Management of Intrathoracic Defects

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ABSTRACT

Intrathoracic defects continue to provide one of the most challenging problems faced by the reconstructive surgeon, particularly in the presence of bronchopleural fistula. We review the principles of management of bronchopleural fistulae and empyema, with an emphasis on the Clagett principle, pedicled and free muscle flaps, and the concept of a “designed air fistula” in bronchopleural fistula management. Although the importance of muscle flap closure in intrathoracic defects is undisputed, the timing and relative superiority of muscle flap closure versus conventional thoracic-surgical techniques remains an unanswered question.

KEYWORDS: Bronchopleural fistula, empyema, Clagett, muscle flap, designed air fistula

Intrathoracic defects are relatively infrequently encountered, with empyema occurring in 1 to 11% of patients and bronchopleural fistulae in 1.5 to 28% of patients after pneumonectomy.¹ Yet they are one of the most challenging areas faced in reconstructive surgery, with a mortality of 16 to 50%.^{2,3} The major reconstructive problems encountered are empyema with or without bronchopleural fistula, making up 64% of referrals, with less frequent indications for intrathoracic defect reconstruction including tracheal fistula, esophageal fistula, and heart or great vessel perforation.³

HISTORICAL ASPECTS OF INTRATHORACIC DEFECT MANAGEMENT

Intrathoracic defects present several unique challenges, in particular the problems associated with persistent dead space and bronchopleural fistulae. Mediastinal, diaphragmatic, or remaining pulmonary segment shift cannot always be relied upon to fill the thoracic dead

space, especially in post-radiotherapy patients, thereby providing a continued environment for empyema and infection. Bronchopleural fistulae provide a continuous, high-pressure leak that makes flap adherence especially difficult.

There are a few key surgical principles that attempt to address the problems of dead space and bronchopleural fistula: first, the Clagett principle of staged empyema closure without direct dead-space obliteration; second, the role of muscle flaps in bronchial stump coverage and dead-space filling; third, controlled closure of bronchopleural fistulae by creation of a “designed air fistula.”

Clagett and Geraci described the staged closure of empyema defects by creation of a large open window thoracostomy, debridement, and open pleural drainage.⁴ Once healthy granulation tissue is present, which may take several months, the cavity is filled with an antibiotic solution, and the wound is closed. No attempt is made to close the dead space. Although Clagett’s own series

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reported an 88% overall success rate, this has not been replicated by others, although there is some promise in a recent modification without the use of open thoracotomy.⁵⁻⁹ As closing a wound without obliteration of dead space appears to flaunt basic surgical tenets, some authors have suggested the need for total cavity filling with muscle flaps, yet this is neither necessary nor always possible.⁷ A modification of the Clagett principle can be used in conjunction with muscle flaps, obviating the need for total dead-space obliteration.^{6,10} The muscle flap is therefore used for bronchial coverage rather than volume replacement.

Muscle flaps have long been established as a reliable and successful approach to managing intrathoracic defects. Although the use of muscle flaps in bronchopleural fistula was first described in 1911 (Table 1), it has been the work of Arnold and Pairolero that has popularized the intrathoracic transposition of extrathoracic muscle flaps.^{3,6,11} More recently, free flaps have been advocated in defects where multiple thoracotomies prevent local muscle transposition.^{10,12-14} Other perceived advantages of muscle flaps include their role in combating infection in experimental and clinical models, ability to conform to the contours of a three-dimensional bronchial defect, re-exposure of the bronchial stump to immune surveillance, and potential revascularization of ischemic bronchial segments.^{15,16} Omentum has also been described for intrathoracic defects, but this potentially connects the septic pleural cavity with the peritoneum and risks further respiratory compromise from laparotomy and transdiaphragmatic transfer.^{17,18}

The concept of a “controlled air fistula” is especially important in the presence of bronchopleural fistulae. A controlled air fistula is created using a drain with a collapsible lumen (10-mm flat silicone), inserted directly into the bronchopleural fistula. This diverts the fluctuating air pressures away from the bronchial stump edges,

allowing the muscle flap to adhere to the bronchial stump. Hard packing of gauze over the muscle flap gradually collapses the drain lumen, closing the air leak from the controlled air fistula. Thereafter, gradual removal of the drain over 1 week allows healing of the subsequent drain “track.”¹⁰ By diverting the bronchial fistula in this manner, the muscle flap is thus given a better chance at adhering to the bronchial stump.

