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REVIEW ARTICLE

Reconstruction of the chest wall

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Summary

Chest wall reconstructions can be a complex and challenging procedure and may require a multidisciplinary approach. The most common indications for chest wall reconstruction are repair of defects due to tumor resection, infection, radiation necrosis, congenital deformities or trauma. The repair of complex chest wall defects presents a challenging problem for the reconstructive surgeon. Although the majority of such defects can be repaired with the use of local and regional musculocutaneous flaps, more complicated cases require increasingly sophisticated reconstructive techniques. As defects increase in size, microsurgical techniques are necessary to augment blood flow to pedicled flaps or to provide free flap coverage from distant sites. A better understanding of the respiratory mechanics and local anatomy is crucial in managing these complex defects.

Key words: cancer, chest wall defects, reconstruction, microsurgery, radiation therapy

Introduction

For almost a century, chest-wall reconstruction has been a challenge that surgeons have confronted with varying levels of fear and trepidation, as evidenced by Parham's description in 1898 of the surgically created pneumothorax [1].

Surgeons have since worked diligently at acquainting themselves with the various dangers and have dealt with them in various and fascinating ways. Fell [2] and O'Dwyer [3,4] described positive-pressure ventilation and the importance of upper airway control. They also introduced proper intubation techniques and provided a large experience with the utilization of these techniques. In the early 1930s, Graham and Singer [5] performed the first successful pneumonectomy for carcinoma of the lung. Tumors of the chest wall were classified by Lund [6], Hedblom [7], Harrington [8], and Zinninger [9]. In addition, the risk of pulmonary and chest-wall resections was dramatically improved by utilizing endotracheal ventilation, closed chest drainage, and antibiotics.

The 1940s brought further contributions in the form of reconstruction techniques. Watson and James [10] discussed the use of fascia lata grafts for closure of chest-wall defects. Bisgard and Swenson [11] utilized rib grafts as horizontal struts to reconstruct the resected sternum. Maier [12] treated large anterior defects due to cancer and radiotherapy with cutaneous flaps that commonly included the remaining breast. Pickrell et al. [13] advanced surgical treatment of recurrent breast carcinoma by resecting a portion of chest wall.

The latissimus dorsi musculocutaneous flap was originally described by Tansini [14] in 1906 for coverage of the anterior chest wall after radical mastectomy. Hutchins [15] also used the latissimus dorsi muscle to

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close radical mastectomy defects and described this procedure in 1939. The latissimus dorsi flap was again presented to the surgical world by Campbell [16] in 1950. This was covered immediately with a split-thickness skin graft for reconstruction of a full-thickness defect in the anterior thorax. Regrettably, this method of reconstruction went unnoticed for nearly 20 years, until interest in muscle transposition was revived and the technique was rediscovered and refined. Blades and Paul [17], Converse et al. [18], and Myre and Kirklin [19] also reported on successful reconstruction of extensive chest-wall defects in the 1950s.

Rees and Converse [20], Starzynski et al. [21], Martini et al. [22], Graham et al. [23], and Le Roux [24] all made further refinement of chest-wall reconstructive techniques in the 1960s. Many of these procedures continue to be multistaged. In 1963, Kiricuta [25] described transposition of the greater omentum for reconstruction of chest-wall defects due to excision of malignancies of the chest.

During the last 25 years, numerous authors have made remarkable contributions to the reconstruction of the thorax. Muscle and musculocutaneous flaps of the latissimus dorsi, pectoralis major, serratus anterior, rectus abdominis, and external oblique muscles have been used frequently in the reconstruction of the chest wall. Tissue expansion has been used with latissimus dorsi musculocutaneous flaps. Recently, free microvascular transfers of these muscle and musculocutaneous units have been described, when transposition units were damaged or not available [26]. The functional anatomy and blood supply have been clarified [27], and aggressive resections have been undertaken for chest-wall tumors, as well as for radiation damage of the chest wall [28-32]. Intrathoracic transposition of external muscles has been also developed over the past 20 years.

