Review Article

Chest wall resections for non-small cell lung cancer: a literature review

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Background and Objective: The development of early screening for lung cancer has led to improved overall survival in patients with non-small cell lung cancer (NSCLC). However, the management of NSCLC patients with resectable and potentially resectable chest wall invasion (CWI) requires attention. The purpose of this review is to summarize the role of surgery (chest wall resections) in NSCLC patients with CWI.

Methods: A literature search and review from three databases (PubMed, Embase, and ScienceDirect) comprised the last 39 years. This review was focused on the treatment of NSCLC patients with CWI, mainly including the preoperative evaluation, principles of treatment and strategic decision-making, surgical complications, and prognostic factors.

Key Content and Findings: Through the collection of relevant literature on NSCLC that invades the chest wall, this narrative review describes the actual role in clinical practice and future developments of chest wall resections. Preoperative treatment requires the multidisciplinary team (MDT) team to conduct accurate clinical staging of the patient and pay attention to the patient's lymph node status and rib invasion status. The successful implementation of chest wall resection and possible chest wall reconstruction requires refined individualized treatment based on the patient's clinical characteristics, supplemented by possible postoperative systemic treatment.

Conclusions: Surgery plays an important role in treating NSCLC patients with CWI, and a collaborative, experienced MDT is an essential component of the successful treatment of CWI with lung cancer. In the future, more high-quality clinical research is needed to focus on CWI patients so that patients can receive more effective treatment options and better clinical prognosis.

Keywords: Non-small cell lung cancer (NSCLC); thoracic wall; surgery; chest wall resection; chest wall reconstruction

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Introduction

Background

Malignant tumors of the chest wall can be largely divided into primary and secondary types. Secondary chest wall tumors are mainly caused by invasion or metastasis from breast, lung cancer, or other malignancies, and the incidence rate is higher than that of primary tumors. A chest wall structure can be layered anatomically as follows: the skin, the fat, the parietal pleura, the internal thoracic fascia, the ribs, the intercostal muscles, the extracellular vessels, and the nerves (1).

A rare clinical entity, chest wall invasion (CWI) accounts for 3% to 8% (2-6) of all resected non-small cell lung cancer (NSCLC) cases and approximately 45% of T3 tumors (7). However, the optimal treatment strategy for such advanced tumors remains controversial as to the role of neoadjuvant therapy (NAT), surgical strategies/techniques, and reconstruction of the chest wall.

The most recent National Comprehensive Cancer Network (NCCN) 2023 guidelines recommend *en-bloc* resection as the predominant treatment for patients with T3N0–1 or resectable T4N0–1 disease for patients with CWI. In the absence of functional limitations, there are no absolute contraindications to chest wall resection and reconstruction.

For IIIA tumors (T4, N0–1), it is preferred to re-evaluate the possibility of surgery after preoperative systemic therapy (concurrent chemoradiotherapy or chemotherapy) on a planned basis, and then consider further treatment options (redo-operation and chemotherapy or chemoradiation therapy) based on the status of the postoperative margins. For patients with positive surgical margins (R1/R2), reoperation combined with adjuvant chemotherapy or radiotherapy and chemotherapy is recommended.

Rationale and knowledge gap

The first reports of chest wall resection and reconstruction were published in the 19th century (8), and the first surgical treatment for lung cancer with CWI was described in 1947 (9). Patient prognosis is influenced by various factors such as the radicality of surgery, lymph node status, depth of CWI, and histological findings.

In the management of NSCLC with CWI, the surgeon must be proactive and consider the following:

(I) Correct preoperative staging and complete preoperative evaluation and assessment (indications/contraindications);
(II) A detailed preoperative plan to ensure adequate operative cardiopulmonary support and possible chest wall resection/reconstruction options;
(III) Radical resection and simultaneous chest wall reconstruction (if necessary);
(IV) Multimodal systemic therapy combined with preoperative induction/NAT and postoperative adjuvant therapy.

Objective

This review is intended to summarize the role of surgery regarding chest wall resection for NSCLC patients with CWI. We present this article in accordance with the Narrative Review reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-774/rc).

Methods

This narrative review was based on a literature search of three databases from January 1984 to May 2023. The literature databases included PubMed, Embase, and ScienceDirect, searched in English. Some groundbreaking or historically significant literature was also included. Search topics focused on the management of patients with NSCLC that invaded the chest wall, particularly surgery (chest wall resection and chest wall reconstruction). The specific entity of Pancoast tumor or superior sulcus tumor (SST) and the role of the different surgical approaches for these tumors will be not addressed here. Studies with lower levels of evidence or single case reports were excluded. *Table 1* summarizes the search strategy of this review.

