Review Article

# Management of complications after chest wall resection and reconstruction: a narrative review

**Savvas Lampridis[1]^, Fabrizio Minervini[2]^, Marco Scarci[1]^**

[1]Department of Cardiothoracic Surgery, Hammersmith Hospital, Imperial College Healthcare NHS Trust, London, UK; [2]Department of Thoracic Surgery, Cantonal Hospital Lucerne, Lucerne, Switzerland

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*Correspondence to:* Savvas Lampridis, MD, MSc, MRCS(Ed). Department of Cardiothoracic Surgery, Hammersmith Hospital, Imperial College Healthcare NHS Trust, 72 Du Cane Road, London W12 0HS, UK. Email: savvas.lampridis@doctors.org.uk.

**Background and Objective:** Chest wall resection and reconstruction procedures carry high postoperative morbidity. Therefore, successful outcomes necessitate prevention, prompt identification, and appropriate management of ensuing complications. This narrative review aims to provide a comprehensive overview of evidence-based strategies for managing complications following chest wall resection and reconstruction.

**Methods:** A literature search was conducted using the PubMed database for relevant English-language studies published since 1980.

**Key Content and Findings:** Complications following chest wall resection and reconstruction can be broadly classified into surgical site-related, respiratory, or other systemic complications. Surgical site and respiratory complications are the most common, with reported incidence rates of approximately 40% across some series. Predisposing factors for respiratory morbidity include greater numbers of resected ribs and concurrent pulmonary lobectomy. Definitive correlations between specific prosthetic materials and complications remain elusive. Management should be tailored to the type and severity of the complication, surgical variables, and patient factors. Specific approaches for managing common complications are discussed in detail. Emerging preventive approaches, such as minimally invasive surgical techniques, are also briefly highlighted to help guide future research.

**Conclusions:** An emphasis on anticipating and judiciously managing complications of chest wall resection and reconstruction, alongside a coordinated multidisciplinary approach, can optimize outcomes for patients undergoing this intrinsically complex surgery.

**Keywords:** Chest wall; complication; reconstruction; resection; thoracic wall

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## Introduction

Chest wall resection, which entails the excision of a partial- or full-thickness segment of the chest wall, is commonly performed to manage a diverse range of clinical conditions, including neoplasms, infections, radiation necrosis, and traumatic injuries. Depending on the size and location of the defect, chest wall reconstruction may be required to maintain protection of the thoracic and upper abdominal

^ ORCID: Savvas Lampridis, 0000-0003-2827-5826; Fabrizio Minervini, 0000-0003-3595-7307; Marco Scarci, 0000-0002-4459-7721.

 

**Table 1** Summary of the search strategy

| Item | Specification |
|---|---|
| Date of search | March 15, 2023 |
| Database searched | PubMed |
| Search terms used | Chest wall, thoracic wall, resection, reconstruction, complication |
| Timeframe | 1980 to date of search |
| Inclusion criteria | Articles written in English with available full text; all study designs |
| Exclusion criteria | Articles written in non-English languages or with unavailable full text |
| Selection process | Independent screening by all authors with consensus through discussion |

organs, optimize the mechanics of respiration, and restore the body contours to a cosmetically acceptable level. Since the first reports in the early 20$^{th}$ century, chest wall resection and reconstruction has evolved significantly due to substantial developments in surgical techniques and materials science. The initial practice of autologous reconstruction with bone and fascia grafts was followed by the use of pedicled flaps, tissue expansion, and microsurgery (1). In addition, the introduction of various synthetic and biologic implantable materials over the past few decades has allowed the successful reconstruction of sizeable chest wall defects. Despite these considerable advances, however, chest wall resection and reconstruction remains an intricate surgical procedure. Owing to this complexity and the involvement of critical anatomical structures, this intervention carries a heightened risk of postoperative morbidity and mortality.

Complications stemming from chest wall resection and reconstruction range from mild to life-threatening and can be broadly categorized into surgical site complications, which largely pertain to the surgical technique and prosthetic materials, respiratory complications, and other systemic complications that may arise as a result of a major procedure. Several of these complications can have a consequential impact on the patient's recovery, functional capacity, and quality of life. Therefore, prevention, prompt identification, and appropriate management of such complications is crucial for successful outcomes. As novel materials and innovative surgical techniques continue to emerge, it becomes evident that an up-to-date review on the subject is timely and needed. The aim of this article is to provide an overview of the management of complications following chest wall resection and reconstruction, with a focus on surgical site complications and respiratory complications. We present this article in accordance with the Narrative Review reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-621/rc).

## Methods

We conducted a literature search using the PubMed database on February 12, 2023. To identify newly published material, auto-alerts were enabled through March 15, 2023. The search incorporated the following terms: chest wall, thoracic wall, resection, reconstruction, complication (Table S1). The results were filtered to include only articles published in English after 1980. No restrictions were applied regarding study design. We subsequently screened the titles and abstracts to exclude articles clearly outside the scope of postoperative complications, such as those focused solely on surgical techniques, prosthetic material comparisons, non-human studies, etc. The full-text versions of the remaining articles were obtained for further evaluation. All authors independently assessed pertinent publications, with any disagreements resolved through discussion. The search strategy is summarized in *Table 1*.