There are basically 4 indications that require both the thoracic and plastic surgeon to combine their efforts in chest-wall resection and reconstruction: tumor (primary or recurrent), infection, radiation injury, and trauma. Not uncommonly, various combinations of these afflictions occur in the same patient. These dilemmas are double-edged swords at best. The extirpative surgeon is anxious to obtain wide margins and rid the patient of all possible malignant, contaminated, or irradiated tissue, but still leave a defect that should be closed in order to maintain life itself. A thorough knowledge of reconstructive techniques with a clear operative plan and more than one secondary or fallback procedure is most desirable, if possible. The patient's previous radiation treatment and smoking history are important when considering muscle transpositions [30, 33]. The vital importance of chest wall reconstruction cannot be underestimated. Stable and reliable coverage of the chest wall is necessary for the maintenance of normal physiological function and, ultimately, for the survival of the patient afflicted by disease of the chest wall. Reconstruction of the chest wall skeleton preserves pulmonary compliance and functions as a barrier to protect the vital organs and structures contained within the chest [34-40].

It is critical the location of the defect on the chest wall to be assessed. Defects are broken down into lateral, central, high (infraclavicular), or low (supracostal margin) regions. Next, the size of the defect is taken into consideration. Defects greater than or equal to 300 cm^2 are considered large, whereas defects less than 300 cm^2 are considered small. Clearly, 300 cm^2 is a relative value, simply representing one method of differentiating between large and small defects. Flap selection includes the latissimus dorsi flap for large or small lateral defects, or free tissue transfer for large lateral defects. Small central defects are typically reconstructed with the pectoralis muscle, whereas large defects are reconstructed with either a pedicled vertical rectus abdominus musculocutaneous (VRAM) flap when the internal mammary artery is patent or a VRAM free flap if the internal mammary vessels have been resected. Omentum could be used in this situation, either alone or in conjunction with another flap. High (infraclavicular) defects, whether large or small, represent a problematic area necessitating the use of either a VRAM flap or a free flap. Low (supracostal margin) defects, whether large or small, are typically reconstructed with the external oblique and/or an omental flap. Bony reconstruction of the chest wall is more variable. It depends on the philosophy of the ablative surgeon, but typically is performed with either mesh only or a combination of mesh and methylmethacrylate. In general, when less than 4 ribs are resected, a mesh-only reconstruction is applied, whereas when 4 or more ribs and/or a sternal resection is performed, mesh with methylmethacrylate is used to reconstruct the defect [41].

Local and regional flaps

Pectoralis major

The pectoralis major muscles have been the most frequently used muscles and are well suited for managing defects of the anterior central chest wall, particularly in the upper portion of the chest. When mobilization and transposition are accomplished utilizing the dominant thoracoacromial neurovascular leash, the muscle remains not only viable but also functional.

This is very important when closing wounds such as those resulting from an infected median sternotomy. The vast majority of the patients with infected median sternotomy wounds are open and draining for some time [41]. When these wounds are seen early and can be treated right away, immediate sternal debridement and reconstruction in one stage are useful [42]. However, patients with chronic infections require a sternectomy and multiple dressing changes and further wound inspections and debridement in the operating room until the wound remains clean. When the dressings removed are clean, we proceed with muscle-flap closure. Thus bilateral transposed, innervated pectoralis major muscles offer the best muscular reconstruction in this area. Such flaps offer the added benefit of allowing a second median sternotomy to be made back through the transposed pectoralis muscles with complete safety as far as survival of the muscles is concerned. If further lateral resection of sternal components and cartilaginous portion of ribs is necessary, this type of pectoralis transposition is unaffected. However, if the muscles are based on the perforators of the internal mammary vessels, a secondary cartilage resection could result in death of the previously transposed muscle. Thus transposing the muscle on the thoracoacromial vessel obviously offers the most dynamic and reliable reconstructive choice for this defect. The musculocutaneous flaps, including paddle flaps, that use the pectoralis major are readily designed and transposed to all areas of the anterior superior chest [43].

Latissimus dorsi

The latissimus dorsi muscle and musculocutaneous unit have been and remain the other remarkable workhorse in chest-wall reconstruction. Anterior and anterolateral wounds are ideally suited for use of the latissimus dorsi either as a muscle alone or as a musculocutaneous flap. These units transposed on their dominant thoracodorsal neurovascular leash are some of the most reliable reconstructive units available. Virtually two-thirds of the back can be transposed to the front of the chest with a high degree of reliability utilizing this muscle. Back wounds themselves can often be treated effectively with latissimus dorsi muscle transpositions. The most common back defect is the central defect, which can readily be closed by advancing the latissimus dorsi muscles with their overlying skin centrally to close the defect. This technique has the advantage of preserving the blood supply, nerve supply, and function of the muscle. This is of considerable benefit because many of the wounds are due to neurosurgical conditions, and hemiparesis or paraplegia is sometimes a strong possibility [44]. Thus saving the function of the latissimus dorsi muscle the transferring from bed to wheelchair or cart is a very positive consideration (Figure 1).

