaphragm, DF has many advantages to other vascularized pedicle flaps. The flap is usually easy to prepare, to rotate, and to adapt to the specific application in the chest. The DF is thick enough, resistant to necrosis because of the extensive blood supply to the diaphragm, and immobile once denervated. By virtue of denervation, unlike other muscle flaps, the DF does not shrink in length and remains in place. A long DF can easily be tailored, and it can reach any area of the thoracic cavity without torsion or tension. DF is practical and readily available without changing the position of the patient or performing other incisions. The DF is sufficiently large to close any defect in the pericardium, and because it is autologous, it is preferable to bovine pericardium or any synthetic material.

Like other vascularized pedicle flaps, microscopic studies have shown early neo-angiogenesis [9]. The vascularized pedicle muscle flap protects the bronchial suture line during the critical 3 to 4 week revascularization period [5] [10] [11]. Endoscopic surveillance of bronchial closures which are reinforced with the PF have shown rapid and uncomplicated healing [5]. DF can also provide adjunctive properties, such as antiseptic activity and pleural space reduction, because of its bulky and amorphous shape. In potentially infected or high-risk cases for infection, PF provides a vascularized muscle that is suitable providing a serosal cover for the defect, buttresses the suture line, and supplies it with healthy and well-vascularized tissue.

Like any other vascularized muscle flap, the technical aspect of harvesting the flap plays a significant role in the viability of the flap and the ultimate success of the procedure. DF is particularly difficult to harvest for the less experienced surgeon due to the fact that the blood supply of the diaphragm is not easily seen from the thoracic vantage point. In addition, the position and course of the lateral phrenic artery is different on the right versus the left hemidiaphragm. Using the anterior and posterior aspect of the tendonous portion of the diaphragm on each side as a landmark allows the surgeon to make a safe first incision. The use of a videoendoscope and transillumination of the diaphragm facilitates visualization of the lateral phrenic artery. By placing the lateral artery in the middle of the flap, a second incision can be made parallel to the artery and the first incision and the flap can be developed safely.

Another technical aspect of harvesting the DF is to protect the main branch of the phrenic nerve which runs with the anterior phrenic artery. Preservation of the anterior artery and the main branch of the PN, plays a significant role in the viability, healing and post operative function of the hemidiaphragm. Preserving the blood flow and innervation of the remaining hemidiaphragm is crucial in preventing poor healing and late visceral herniation. Lardinois *et al.* reported a 23% rate of postoperative visceral herniation in the early phase of their experience [7]. Ayalp *et al.* reported a single case of visceral herniation with the use of a DF after a right pneumonectomy [8]. Although visceral herniation has been reported as a major complication of using a DF, it is usually attributable to technical errors during the learning curve. The technical errors are usually due to damage to the anterior phrenic artery and the main branch of the phrenic nerve and the resultant neurovascular compromise of the remaining diaphragm, or the technique for diaphragmatic re-approximation. The diaphragm should be reapproximated with interrupted mattress type nonabsorbable sutures with 2 cm square pledgets of absorbable vicryl mesh. These complications can be averted by a clear understanding of the anatomy and rigid adherence to the principles that have been outlined in this communication.

4. Conclusion

The muscle of the diaphragm is strong, elastic, well vascularized, resistant to necrosis and has good regenerative capacity. A DF based on the lateral phrenic artery is an ideal vascularized pedicle flap for reinforcement of bronchial and esophageal suture lines and other uses in the chest. Despite these favorable data, the use of diaphragmatic muscle flaps for reconstructive procedures in thoracic surgery has not become popular, and the surgeons have used less satisfactory flaps. Clearly the reason for this preference is the anatomic complexity of the vasculature and other technical considerations for harvesting the flap, the apprehension to incise into the diaphragm, and the lack of experience of the surgeon in performing the procedure. With a clear understanding of the vascular anatomy of the diaphragm and a formal methodical approach to harvesting the DF, more surgeons will use DF with excellent results.

Contributed

Both authors contributed equally to the design of the procedure, collection of data, and preparation of the manuscript.

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Competing Interests

The authors declare that they have no competing interests.

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