## Management of complications

The management of complications that may arise after chest wall resection and reconstruction is principally governed by the nature and severity of the complication, the specific surgical technique and prosthetic materials employed, as well as the patient's clinical characteristics, preferences, and values. Undoubtedly, of greater importance than their successful management is the prevention of complications, especially in this patient population with compromised respiratory mechanics and potentially impaired pulmonary function. In what follows, consequently, we will also delve

 

**Table 2** Morbidity and mortality rates in large studies of chest wall resection and reconstruction†

| First author | Year | N | Surgical site complications % | Respiratory complications % | Overall morbidity % | Reoperation % | Mortality % |
|---|---|---|---|---|---|---|---|
| McKenna (2) | 1988 | 112 | 17.9 | NR | NR | 3.6 | 3.6 |
| Arnold (3) | 1996 | 500 | NR | NR | NR | NR | 3.0 |
| Deschamps (4) | 1999 | 197 | 13.7 | 24.4 | 46.2 | 2.5 | 4.1 |
| Walsh (5) | 2001 | 51 | 5.9 | 7.8 | 23.5 | 3.9 | 0.0 |
| Warzelhan (6) | 2001 | 82 | NR | NR | NR | NR | 1.2 |
| Mansour (7) | 2002 | 200 | 11.0 | 19.0 | 24.0 | 5.0 | 7.0 |
| Kilic (8) | 2006 | 59 | 18.6 | 3.4 | 11.9 | NR | 1.7 |
| Weyant (9) | 2006 | 262 | 7.3 | 11.0 | 33.2 | 3.8 | 3.8 |
| Daigeler (10) | 2009 | 92 | 35.9 | 13.0 | 42.4 | 28.3 | 5.4 |
| Lans (11) | 2009 | 220 | 27.3 | NR | 34.0 | 4.1 | 2.3 |
| Aghajanzadeh (12) | 2010 | 162 | 4.3 | 8.6 | 17.3 | NR | 3.7 |
| Koppert (13) | 2010 | 68 | 23.5 | 5.9 | 32.4 | 11.8 | 2.9 |
| Girotti (14) | 2011 | 101 | 22.6 | 1.9 | 46.4 | 6.9 | 0.9 |
| Leuzzi (15) | 2015 | 175 | 4.0 | 2.3 | 12.6 | NR | 0.6 |
| Tsukushi (16) | 2015 | 50 | 16.0 | 10.0 | 22.0 | 4.0 | 0.0 |
| Spicer (17) | 2016 | 427 | NR | 23.9 | NR | 2.8 | 7.4 |
| Hayashi (18) | 2019 | 68 | 8.8 | 36.8 | 44.1 | NR | 1.5 |
| Giordano (19) | 2020 | 146 | 49.3 | NR | 58.9 | 10.3 | 6.2 |

†, studies include at least 50 patients. NR, not reported.

into preventative aspects of the perioperative management of these patients. *Table 2* summarizes the incidence of complications reported in large studies investigating the morbidity and mortality following chest wall resection and reconstruction. For the sake of simplicity, the following sections will discuss the management of complications according to the previously mentioned categories.

### *Surgical site complications*

Surgical site complications are mainly related to the wound, prosthesis, or soft tissue flap and have been reported to occur at rates ranging from 4% to as high as 49% of patients undergoing chest wall resection and reconstruction (*Table 2*). Depending on the type and severity of the complication, management varies significantly from monitoring or pharmacological therapy to reoperation. In a review of 16 studies analyzing the surgical outcomes of 1,089 patients who underwent chest wall resection for benign or malignant tumors and subsequent reconstruction with nonrigid materials, a reintervention due to complications related to the first operation was necessary in 34 (3.1%) cases (20).

Identifying predictors of wound complications after chest wall resection and reconstruction can aid in reducing their incidence and informing clinical management. Lans *et al.* (11) retrospectively reviewed 220 patients who underwent chest wall resection for malignant diseases followed by reconstruction using pedicled omentoplasty in 58 (26%) cases and synthetic or biologic mesh in 129 (59%) cases. A multivariate analysis of potential prognostic factors indicated that use of omentum for soft tissue reconstruction and the presence of tumor or chest wall ulceration were independent determinants of impaired wound healing [odds ratio (OR), 2.66; 95% confidence interval (CI): 1.34–5.30; P=0.005; and OR, 2.51; 95% CI: 1.03–6.07; P=0.04, respectively]. Concerning tumor or chest wall ulceration, the authors reported a prevalence of 13.6% in their study cohort but did not provide further insights. When devising strategies for resection of ulcerated tumors or chest wall lesions resulting from radiation necrosis, it is crucial to acknowledge that the reconstructive process may involve a substantially larger area than the apparent ulceration. This can facilitate the selection of appropriate prosthetic materials and surgical techniques. Regarding the use of omentum, Lans *et al.* (11) highlighted that omentum folding, extensive omentoplasty, and gravitational descent of the omentum due to insufficient structural support on the chest could result in omental flap necrosis. Despite these technical considerations, other authors have reported more favorable outcomes with omental flaps, especially for the reconstruction of radiation-induced injuries of the chest wall (21). Indeed, the anti-inflammatory and angiogenic agents produced in the omentum can make it a suitable graft in this patient population, which carries a high risk of wound-healing complications (22).