Serratus anterior

The serratus anterior muscle is used most commonly as a muscle to be transposed to an intrathoracic position to manage real or impending problems in the chest [32,45]. It can, however, be used with the latissimus dorsi muscle to carry even more skin to the front of the chest in chest-wall reconstructions from the auxiliary region of the chest. It is rarely used as an isolated muscle for external chest-wall reconstruction.

Rectus abdominis

The rectus abdominis muscle and musculocutaneous flaps have been used with regularity in anterior chest-wall reconstruction [32]. The skin component can be oriented in the transverse fashion, as in the transverse rectus abdominis musculocutaneous (TRAM) flap, or vertically over the full extent of the muscle, depending on the geometry and the location of the chest-wall defect. Although the muscle can be transposed on a superior pedicle even in the absence of the internal mammary artery, this approach is not commonly the first choice. The blood supply entering this muscle su-

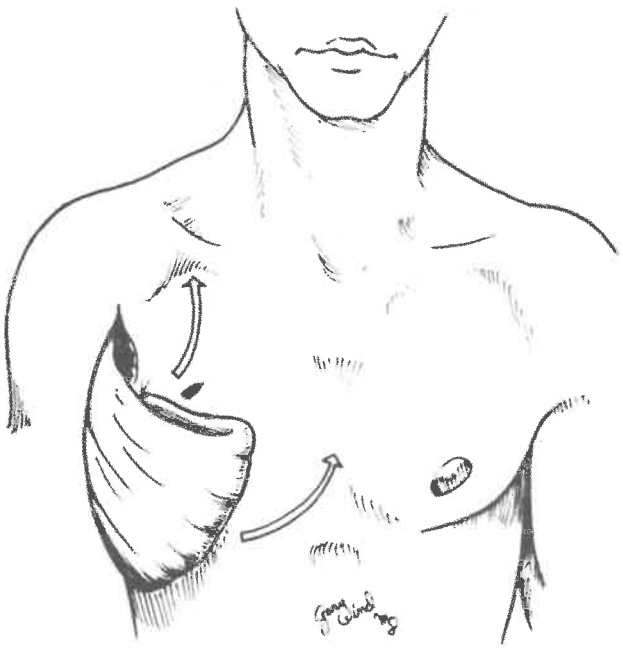


Figure 1. Latissimus dorsi transfer to the central chest wall. It covers the region from the ipsilateral clavicle to the sternum [44].

periorly is not as robust or reliable as that of either the latissimus dorsi or the pectoralis major muscle. The other comparative disadvantage is that there is far less robust muscle once this unit has been transposed than in either the pectoralis or the latissimus dorsi muscle. Figure 2 demonstrates a case with a large basal cell carcinoma (BCC) of the anterior chest wall that was resected and reconstructed with a combination of a TRAM and a latissimus dorsi flap.