Perioperative evaluation of chest wall resection and reconstruction

Preoperative assessment

A complete and adequate preoperative evaluation is the basis for successful surgery. Adequate preoperative cardiopulmonary evaluation may include echocardiography, lung function tests, perfusion scans, etc. It is very important to ensure that the patient has the physiological functional reserve to tolerate chest wall resection and possible subsequent chest wall reconstruction.

Preoperative evaluation should also focus on the possible invasion of the pleura, ribs, and adjacent soft

Table 1 The summary of the literature search strategy

Items	Specification
Date of search	May 6, 2023
Databases and other sources searched	PubMed, Embase, ScienceDirect
Search terms used	(chest wall resection) OR (chest wall resection and reconstruction) OR (chest wall resection and reconstruction and complications) OR (chest wall resection)) AND ((NSCLC) OR (non small cell lung cancer) OR (non small cell lung carcinoma)
Timeframe	January 1984 to May 2023
Inclusion and exclusion criteria	Inclusion criteria: clinical trial, meta-analysis, randomized controlled trial, systematic review, case series, guideline, English article
	Exclusion criteria: (pulmonary sulcus tumor) OR (superior sulcus tumor) OR (pancoast tumor) OR (superior sulcus lung neoplasm); case report
Selection process	L.H. and F.L. conducted the selection, independently. Consensus was reached after a discussion among five experienced thoracic surgeons from two centers

tissues. Reliable prediction of CWI depth by preoperative assessment can reduce incomplete resections, overly extended surgery, upstaging of clinical stages found during surgery, complicated thoracoscopic surgery, and the rate of conversion to conventional thoracotomy (10,11).

Possible techniques for detecting CWI are shown below. Chest computed tomography (CT) can detect CWI to some extent (12). Compared with chest CT, ultrasonography (13,14) has better sensitivity and specificity and can be considered an adjunctive preoperative diagnostic modality for patients with lung cancer CWI. Magnetic resonance imaging (MRI) is an ideal method for determining the depth of CWI, in particular, when soft tissue invasion is presented (15). MRI has been reported to distinguish chest wall tumors from infection or inflammation (16). Bone scintigraphy (17), which is routinely used in clinical practice, is also a specific method for detecting rib invasion. Fluorine-18-fluorodeoxyglucose (FDG) positron emission tomography (PET)/CT plays an important role in staging disease, assessing response to treatment, and detecting recurrence and has been recognized as an important test. Due to its cost, however, it is not routinely performed in clinical practice. In a study of 157 people, Motono *et al.* (18) demonstrated that standard uptake value (SUV) max is one of the predictive factors for CWI in NSCLC patients.

For chest wall and soft tissue infiltrates that cannot be evaluated on preoperative imaging, preoperative biopsy can be used to aid diagnosis when possible, and the method of biopsy should be minimally invasive (including thoracoscopic). The following biopsy modalities are available for surgeons to use fine needle aspiration/punch biopsy incisional biopsy/excisional biopsy and so on.

Evaluation and implementation of induction/NAT

As shown in the background, there is currently a lack of clinical guidance on the indications and contraindications for NAT in patients with CWI. Indications for NAT are based on multidisciplinary team (MDT) discussions and no clear criteria are established.

The status of lymph nodes is one of the factors that should be considered whether to use NAT. In NSCLC patients with suspected severe nodal involvement, mediastinoscopy should be used to assess nodal status preoperatively. If hilar or mediastinal involvement is found preoperatively, NAT is one of the treatment options that should be discussed by the MDT (19).

Another factor to consider is whether the tumor has invaded the ribs. A propensity score-matched retrospective study of 521 patients with pT3–T4 NSCLC from Zhao *et al.* (20) demonstrated that patients in the pathological rib invasion subgroup had similar 5-year overall survival (OS) rates as patients with pT4 tumors. Another study (21) demonstrated that rib invasion is a poor prognostic factor, in which three patients who did not receive preoperative treatment were confirmed to have insufficient surgical margins. Postoperative local and distant recurrences were more common in patients with pathological rib invasion.