**Infection**

Local infection constitutes the most prevalent surgical site complication following chest wall resection and reconstruction. The incidence of local infection displays considerable variation, ranging from 2% to 23% (20,23), which is likely attributable to diverse patient populations and differing definitions of the condition. A wound infection after chest wall resection and reconstruction may not present with overt signs or symptoms of sepsis but may rather manifest more subtly as cellulitis or pus discharge. It is important to note that wound infections may sporadically arise several weeks to months after the procedure. In cases of prosthetic chest wall reconstruction, the clinical presentation of local infection necessitates meticulous evaluation of possible underlying infection or compromise of the prosthesis. When local infection develops, a comprehensive approach integrating clinical assessment and imaging studies should be employed to inform decision-making. Computed tomography (CT) serves as the primary imaging modality for the assessment of the prosthesis and potential identification of fluid and air accumulation adjacent to the prosthesis, which are indicative of deeper wound infection or associated pleural empyema. Management of wound infections should be tailored to the severity of the infection, underlying disease, and patient's immune status. In all cases, it is recommended to collect samples for routine aerobic and anaerobic bacterial cultures, as well as fungal and mycobacterial analyses. The initial antibiotic regimen should encompass broad-spectrum coverage to address a wide array of potential pathogens, with subsequent adjustments based on microbiological findings.

Failure of antibiotic therapy and persistence of wound infection may mandate reoperation. In such instances, thorough debridement of necrotic tissue, especially infected bone and cartilage, is imperative (24). Any dead space in the thoracic cavity, such as that created after major lung resection, should be adequately decontaminated with antibiotic solution and drainage. Obliteration of dead space may be required and can be achieved with one or more pedicled flaps. Commonly utilized muscles for this purpose include pectoralis major, latissimus dorsi, serratus anterior, rectus abdominis, and intercostal muscles (25). A multidisciplinary approach with the involvement of thoracic and reconstructive surgeons, as well as careful operative planning, are key for positive clinical outcomes in this setting.

Vacuum-assisted closure (VAC) therapy has become an effective option for managing wound infection following chest wall resection and reconstruction. By promoting drainage and accelerated healing, VAC therapy can enable infection control and facilitate coverage of defects with soft tissue flaps. A retrospective study by Rocco *et al.* (26) demonstrated the utility of VAC therapy for treating local sepsis in a cohort of 86 patients who underwent resection of chest wall tumors and subsequent reconstruction with biologic or synthetic materials. Among seven patients who developed local sepsis requiring reoperation, VAC therapy enabled complete wound healing in all cases over a median period of 14 months (range, 5–60 months). Prosthesis removal was deemed necessary in four of these patients (three cases of polytetrafluoroethylene mesh and one patient with porcine acellular collagen matrix). Therefore, VAC therapy can be a useful tool for controlling local infection following chest wall resection and reconstruction, potentially reducing the need for prosthesis removal. However, further research is warranted to clarify optimal protocols for integrating VAC therapy to reduce infectious complications in this clinical setting.

The occurrence of wound infection after prosthetic chest wall reconstruction does not necessarily require removal of the prosthesis. A combination of imaging investigations, particularly CT, and clinical assessment with thorough wound inspection should be used to determine the need for prosthesis removal. In a retrospective analysis of 197 patients who underwent chest wall resection mostly for primary or metastatic malignancies, reconstruction was performed using polypropylene mesh (Prolene, Ethicon, Bridgewater, NJ, USA) in 64 (32.5%) patients or expanded polytetrafluoroethylene mesh (Gore-Tex, W. L. Gore & Associates, Newark, DE, USA) in 133 (67.5%) patients (4). Wound infections were documented in 9 (4.6%) patients, with Prolene and Gore-Tex meshes involved in 5 and 4 cases, respectively. Among those who experienced wound infection, only 5 (55.6%) patients underwent prosthesis removal, all of whom had Prolene mesh reconstructions. Conversely, prosthesis removal was not required in the four patients with Gore-Tex mesh, who were successfully managed with debridement, gauze packing, and closure via secondary intention. Determining whether the type of mesh contributed to prosthesis removal is challenging, considering the potential influence of various confounding factors.

Comparable rates of prosthesis removal following wound infection were observed by Weyant *et al.* (9). In a retrospective study of 262 patients who underwent chest wall resection due to neoplasms (96%), radiation necrosis (2.7%), or infection (1.3%), the median number of resected ribs amounted to 3 (range, 1–8 ribs), with concomitant lung resection performed in 141 (54%) patients. Rigid reconstruction comprised a composite prosthesis of polypropylene mesh (Marlex, C. R. Bard, New Providence, NJ, USA) and methyl methacrylate in 112 (42.8%) patients. Nonrigid reconstruction consisted of either Marlex or Gore-Tex mesh alone in 97 (37%) patients, while 53 (20.2%) patients did not receive a prosthesis. Wound infections developed only in patients who underwent prosthetic chest wall reconstruction. Of the 14 patients who developed wound infection, only 8 (57.1%) patients required prosthesis removal. Notably, the rate of prosthesis removal was similar between patients who underwent reconstruction with rigid or nonrigid materials.