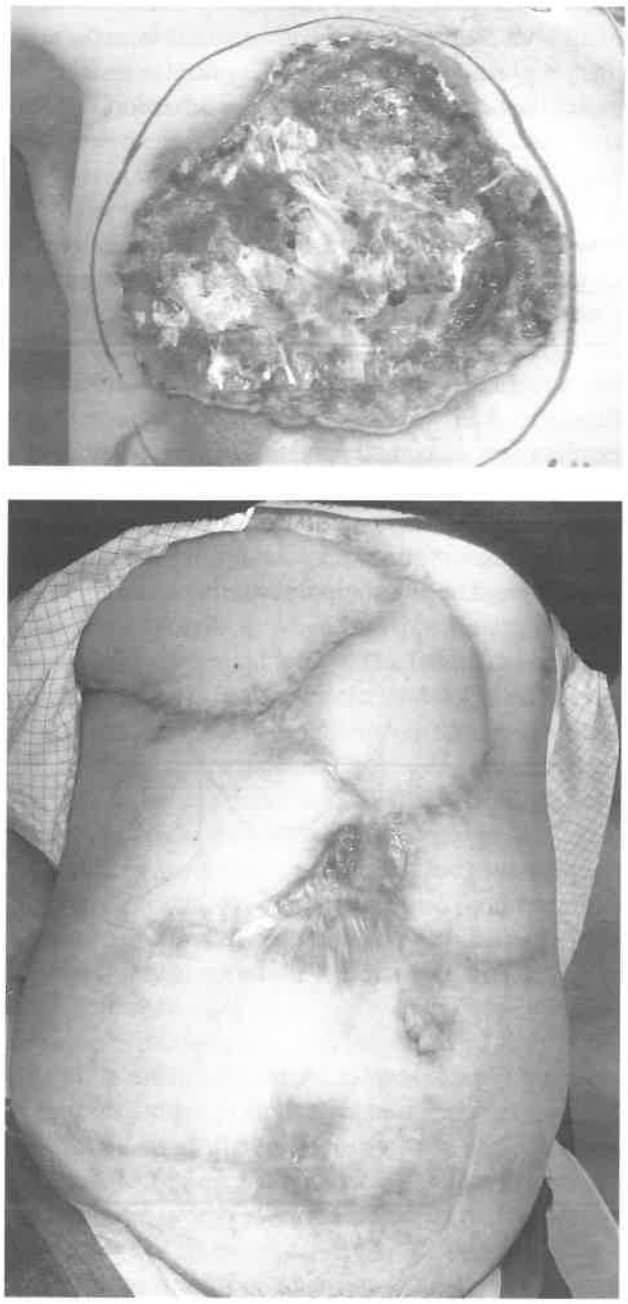


Figure 2. (a) Large basal cell carcinoma (BCC) of the anterior chest wall that was resected and (b) reconstruction with a combination of a transverse rectus abdominis muscle (TRAM) and a latissimus dorsi flap.

External oblique

The external oblique muscle and musculocutaneous flap are used far less frequently but are very useful in the lower anterior lateral chest. A general rule of thumb for use of this muscle is that basically it is used to close defects up to the level of the inframammary fold. The musculocutaneous flap should be widely dissected, and the cutaneous defect in the lower portion of the abdomen can be closed in a V-Y fashion or with a skin graft [32]. If necessary, the musculocutaneous unit can be separated to close a diaphragmatic wound and to provide coverage for that area of the chest wall [46].

Greater omentum

The greater omentum continues to be the ultimate security blanket for chest-wall reconstruction. It can be transposed to any area on the anterior chest wall and readily accepts and supports grafts of bone and skin. Its primary advantage is that it brings in a reliable blood supply of undamaged tissue [45]. It is of little use in full-thickness chest-wall injuries that allow the lung to fall away once the chest has been opened. It is of particular benefit in radiation-damaged skin that does not involve recurrent tumor. In this situation, the skin and subcutaneous tissue can be excised including sometimes ribs. This defect is then reconstructed with transposed greater omentum and eventually a skin graft. This method of reconstruction allows a very large area to be covered, and it is particularly helpful when the size of the wound is greater than that of the aforementioned muscles.

Despite proper planning, the busy reconstructive surgeon will encounter situations in which radiation damage was underestimated or postoperative infections occurred and left a secondary defect that requires soft-tissue closure [32]. The omentum is truly the reconstructive surgeon's best friend in these situations.

The use of the omentum for mediastinal obliteration in infected median sternotomy wounds has been of value on occasion. More often, however, we remove the entire sternum, including the costal cartilages, for these problems. If these are managed as open wounds with dressing changes, they fill in, and the deep defect is not as threatening after 10 days to 2 weeks. In many instances, a separate tissue transposition for the previous space problem is not required, and this wound can be closed with pectoralis transposition alone.

Prosthetic materials

The prosthetic materials available today are re-

liable and provide very reasonable stability [32,45]. Thus we have not used rib grafts in recent years and rely totally on synthetic meshes when reconstructing the thoracic skeleton. We should also recall that after very significant chest-wall resections, such as removal of the entire sternum, pulmonary function is ultimately not compromised, even though hospitalization and time on the ventilator may be shortened with the use of prosthesis. One of the most important developments in chest wall surgery and reconstruction has been the use of prosthetic materials. Definitive skeletal resections can be accomplished because of the availability of these materials, which can be easily used to reconstruct the chest wall skeleton [47]. Over time, many inert materials have been introduced and used to accomplish skeletal reconstruction in the chest. The choice of prosthetic material is confusing. Numerous synthetic meshes exist, and all work reasonably well. For the most part, choice is based on the surgeon's preference [48].