THORACIC SURGERY VERSUS PLASTIC SURGERY APPROACH

Defining the exact timing of flap coverage for intrathoracic defects is unclear, as there are no prospective trials to indicate whether early defect cover with flaps provides any advantage over current thoracic-surgical practice. Such data exist for median sternotomy defects, where early flap cover has been shown to be superior to debridement and drainage, but is lacking at present in intrathoracic defects.¹⁹ In the majority of thoracic-surgical centers, the plastic surgeon is therefore involved only at a late stage, after failed management of such defects.

The traditional thoracic-surgical approach includes early thoracocentesis and targeted antibiotic therapy, followed in the first instance by chest tube placement. Controversy exists as to the best approach after chest tube failure, with video-assisted thoracoscopic surgery decortication (removal of the noncompliant fibrous lining of the lung that develops in empyema, allowing pulmonary segment expansion) and open drainage with a dependant drainage window both advocated.²⁰ Thoracoplasty—the removal of multiple ribs to collapse the chest wall—remains a late option in certain circumstances. Yet it is not the panacea that may be expected, with failure rates of 17 to 33%, significant cosmetic deformity, and detrimental effects on respiration.²¹ Guidelines exist to aid the early management of intrathoracic defects such as empyema, but none as yet exist that include the early role of flap cover.²²

Table 1 Key Events in Intrathoracic Defect Management

1879	Estlander: thoracoplasty
1911	Abrashanoff: muscle flap for bronchopleural fistula
1935	Eloesser: rib resectional open drainage
1963	Clagett and Geraci: staged empyema closure with open drainage and without direct dead-space obliteration
1983	Arnold and Pairolero: muscle flap closure without total dead-space obliteration
1990	Chen: free flap reconstruction in bronchopleural fistula
1998	Gharagozloo: modified Clagett without open thoracostomy
2009	Chen: “designed air fistula” and muscle plug technique with free ALT-VL flap

OPERATIVE TECHNIQUE

Empyema cavity of the chest can be divided into three main treatment groups, depending on the presence or absence of bronchopleural fistula, and the availability of regional muscle flaps.

Empyema without Bronchopleurocutaneous Fistula

These are managed initially by thoracic surgeons, with the modified Clagett procedure and secondary closure of dead space by mediastinal and diaphragmatic shift. They are only referred for flap reconstruction in the event of failure of the Clagett procedure. Whether there is a role

for earlier flap intervention in selected cases remains to be seen.

Empyema with Bronchopleurocutaneous Fistula and Pedicled Flap Options Preserved

The presence of a bronchopleural fistula mandates the use of a flap reconstruction for optimum outcomes. The Clagett procedure used in these cases has been historically associated with a high failure rate. Regional flaps (such as latissimus dorsi, pectoralis major) can be transposed into the chest to cover the bronchial stump. There are four important points regarding the successful management of these defects, other than simply transposing muscle. First, the muscle flap is not primarily sutured to the friable bronchial tissues but is simply draped over them. This relates to the second point; that is, healing of the bronchial fistula-muscle flap interface is thereby achieved by soft and hard gauze packing and the use of a “designed air fistula.” Soft intrathoracic gauze packing is used for the first few weeks to prevent pedicle compression, followed by hard packing. The hard packing has a twofold aim: to compress the flap onto the bronchial stump and to close the “designed air fistula.” The third key point is the use of a “designed air fistula.” This uses a flat silicone drain (10-mm flat silicone) that allows changes in pressure to bypass the bronchial stump-muscle flap interface and thus facilitate the adherence of the muscle