Improved outcomes regarding the need for prosthesis removal after wound infection have been reported by Spicer *et al.* (17). In a single-center, retrospective study of 427 patients who underwent chest wall resection and reconstruction for primary or secondary malignant tumors, infectious outcomes were analyzed based on the type of prosthetic materials, namely rigid or flexible. Rigid prostheses were used in 82 (19%) patients and included methyl methacrylate and titanium plates (Synthes, West Chester, PA, USA). Flexible prostheses were employed in 345 (81%) patients and comprised Marlex, Gore-Tex, Prolene, polyglactin 910 (Vicryl, Ethicon), and polyglycolic acid (Dexon, Covidien, Dublin, Republic of Ireland) meshes, as well as acellular dermal matrices of bovine (SurgiMend, Integra LifeSciences, Princeton, NJ, USA) or porcine (Strattice, LifeCell, Somerville, NJ, USA) origin. The median number of resected ribs in each group was the same (3 ribs), albeit with a range of 1–6 ribs in the rigid prosthesis group and 1–8 ribs in the flexible prosthesis group. Only 12 (2.8%) patients developed wound infections, while 3 (0.7%) patients were complicated with empyema. None of these patients required removal of the prosthesis.

Recent advancements in bioengineering have led to the development of bioprostheses as an alternative to their synthetic counterparts. Biologic meshes for soft tissue reconstruction are derived from the extracellular matrix of various tissue types of bovine, porcine, or human origin (27). Although they have not been investigated as thoroughly as synthetic meshes, biologic meshes demonstrate certain properties that make them an appealing candidate for chest wall reconstruction. Such a property is the rapid vascularization after implantation, which has allowed their successful use in contaminated and infected fields of abdominal soft tissue reconstruction (28-30). However, this theoretical advantage of resistance to infection has not been consistently demonstrated in chest wall reconstruction. As an example, a retrospective study reviewed 146 patients who underwent resection of chest wall tumor and subsequent reconstruction of the defect with either synthetic materials (65.1%) or acellular dermal matrix (34.9%), combined with a soft tissue flap (19). Of the 51 biologic meshes used, 24 (47.1%) were bovine (SurgiMend), 17 (34.9%) were porcine (Strattice), and 10 (19.6%) were human cadaveric (AlloDerm, BioHorizons, Birmingham, AL, USA). The rate of surgical site infection was similar between the groups of patients with synthetic materials and acellular dermal matrix (12.6% and 13.7%, respectively; P=0.851). Likewise, in the study by Spicer *et al.* (17), when the authors categorized the prosthetic materials used based on their permanent *vs.* absorbable or biologic nature, no significant difference was identified between the two groups in terms of either wound infection (P=0.477) or empyema (P=0.091).

**Hematoma, seroma, dehiscence**

Additional wound complications include hematoma, seroma, and dehiscence. The reported incidence of hematoma after chest wall reconstruction with nonrigid materials ranges between 2% and 9.1% (20). The management of bleeding and hematoma involves careful monitoring of hemodynamic stability and hematocrit level, alongside the correction of coagulation abnormalities. In certain cases, surgical intervention may be required for control of bleeding or evacuation of hematoma, which can become a nidus of infection if left untreated. Seroma refers to the accumulation of fluid within the surgical site. The application of fibrin sealant has been suggested as a means of preventing seroma formation. Nevertheless, a systematic review and meta-analysis of 11 randomized controlled trials showed that fibrin sealant did not reduce the rate of seroma after breast cancer surgery (31). Although usually regarded as a minor complication, seromas can be associated with wound infection and dehiscence. Therefore, cautious monitoring and fluid aspiration, in case of large seromas, are essential to prevent serious sequelae. Wound dehiscence has been observed in 1% of patients undergoing chest wall resection and reconstruction with rigid or flexible prosthesis (9). Depending on its severity, dehiscence may necessitate VAC therapy or reoperation for wound repair and debridement.

**Flap complications**

Autologous soft tissues are frequently utilized to reconstruct large chest wall defects. The vast majority of these reconstructions can be accomplished with vascularized pedicled flaps. Given the abundancy of such flaps, the necessity for free tissue transfer in reconstructing chest wall defects is minimal. Free flaps may be required when local flaps are unavailable, compromised, or insufficient to adequately cover the defect. Postoperatively, repeated physical examination of free flaps is imperative, which can be supplemented by Doppler ultrasonography to assess flap perfusion. This allows early identification of vascular compromise to preserve flap viability. Procedures involving free tissue transfer carry the additional risk of complications at the donor site.

Arguably, the most formidable complication of soft tissue coverage is flap failure. Flap failure can result from various reasons, including ischemia, infection, and technical factors. In a retrospective study of 200 patients who underwent chest wall resection and reconstruction for benign or malignant diseases, soft tissue coverage was provided using pedicled flaps in 96 (48%) cases and free flaps in 17 (9%) cases (7). Of the patients who underwent flap reconstruction, the most frequently employed flaps included latissimus dorsi flap in 40 (35.4%) patients, transverse rectus abdominis myocutaneous flap in 33 (29.2%), pectoralis major flap in 31 (27.4%), omental flap in 20 (17.7%), and serratus anterior flap in 17 (15%). The observed flap loss rate was 8.8%, which exceeds the rates documented in most comparable studies. While the authors did not offer an explicit explanation for this result, it could be attributed to the utilization of less conventional flaps, such as the deltoid muscle, and the frequent employment of free flaps.