The list includes Gore-Tex, Vicryl mesh, Marlex mesh, methylmethacrylate, and combinations of these [49]. Prolene is a little more difficult than Gore-Tex to stretch and suture without wrinkles and surface irregularities. Obviously, Prolene mesh does not achieve a watertight seal. Gore-Tex soft-tissue patch, however, is much easier to suture, stretch, and mold into the wound, and it provides a much more watertight closure. The vital importance of skeletal reconstruction in the chest wall is well known. Especially in cases in which more than 4 or 5 ribs are resected, reconstruction of the skeleton is paramount to prevent the development of chest wall flail [49]. It is, furthermore, necessary for the dynamic stability of the chest, preserving physiological pulmonary function [50]. Also, the reconstructed skeleton serves to protect the vital structures contained within the chest. Prosthetic materials have many advantages when used for skeletal reconstruction in the chest. They are widely available. In addition, they are inherently flexible, with the ability to conform to any size or shape of defect. Composite resection and reconstruction of chest wall disease would be virtually impossible without the use of prosthetic materials.

Complex chest wall defects

The defect after full-thickness resection of radiation-induced necrotic tissue or locally advanced breast cancer can be successfully reconstructed with laparoscopically harvested pedicled omentoplasty and meshed skin graft in combination with vacuum assisted closure (V.A.C.). Reports of such patients receiving meshed skin grafts in combination with V.A.C. therapy have been very encouraging. Long-term follow-up of treated patients confirms durable control of infection and an excellent clinical outcome [51].

Microsurgery in reconstruction of chest wall defects

In a select group of patients with massive resections of the chest wall for tumor, microsurgical techniques can clearly help to augment the blood supply to local flaps or to transfer tissue from distant sites. After all local sites are exhausted, these techniques can provide very reliable, hearty flaps to cover even the largest chest wall defects. The algorithm for chest wall reconstruction using microsurgical techniques includes supercharging the failing superior pedicled vertical rectus abdominis myocutaneous flap, free rectus abdominis myocutaneous flaps for anterior midline full-thickness defects, and free forearm filet flaps for extensive forequarter amputation defects [51].

Discussion

Chest wall resection is a frequent procedure in thoracic surgery units. Close cooperation among multidisciplinary surgical teams is highly desirable for the extent of tumor resection should not be compromised because of concern on the ability to reconstruct large and complex defects [29].

It has been largely discussed what can be considered a safe resection margin. McCormack et al. [31] suggested that in sarcomatous tumors, resection should include the superior and inferior sound ribs and intercostals muscles besides all the affected tissues. Later on, King et al. [42] recommended a 4 cm free margin for highly aggressive primary tumors and 2 cm for metastases or benign or low-grade malignancies to avoid local recurrences. Following McKormack's recommendations, in 2001 Warzelham et al. [43] found a 64% 3-year and 58% 5-year survival rates in chest wall sarcomas.

Stabilization of chest wall with prosthesis is considered to decrease the need of prolonged mechanical ventilation and improve postoperative pulmonary function [34]. The size and site of the lesion influence the selection of the prosthesis. A rigid one seems necessary for sternal and parasternal defects but soft prosthesis is enough in anterolateral defects in order to avoid paradoxical chest movement [42]. Losken et al. [36] reported that mesh closure was required more often for lateral defects when compared to posterior and anterior ones.

The use of prosthesis has not been reported to increase septic complications or foreign body reactions. Little differences exist between polypropylene mesh and expanded Polyte-TraFluorEthylene (e-PTFE) in terms of resistance to infection and rejection [49], so the final decision on the type of prosthesis to be used depends on the unit policy.

Muscle and musculocutaneous flaps are the tissues of choice to cover the wound, avoid or decrease the risk of infection, obliterate spaces and cover the synthetic mesh [30]. They are chosen by proximity, knowing the arc of rotation and calculating the area of possible coverage. In most cases, only a single muscle is transferred. Also, the greater omentum can be transposed to any area on the anterior and lateral chest wall, bringing a reliable blood supply and allowing covering very large areas [30]. The reported prevalence of flap loss is around 5% [37,38], although 0% has been reported by Rivas et al. [46]. Total or partial flap necrosis represents a serious problem since reconstruction has to be attempted using alternative myocutaneous flaps.

Survival after chest wall resection for primary malignant tumors depends on the histology, the existence of free resection margins and the absence of distant metastases [52]. The reported 5-year survival is around 50%.

Conclusion

Reconstruction of chest wall defects continues to pose interesting challenges. Surgical treatment of chest wall oncologic disease has enhanced local disease control and long-term survival. Definitive chest wall reconstruction contributes to full recovery after oncologic extirpative surgery of chest wall disease. Such coverage could be safely and successfully accomplished in a single stage with minimal morbidity. Increased size and complexity of chest wall resections could require advanced reconstructive techniques.

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