For definite hilar/mediastinal lymph node and rib invasion, NAT is recommended for patients after discussion with an MDT. The purpose is to improve the radical rate of resection, obtain a reliable safety margin, preserve

Table 2 NAT study in patients with potentially operable NSCLC

Authors	Study design	Study period	Number of patients	Stage	Induction therapy regimen	Survival benefits from induction therapy
Kawaguchi *et al.* (23,24)	Phase II trial	2009.01–2012.11	51 (CHT/RT: 49)	T3N0/T3N1	CHT/RT: cisplatin and vinorelbine chemotherapy concurrent with 40 Gy of radiation therapy	Yes. PCR (N=12, 25%) cases exhibited much better survivals than MRD (N=31, 65%)
Forde *et al.* (25)	International, open-label, phase 3 trial	2017.03–2019.11	358 (nivolumab plus chemotherapy:179; CHT: 179)	Stage IB to IIIA	Nivolumab plus platinum-doublet chemotherapy. CHT: platinum-doublet chemotherapy alone	Neoadjuvant nivolumab plus chemotherapy resulted in significantly longer event-free survival and a higher percentage of patients with a pathological complete response than chemotherapy alone
Bilfinger *et al.* (26)	Retrospective study	2002–2014	127 (CHT: 33; definitive chemoradiation therapy: 94)	Stage IIIA	CHT: platinum-based chemotherapy. Definitive chemoradiation: concomitant platinum-based chemotherapy and 58 G over 30 sessions	Yes
Chiappetta *et al.* (27)	Retrospective study	2002.01–03.2013	59 patients (induction therapy: 18; AC: 36)	Stage IIB (T3N0) to IIIA (T3N1–2, T4N0)	Radiotherapy (50.4 Gy), chemotherapy (protocols were not uniform), or both	Yes, especially in p stage IIB (T3N0)
Sinn *et al.* (28)	Retrospective study	2002–2014	84 (CHT/RT: 34; CHT: 50)	Stage III/N2	CHT: platinum-based regimen. Neoadjuvant RT: mean total cumulative dose of 57 Gy (range, 45–75 Gy)	CHT/RT: improved DFS and OS, induced pathological mediastinal downstaging
Yutaka *et al.* (21)	Retrospective study	2006.01–2019.12	CHT/RT: 27	pT3N0–1	CHT/RT: cisplatin + vinorelbine or carboplatin + paclitaxel with radiotherapy (40–70 Gy)	Major pathological effect (N=13, 48.1%); Complete pathological effect (N=5, 18.5%)

NAT, neoadjuvant therapy; NSCLC, non-small cell lung cancer; CHT, neoadjuvant chemotherapy; CHT/RT, neoadjuvant chemoradiotherapy; PCR, pathological complete response; MRD, minimal residual disease; AC, adjuvant chemotherapy; DFS, disease-free survival; OS, overall survival.

important structures, eradicate micrometastases, and extend the patient's survival benefit (22).

Table 2 shows the status of NAT research for patients with potentially operable NSCLC. A phase 2 trial in Japan (23,24) demonstrated that the survival advantage for patients who received NAT was most pronounced when they achieved complete pathological response, compared with patients who had residual disease. However, this study included SSTs, and the proportion of CWI among patients is unknown. Lack of radiographic response to NAT is associated with a significantly increased risk of poor OS, which helps select patients who may benefit from subsequent adjuvant therapy (29). For patients who do not respond radiologically to induction therapy, additional adjuvant therapy should be considered, as surgery alone may not provide long-term benefits. MDT discussion should be carried out throughout the entire course of patient treatment, including subsequent adjuvant therapy, because in another Japanese study (21), even though five of the patients achieved pathological complete response (PCR) after induction therapy, two developed brain metastases.

An international, open-label, phase 3 trial from Forde *et al.* (25) shows that preoperative immunotherapy using checkpoint inhibitors can improve pathological response and OS compared with neoadjuvant chemotherapy alone, which provides a new option for NAT.

Currently, there is still a lack of high-level evidence on whether and which type of NAT patients with CWI should receive.

Planning and execution of chest wall resection

Due to the high potential for perioperative complications in NSCLC patients with CWI, patients with advanced disease requiring complete tumor resection and complex chest wall reconstruction require management by an MDT (including surgeons, oncologists, radiation oncologists, anesthesiologists, and nurses) for comprehensive preoperative evaluation and treatment selection. And should be referred to an experienced cancer center (30).

Choice of surgical approach

Thoracotomy is the first choice for radical resection and chest wall reconstruction. The choice of surgical approach is influenced by many factors, including the experience of the surgical center.

An initial exploration of the thoracic cavity with thoracoscopy may be useful. This can be done at the beginning of the resection or as a stand-alone step.

It can be used to perform a preoperative/surgical biopsy or to visually assess the depth of tumor involvement in the chest wall and the extent of intrathoracic metastasis, and to assist in the evaluation of the appropriate incision site for thoracotomy or specific rib resection to ensure adequate surgical margin (31).