flap to bronchial stump edges (Fig. 1). The lumen of this drain can be obliterated by the pressure exerted by hard gauze packing. Therefore, the “designed air fistula” can be closed a few weeks after initial surgery, when bronchial-muscle flap wound healing is well under way. The drain is gradually removed over a 1-week period to allow healing of the drain track. The fourth point is that as single-pedicled flaps rarely provide sufficient volume to obliterate dead space, the Clagett principle is used in conjunction with the pedicled flap to allow dead-space closure. Once soft and hard gauze packing has been completed, and the “designed air fistula” has been removed, the amount of gauze packing is gradually decreased over the following weeks. Definitive obliteration of dead space comes from mediastinal and diaphragmatic shift (Table 2).

Empyema with Bronchopleural Fistula and No Pedicled Flap Options

When regional flaps have been divided by previous thoracotomies (e.g., multiple failed decortication and open bronchopleural fistula repair attempts), free flaps can be used. These are typically taken from the contralateral chest wall (latissimus dorsi with/without the lower half of serratus anterior muscle), although we have described the use of the thigh (vastus lateralis [VL] muscle with antero-lateral thigh flap [ALT] which is de-epithelialized). Despite the fact that

Figure 1 Designed air fistula technique. (A) The silicone flat drain is placed within the bronchopleural fistula if large, or nearby if small and multiple. It exits through the substance of the muscle flap. (B) The hard gauze packing (white arrows indicating compression) at week 3 obliterates the drain lumen, thereby closing the designed air fistula a few weeks after surgery. The drain is removed over a 1-week period (black arrow). (C) Hard packing continues while the drain is removed, thereby allowing the drain track to heal, sealing the fistula.

Table 2 Muscle Plug Technique Key Steps

Step 1	Free or pedicled muscle flap	Draped onto bronchus, not sutured
Step 2	Soft gauze packing	Weeks 1 to 3
Step 3	Hard gauze packing	Weeks 3 to 5 (commenced earlier at 1 week for pedicled flaps, 3 weeks for free flaps) Achieves three aims: (1) compression of muscle flap-bronchus interface; (2) closure of lumen of "designed air fistula"; (3) healing of drain track
Step 4	Closure of "designed air fistula"	Approximately weeks 3 to 5 Coincides with hard packing. Drain is removed gradually over 1 week
Step 5	Gradual reduction in gauze packing	Weeks 5 to 9 Definitive dead-space obliteration by mediastinal and diaphragmatic shift

greater volumes can be obtained with free flaps, we have found that in post-pneumonectomy cases, we have nearly always had to use the Clagett principle to close the dead space. It should also be noted that even when the local muscles have been divided by previous thoracotomies, the remaining proximal portions are still useful for protection of microvascular anastomoses and for augmentation of the soft tissue volume inserted into the thoracic cavity.

FREE FLAP OPTIONS

Latissimus dorsi (with or without lower half serratus anterior muscle) is flat with a large surface area, making it ideally suited to drape over the complex three-dimensional defect of the bronchial stump and for coverage of multiple air fistulas. VL muscle (with or without de-epithelialized ALT flap) has the advantages of a remote donor site and a greater volume of transferred flap. It can be used for complete obliteration of dead space in smaller defects, such as the defect after lobectomy (the defect is smaller compared with post-pneumonectomy defect). Combination flaps consisting of the residual portion of a regional flap and a free flap can be used in smaller intrathoracic defects to allow primary closure of dead space. The free flap is used to close the bronchopleurocutaneous fistula, and the residual part of the regional muscle flap is used to add to the volume of the free flap and to provide coverage for the vascular anastomosis (Fig. 2).