In another retrospective study of 112 patients who underwent chest wall resection for benign or malignant conditions, soft tissue reconstructions were performed in 80 (71.4%) patients (2). Five different types of flaps were used in total, namely latissimus dorsi myocutaneous flap in 26 (32.5%) patients, rectus abdominis myocutaneous flap in 25 (31.3%), omental flap with skin graft in 13 (16.3%), pectoralis major myocutaneous flap in 9 (11.3%), and contralateral breast flap in 7 (8.8%). Flap loss occurred only in 3 (3.8%) cases, including a pectoralis major, latissimus dorsi, and rectus abdominis myocutaneous flap, respectively. The authors attributed all three instances of flap loss to technical issues. Similarly, low rates of flap failure, ranging from 2% to 3.3%, were reported in other studies with smaller sample sizes (10,16). Even more favorable results were achieved by Weyant *et al.* (9), who reported no flap necrosis among 51 (19%) patients who received soft tissue coverage of chest wall defects. Among the 38 pedicled myocutaneous flaps, 8 free myocutaneous flaps, and 5 rotation/advancement flaps utilized, no occurrences of transposed tissue or muscle flap necrosis were reported.

The management of flap failure may be challenging and requires vigilant patient monitoring, expeditious surgical intervention with alternative methods of soft tissue coverage, and close collaboration between thoracic and reconstructive surgeons. In the infrequent event of pedicled flap loss, alternative pedicled flaps may be employed for salvage procedures (2,3). In cases of free flap failure, the typical course of action involves the use of another free flap, as pedicled flaps would generally be unavailable.

Additional flap complications include bleeding and hematoma, which have been documented to occur in as many as 5.9% of patients undergoing soft tissue reconstruction of chest wall defects. Evacuation of hematoma in the operating room and correction of coagulopathies generally prove sufficient for treatment. Donor site complications, such as bulges and hernias, are uncommon. An abdominal hernia may develop following the use of rectus abdominis muscle flap. Moreover, the subcutaneous passage of omentum to the chest results in epigastric hernia, although the risk of hernia formation can be attenuated by splitting the diaphragm and passing the omentum through the created opening (24). By skeletonizing the omentum pedicle on either the left or right gastroepiploic vessels, the compulsory tunnel for the omentum's passage can be effectively minimized.

### Titanium implant failure

Titanium implants are often utilized in reconstruction of chest wall defects to provide stabilization and acceptable cosmetic outcomes. However, these rigid materials carry a risk of delayed failure, including fractures, displacements, and disconnects between components. To characterize titanium implant failure after chest wall osteosynthesis, Berthet *et al.* (32) reported outcomes from two centers using the STRATOS (MedXpert, Heitersheim, Germany) or Matrix Fixation System (DePuy Synthes, Raynham, MA, USA) for repair of defects spanning over three ribs and with or without sternal involvement. In a retrospective analysis of 29 patients undergoing oncological chest wall resection, the rate of implant failure identified on follow-up thoracic CT was 44.8%, although only 10.3% of patients were symptomatic. Interestingly, failures occurred after the fourth postoperative month, excluding technical factors. Anterior implant location and use of three or more devices increased failure risks. Similarly, Bongiolatti *et al.* (33) described fracture and dislocation of titanium bars in 1 of 11 patients following sternectomy and reconstruction with the STRATOS. This implant failure presented at 3 months with arrhythmia and chest pain, requiring bar removal and flap reconstruction. Collectively, these findings reveal delayed titanium implant failure is an important potential complication after chest wall reconstruction that warrants close radiologic monitoring and consideration of preventive techniques, such as limiting the number of implants used. Ongoing refinements in titanium osteosynthesis devices are warranted to help address this issue.

## *Respiratory complications*

Respiratory complications are among the most frequently occurring complications after chest wall resection and reconstruction. While their estimated incidence varies, they have been reported to affect up to approximately 37% of patients undergoing such procedures (*Table 2*). This high incidence can be ascribed to the compromised structural integrity of the chest wall, which may hinder respiratory function. Another contributing factor is the concurrent resection of functional pulmonary parenchyma when the procedure is performed for lung cancer. In the study by Spicer *et al.* (17), a multivariate analysis of factors associated with pulmonary complications identified the number of resected ribs and concomitant lobectomy as important variables for pulmonary complications (OR, 1.26; 95% CI: 1.00–1.59; P<0.001; and OR, 3.59; 95% CI: 1.62–7.92; P=0.002, respectively). However, the increased incidence of pulmonary complications has not been shown to be directly related to a reduction in lung function. In a retrospective study of 175 patients who underwent chest wall resection for malignant or benign tumors and prosthetic reconstruction with Vicryl or Gore-Tex mesh, pulmonary function was not affected considerably (15). Lung function tests revealed that postoperative reductions in forced expiratory volume in 1 second (from 87.1%±18.9% of predicted to 82.3%±23.0% of predicted), forced vital capacity (from 94.1%±19.3% of predicted to 82.0%±21.6% of predicted), and diffusing capacity of the lungs for carbon monoxide (from 15.7±7.4 to 12.1±4.1 mL/min/mmHg) were not statistically significant. Interestingly, the mean reductions in pulmonary function tests were affected by concurrent lung resection (P<0.001) and the anterolateral location of the chest wall defect (P=0.026) but not by the resection of three or more ribs, while the impact of sternal resection was observed to be marginally significant (P=0.079).

The potential influence of the reconstructive technique and prosthetic materials on postoperative respiratory outcomes is a subject of ongoing discourse. Several studies have attempted to answer the question whether reconstruction of the chest wall with a rigid prosthesis is more beneficial than a mesh alone. In the absence of randomized clinical trials, the best available evidence is provided by large cohort studies. Nonetheless, due to heterogeneous patient populations and considerably varied surgical techniques and materials, definite conclusions are difficult to establish.

In an attempt to determine whether the characteristics of a reconstructive material influences respiratory outcomes, Weyant *et al.* (9) investigated the selective use of rigid prosthesis for chest wall reconstruction. Respiratory complications occurred in 29 (11%) patients and included respiratory failure in 8 (3.1%) patients, atelectasis requiring bronchoscopy in 8 (3.1%), pneumonia in 7 (2.7%), pneumonitis in 5 (1.9%), and aspiration pneumonia in 1 (0.4%). Notably, there was no significant difference in the rate of respiratory complications between the three groups of patients according to the reconstructive technique (i.e., rigid prosthesis *vs.* flexible prosthesis *vs.* no reconstruction; P=0.87). Because the incidence of respiratory failure was lower than previously reported, the authors concluded that this difference may relate to the use of rigid prosthesis for defects likely to cause a flail segment. Nevertheless, their recommendation for routine rigid reconstruction appears to be influenced more by their personal preference rather than conclusive evidence. Indeed, patients undergoing rigid prosthesis reconstruction in this study likely had larger and more anterior defects than those undergoing nonrigid or no reconstruction. The comparability of these uneven patient groups should be considered when interpreting the reported respiratory complication rates.

Similar findings were documented by Spicer *et al.* (17), although the prosthetic materials and surgical techniques used in their study were partly different. The overall rate of pulmonary complications for the entire cohort was 23.9%. Pulmonary outcomes were further analyzed based on the type of reconstructive material used. No significant differences in the rates of atelectasis, pneumonia, acute respiratory distress syndrome, aspiration, reintubation, pleural effusion, pneumothorax, or pulmonary embolism were observed in the univariate analysis when comparing rigid and flexible chest wall reconstruction. Likewise, a multivariate analysis demonstrated that the choice of rigid or flexible prosthesis for chest wall reconstruction did not impact pulmonary complications (OR, 1.14; 95% CI: 0.54–2.38; P=0.733). However, patients in the rigid prosthesis group had a higher mean number of resected ribs (3.4 *vs.* 2.7; P<0.001), suggesting larger defect sizes, although median ribs resected was equivalent between groups. The potential impact of this underlying difference in defect extent should be considered when comparing respiratory outcomes between the rigid and flexible reconstruction groups.

Similar to respiratory complications, the selection of prosthetic material (rigid or flexible) also does not appear to influence postoperative lung function. In the aforementioned study by Leuzzi *et al.* (15), the authors analyzed 75 cases of rib resection, 20 sternal resections, and 15 combined resections. A chest wall defect larger than 4 cm was present in 86.7% of patients, while 15.4% underwent concurrent lung resection. In 39 (22.2%) cases, the chest wall was reconstructed with a flexible prosthesis, including Gore-Tex mesh in 31 patients and Vicryl mesh in 8 patients, while a myocutaneous flap was used in 15 (8.6%) cases. Interestingly, the mean postoperative reduction in forced expiratory volume in 1 s in the group of patients who underwent chest wall stabilization with prosthesis was not significantly different compared to that observed in their counterparts without prosthesis stabilization (4.1%±15.9% of predicted *vs.* 17.5%±16.2% of predicted).

Ongoing discussion also surrounds the potential impact of soft tissue flaps for chest wall reconstruction on respiratory outcomes. A retrospective study involving 37 patients who underwent chest wall resection and reconstruction for primary or metastatic tumors categorized patients into two groups based on the size of the residual defect, with a cut-off value of 60 $cm^2$: a small defect group (n=9), with a mean defect area of 51 $cm^2$, and a large defect group (n=28), with a mean defect area of 150 $cm^2$ (34). All patients underwent reconstruction with flexible prosthesis, muscle flaps, or a combination of the two. Nonrigid prostheses included Marlex, Gore-Tex, Prolene, Vicryl, Mersilene (Ethicon), Gore-Dualmesh (W.L. Gore & Associates), and Davol (BD, Franklin Lakes, NJ, USA) meshes, while muscle flaps mainly consisted of pectoralis major, latissimus dorsi, serratus anterior, and rectus abdominis muscles. A prosthetic mesh was used in 11% of patients in the small defect group and 61% of patients in the large defect group (P=0.018). Additionally, muscle flaps were used in 56% of patients in the small defect group and 75% of patients in the large defect group (P=0.14). The rate of immediate postoperative extubation was 100% in the small defect group and 89% in the large defect group (P=0.42). In the large defect group, 42% of patients were admitted to the intensive care unit for ventilatory support as compared to none in the small defect group. The median period of mechanical ventilation was 2 days (range, 1–7 days). The rate of postoperative pneumonia was not significantly different between the groups (0% in the small defect group *vs.* 11% in the large defect group; P=0.31). These outcomes indicate that extensive chest wall defects, measuring more than 150 $cm^2$, may be reconstructed using solely muscle flaps. Nonetheless, this approach may be associated with an increased risk of mechanical ventilation.