RECIPIENT VESSELS

The thoracodorsal and the thoracoacromial vessels are the two preferred options for anastomosis. The recipient vessels should be outside the thoracic cage and be covered with local muscle flaps to protect the anastomotic sites from being affected by infection. A window of thoracic cage should be created for passage of the free flaps into intrathoracic defects. This is achieved by

removing a segment of one or two additional ribs, depending on the size of the flap.

POSTOPERATIVE CARE

Basic principles include avoidance of compression to the pedicle, which is less of a problem when the recipient vessels are the thoracoacromial rather than the thoracodorsal vessels. The patient is positioned supine or in the lateral position with the side of the pedicle upward. Careful respiratory support is required, however physiotherapy should still be done. Postoperative flap compression is initially commenced with soft gauze packing to prevent undue pressure on the pedicle. Hard gauze packing is delayed until 1 week for pedicled flaps and 3 weeks for free flaps. Hard packing continues for 2 weeks and is designed to close the lumen of the flat silicone drain, compress the muscle flap onto the bronchus, and close the subsequent drain track of the silicone drain. Once the "designed air fistula" is closed and the drain removed, a reduction in gauze volume packing over the subsequent 4 weeks takes place or until the cavity is obliterated by mediastinal and diaphragmatic shift.

OUTCOMES

When the intrathoracic defect is successfully closed, the inflammatory process will decrease gradually. Finally the thickened visceral pleura will be pulled toward the thoracic cage, and the residual lung will expand with improved pulmonary function. Because a significant volume of muscle has to be used to treat the intrathoracic defect, some morbidity is unavoidable. However, the price is worthwhile when eventual healing of chest wound is achieved, which is close to 100% in our two series of free flap reconstructions.^{10,13} After physiotherapy, patients generally have no problems in walking or raising the upper extremity, but initial weakness is always the complaint, and the length of this period depends on

Figure 2 Free flap options in post-pneumonectomy and post-lobectomy defects. (A–C) Post-pneumonectomy defects: None of these flaps are designed to completely obliterate the cavity. (A) Contralateral LD to thoracodorsal vessels. (B) ALT-VL flap. (C) ALT-VL combined with residual LD to cover anastomosis. (D) Post-lobectomy defect. Complete cavity obliteration with ALT-VL free flap and ipsilateral pedicled LD.

several factors, such as age, size of the flap harvested, and physiotherapy.

DISCUSSION

Evidence Review and Algorithm for Management

Evidence for the surgical management of intrathoracic defects such as bronchopleural fistula and empyema is lacking. There are no prospective trials comparing thoracic and plastic-surgical approaches to such defects, with the majority of plastic-surgical interventions having been described in retrospective cases

series.^{3,10,12,13,23} Although there is some evidence comparing different types of thoracic-surgical interventions, this does not help us answer a few fundamental questions.^{24–26} First, it is unclear at what stage a flap reconstruction should be considered, and second, whether flap reconstruction is superior to a thoracic-surgical approach. Until such time as these questions are answered, the two approaches to management of intrathoracic defects should be considered complementary rather than mutually exclusive. However, a concept commonly accepted by both thoracic and plastic surgeons is that the bronchopleural fistula should be closed with either locoregional or free flaps so that the empyema space can be closed.

Given the lack of evidence regarding optimum treatment of intrathoracic defects, an algorithm for management cannot be regarded as definitive (Fig. 3). Once simple measures such as chest tube drainage have failed, it is uncertain whether thoracic-surgical interventions or a flap procedure should be the next appropriate step. There is an argument for the earlier use of muscle flap reconstruction in lieu of the traditional

Clagett procedure in selected patients, given its relatively poor success, which has been reported as low as 20%, and the protracted treatment course, which is on average 6 months from open thoracostomy to wound closure.^{7,27} The comparative success rates of muscle flap procedures are higher (at 75 to 100%) than the traditional Clagett procedure, with mean hospital stays of 26 to 34 days for muscle flap procedures.^{3,10,13} However, we continue to

Figure 3 Algorithm for management of post-pneumonectomy defects.

advocate use of the Clagett procedure as first-line treatment in isolated empyema, as do other groups.^{7,28} It should also be noted that there is promise in a recent modification of the Clagett procedure without open thoracostomy, with success rates up to 100%. If the Clagett procedure is used, we would suggest using the modification described by Gharagozloo et al.⁸ It remains to be seen whether early muscle flap reconstruction is superior to the Clagett procedure as first-line treatment in intrathoracic defects, and this is an area that necessitates further investigation.