The association between the use of soft tissue flaps for chest wall reconstruction and prolonged mechanical ventilation was further demonstrated in a retrospective study of 51 patients who underwent resections of primary sarcomas (5). The tumors were located in the sternum (n=11), rib alone (n=36), or posterior rib with extension into vertebral bodies (n=4). A complete sternectomy was performed in 6 of the 11 patients with sternal sarcomas. The average number of resected ribs was 3.8 (range, 1–9 ribs). Prosthetic mesh alone was used in 16 (31.4%) patients, while a composite implant of mesh with methyl methacrylate was required in 18 (35.3%) patients. In total, 24 pedicled muscle or myocutaneous flaps were utilized for soft-tissue coverage, including 8 pectoralis major, 6 rectus abdominis, and 8 latissimus dorsi flaps. For patients requiring soft tissue flaps, the average duration of mechanical ventilation was 3.8 days, compared to 0.9 days for patients without a flap (P=0.04). As a result, the mean stay in the intensive care unit was 4.4 days for patients with soft tissue flaps *vs.* 1.6 days for those without a flap (P=0.05). Nevertheless, the observed differences in respiratory outcomes between patients with and without soft tissue coverage of the chest wall defect likely reflect the greater extent of the operations that necessitated muscle or myocutaneous flaps. More extensive resections could reasonably increase the need for postoperative respiratory support, irrespective of flap coverage. In any case, the clinically significant difference in respiratory support between these patient groups underscores the importance of careful operative planning when muscle or myocutaneous flaps are anticipated for chest wall reconstruction.

Respiratory complications following chest wall resection and reconstruction include pneumonia (1.1–11.3%), acute respiratory failure (2.3–5.4%), atelectasis, acute respiratory distress syndrome, pulmonary embolism, pleural effusion, and pneumothorax (20). It is vital for surgeons to exercise a high degree of caution and awareness regarding the development of respiratory complications, as delayed management may have catastrophic consequences for this patient population. Optimal management requires consideration of the severity of the complication, patient's underlying disease, and cardiorespiratory reserve. Close collaboration between surgeons, anesthesiologists, and intensivists is crucial when making decisions about mechanical ventilatory support. Careful monitoring of vital signs, peripheral oxygen saturation, and arterial blood gases is crucial. Diagnostic testing includes blood levels of inflammatory markers, frontal and lateral chest radiographs, and chest CT; however, CT should be delayed until patients are clinically stable for transfer. In certain cases, bronchoscopy may be indicated to treat atelectasis due to airway secretions and to collect sputum samples or bronchoalveolar lavage for culture analysis of potential pathogens. Empirical administration of antibiotics, guided by local microbiology recommendations, is advised at the earliest symptoms or signs of pneumonia, followed by tailored treatment according to culture growths and antibiotic sensitivities. Effective pulmonary hygiene may require regular chest physiotherapy, bronchodilators, and mucoactive agents. Lastly, drainage of pleural effusion or pneumothorax is important to promote recruitment of functional pulmonary parenchyma and enhance respiratory mechanics.

Although infrequently reported, flail chest and paradoxical breathing motion are important potential risks following chest wall resection and reconstruction, which can lead to significant respiratory morbidity. Patients at greatest risk are those undergoing large resections, especially of the anterior or lateral chest wall. Weyant *et al.* (9) observed paradoxical motion in two patients after total sternectomy and rigid reconstruction, as well as in one patient following subtotal sternectomy. All these patients required prolonged mechanical ventilation, with two needing tracheostomy and one dying from respiratory failure 3 months postoperatively. Comparable results were reported in a retrospective analysis of 71 patients undergoing resection of primary chest wall tumors or lung cancers with thoracic wall invasion (35). Of those, 36 patients were not reconstructed, 33 patients underwent prosthetic stabilization (in six cases with the additional use of muscle flaps), and 2 patients underwent reconstruction with muscle flaps only. Flail chest developed in nine patients, six of whom had not undergone chest wall reconstruction. The authors found a significant correlation between defect location and flail chest incidence, with anterior and lateral areas being most critical. Patients undergoing prosthetic stabilization of these high-risk defects exhibited lower rates of flail chest compared to those without reconstruction. Furthermore, acute respiratory complications occurred in all non-reconstructed patients after resection at critical chest wall sites, compared to only 5.7% of those with reconstruction. In summary, current evidence indicates anterior or lateral chest wall defects and those spanning 3 or more ribs, unless covered by the scapula, typically warrant prosthetic reconstruction to maintain rigidity and minimize respiratory morbidity. In severe cases of postoperative respiratory dysfunction, reoperation for prosthetic reconstruction, especially with rigid materials, should be considered to improve chest wall mechanics, although evidence to guide specific indications is lacking.

### *Other systemic complications*

Other systemic complications may arise due to the prolonged general anesthesia and increased surgical stress, intrinsic to procedures of chest wall resection and reconstruction. These complications typically do not constitute the primary focus of studies investigating postoperative outcomes of chest wall resection and reconstruction, and they are usually analyzed collectively when reported. Among those, cardiovascular complications are likely the most prevalent, with arrhythmias affecting up to 6.5% of patients (9) and myocardial infarction occurring in 1.5% (4). The management of cardiovascular and other systemic complications should adhere to international or national clinical practice guidelines to optimize patient outcomes in these complex cases.

## Discussion

Chest wall resection and reconstruction is associated with high postoperative morbidity, with complication rates across studies ranging from 17% to 59% (*Table 2*). The most common complications are related to the surgical site or affect the respiratory system. In the previous section, we expanded upon the management of different complications based on those distinct categories. However, since diverse complications can occur simultaneously, management strategies may require adjustments to integrate differing and occasionally conflicting treatments. Another noteworthy aspect of the postoperative course is the acknowledgement of rehabilitation as an important component of the recovery process (36). Rehabilitation includes physical therapy, occupational therapy, and psychological support, and it aims to enhance the patient's functional status and health-related quality of life. Moreover, preoperative improvement of physical fitness, nutrition, and emotional wellbeing, a process commonly referred to as "prehabilitation", may lead to better postoperative outcomes (37). Finally, pre-surgery information and education programs can reduce anxiety, pain, and hospitalization time, while enhancing patient satisfaction (38-41).

Typically, chest wall resections and reconstructions are performed through thoracotomy. In recent times, however, minimally invasive surgical techniques have surfaced as an alternative to the open approach. The notion behind minimally invasive thoracic surgery is to alleviate postoperative pain and reduce the incidence of associated complications. While minimally invasive chest wall resection and reconstruction is yet to gain widespread acceptance, preliminary findings have indicated its feasibility and safety in specific patient groups (42).

Multiple authors have described different methods of video-assisted thoracoscopic surgery (VATS) for chest wall reconstruction (43,44). In addition to these methods, there exist case reports of rib reconstruction using VATS and titanium plating (45), as well as chest wall reconstruction with minimally invasive harvesting and transposition of the latissimus dorsi muscle in a patient with Poland Syndrome (46). The largest cohort studies investigating hybrid VATS for combined lung and chest wall resection have reported encouraging short-term outcomes (47,48). In both studies, hybrid VATS patients experienced decreased postoperative pain and shorter hospital stay than contemporary patient cohorts treated via thoracotomy. Finally, these studies also found a reduced need for chest wall reconstruction among patients who underwent VATS due to improved preservation of chest wall structure compared to thoracotomy. However, it should be pointed out that both studies were retrospective, included a small number of participants, and involved highly selected patients.

Chest wall resection and reconstruction has also been recently reported with the application of robotic surgery. Day *et al.* (49) reported the robotic harvest of a pedicled omental flap for reconstruction of an anterior chest wall defect in a 68-year-old woman presenting with recurrent secondary chest wall angiosarcoma following mastectomy and radiotherapy. The patient experienced a recovery marked only by minimal complications of the wound. Robotic surgery possesses certain advantages, including increased degrees of freedom and enhanced flexibility in instrument angulation (50). Moreover, this approach enables surgeons to avoid division of large chest wall muscles, thereby facilitating postoperative recovery and promoting improved functional status. As proficiency in robotic surgery expands and associated technologies advance, wider use of this approach in chest wall resection and reconstruction may enable the realization of its benefits shown in other clinical contexts (51,52).

The lack of a systematic, quantitative analysis of studies reporting on complications following chest wall resection and reconstruction is a limitation of the present review. Yet, given the extreme heterogeneity of these studies, such an effort might not be practical. Indeed, different indications, prosthetic materials, and surgical techniques have been noted both between and within studies. Instead, we chose to focus on clinically relevant aspects of postoperative complications rather than solely documenting their incidence.

## Conclusions

The management of complications after chest wall resection and reconstruction varies significantly and can be a complex and challenging process. Prudent selection of prosthetic materials and meticulous surgical technique can reduce the risk of surgical-site and respiratory complications. Close postoperative monitoring, heightened vigilance for severe complications, and a multidisciplinary approach are essential for successful management. With an emphasis on prevention and prompt treatment of complications, patients undergoing chest wall resection and reconstruction can achieve improved outcomes.

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## Supplementary

**Table S1** Search of the PubMed database

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| ((“chest wall”[Title/Abstract] AND “thoracic wall”[Title/Abstract]) OR “resection”[Title/Abstract]) AND “reconstruction”[Title/Abstract] AND “complication”[Title/Abstract] |

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