Our approach thereafter is to consider two key factors: first, the presence of bronchopleural fistula, which we consider mandates a surgical flap closure for greatest chance of success, particularly in post-radiotherapy patients with limited capacity for postoperative obliteration by expansion.⁶ The traditional Clagett procedure is not particularly successful in the presence of bronchopleural fistula, as the majority of failures in the original series were attributable to the presence of bronchopleural fistula.⁵ We therefore do not consider the Clagett procedure appropriate first-line treatment in the presence of bronchopleural fistula. Second, the comorbid and nutritional status of the patient influences whether the patient has a single-stage or multistage flap procedure. In the patient not optimized for surgery, we would recommend a staged approach, with the major flap procedure reserved after an initial attempt at endoscopic bronchopleural fistula closure, open drainage, and aggressive nutritional input.^{1,29} There is emerging evidence for endoscopic management of small bronchopleural fistulae, and this is predicted to be one of the greatest changes in the future of managing intrathoracic defects.¹

Free Flaps Versus Pedicled Flaps

The largest series of pedicled flaps in intrathoracic defects contains 100 cases, in comparison with series of free flaps, for which the largest had 7 cases. It is therefore difficult to draw valid conclusions regarding their relative merits. The overall success rates are similar, with pedicled flaps reported at 73% and free flaps at 83 to 100%.^{10,12-14,23} The main advantage in terms of outcomes appears to be in the management of bronchopleural fistula, possibly due to the ability to tailor the flap to the defect, the availability of greater tissue bulk, and improved vascularity. Pedicled flaps have a reported success rate of 65% in comparison with that of free flaps at 80 to 100%.^{10,12,13,23}

The relative merits of free and pedicled flaps notwithstanding, there are certain patients in whom the use of pedicled flaps is impossible, whether it be due to multiple thoracotomies, inadequate reach or bulk, or previous failures. There are a number of case series reporting excellent success rates, with more than 24 cases

reported in the literature.^{10,12-14} The rectus abdominus and latissimus dorsi are the most common free flaps used in intrathoracic defects in these series, yet they present several drawbacks. These include lateral positioning for harvesting the latissimus dorsi (LD) flap, requiring patient repositioning and making a two-team approach impossible. Abdominal incisions for harvesting of rectus abdominus or omentum may affect already compromised pulmonary function.¹⁸ Owing to these problems, we have described the use of the anterolateral thigh musculocutaneous flap that allows a two-team approach, abundant muscle volume, and minimal donor site morbidity.¹³

CONCLUSION

Intrathoracic defects remain a challenging problem for the reconstructive surgeon, with poor patient physiology and a high mortality despite surgical intervention. The use of free or pedicled muscle flaps, in conjunction with the principles of the Clagett procedure and the concept of the designed air fistula, enable a more controlled and effective closure of such defects. Success rates approaching 100% are possible using such approaches. However, there is currently little high-quality data on the optimal treatment for intrathoracic defects and on whether reconstructive surgeons should be involved at an earlier stage rather than after multiple failed decortication and drainage procedures. It may be suggested that a prospective multicenter trial, comparing early flap intervention with current thoracic practice, would be of benefit in answering this question. Furthermore, emerging therapies such as endoscopic bronchopleural fistula obliteration and newer modifications of the Clagett procedure are likely to change the management of intrathoracic defects in the future.

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