The feasibility of a hybrid minimally invasive (thoracoscopic) technique to combine anatomical lung resection with *en-bloc* chest wall resection had already been demonstrated by D'Amico *et al.* in 2011 (32). This study illustrated that there was no difference in clinical variables and postoperative events between video-assisted thoracic surgery (VATS) hybrid and thoracotomy. Moreover, minimally invasive techniques may offer the benefit of potentially shorter hospital stays. Nevertheless, the limitations of minimally invasive techniques in complex cases require the selection of a potentially beneficial population (33). To avoid the risk of tumor spread, thoracoscopy should be performed under the "no touch" policy.

Extent of surgical resection

If the depth of invasion cannot be assessed by preoperative imaging, it is recommended to perform limited resection with minimal trauma and confirm it with intraoperative pathology to determine further extended resection or postoperative adjuvant treatment.

Gonfiotti *et al.* (34,35) presented their single-center experience regarding the extent of surgical resection: skin incisions, sites of previous biopsy, cancerous tissue, and tissue previously treated with radiation, and wide surgical resection of rib invasion with a margin of at least 3 cm. To ensure adequate margins, the ribs above and below the tumor are also removed.

For patients with CWI, the standard of surgery is complete surgical resection with lobectomy and *en-bloc* chest wall resection. Traditionally, 2 cm margins have been used to define complete resection of locally advanced NSCLC (36,37). In the recently published expert consensus (38) on chest wall tumor resection and reconstruction, most experts believe that it is necessary to maintain a tumor resection margin of at least approximately 2 cm in NSCLC patients with CWI (T3–4N0–1M0).

Possible complications of chest wall resection

The incidence of perioperative pulmonary complications (20–27%) (39-42) in patients receiving chest wall resection varies between institutions. However, it is not negligible.

Compared to conventional standard lung resection, the addition of chest wall resection and reconstruction is associated with a not negligible increase in morbidity and mortality (up to 9% in recent series) (43). However, a propensity-matched study of 135 patients undergoing chest wall resection by Liu *et al.* (44) showed that chest wall resections did not worsen patients' quality of life or lung function. Towe *et al.* (45) evaluated 41,310 lung cancer patients who underwent lung resection in the Society of Thoracic Surgeons (STS) general thoracic surgery database, of whom 306 patients underwent concomitant chest wall resection. In a multivariable model for all patients who underwent lung resection and in the subgroup who underwent lobectomy, chest wall resection was associated with an increased risk of a composite adverse outcome.

Many studies of chest wall resection are limited to discussing the quality of life and functional recovery of patients after surgery. At present, there is no high-level evidence to prove whether minimally invasive surgery, including thoracoscopic surgery, is beneficial in reducing perioperative complications. Research on minimally invasive procedures remains to be done, and patient-reported outcomes cannot be ignored.

Planning and execution of chest wall reconstruction

The necessity of chest wall reconstruction

The first case of chest wall reconstruction was described by Tansini (46) in 1906, in which a pedicled latissimus dorsi flap was used to cover a defect in the anterior chest wall.

Reconstructive surgery may be required after chest wall resection to stabilize the chest, protect the organs inside the chest cavity, restore anatomic defects, reduce the incidence of paradoxical respiratory movements, respiratory failure, and infectious disease, and, when possible, provide acceptable aesthetic results and maintain satisfactory long-term functional outcomes (47). For patients undergoing chest wall resection for tumor or trauma, the above statement regarding the necessity of chest wall reconstruction also applies. For various patients, the ideal goal of the thoracic surgeon is to achieve the ultimate functional and anatomical repair.

Large defects or resections that interfere with chest wall motion or expose internal chest structures that are susceptible to damage or herniation are indications for chest wall reconstruction. Involvement of the spine, sternum, and ribs is not a strict contraindication to surgery. Relative contraindications include unresectable distant metastatic tumors, high risk of infection of the prosthesis implantation, etc.

Indications for chest wall reconstruction

Azoury *et al.* (48) created an illustrative technique guideline in 2016 to assist surgeons with chest wall reconstruction. The most recent consensus (38) on the resection and reconstruction of the chest wall also recognizes the need for chest wall reconstruction for chest wall defects greater than 5 cm in size.

Large defects requiring chest wall reconstructions can be categorized as (34):

(I) Chest-wall defects larger than 5 cm in diameter or total area >100 cm^2;
(II) Removal >3 ribs from the anterior chest wall;
(III) Removing >4 ribs from the posterior chest wall;
(IV) In the case of posterior resections (including small defects), below the fourth rib reconstructions should be used to avoid scapular entrapment (49).

Other investigators have likewise provided some key points for chest wall reconstruction. Small defects (<5 cm) or resections involving less than three ribs do not require reconstructive procedures, and soft tissue alone is sufficient to cover the chest wall defect (50). Subscapular and posterior apical chest wall defects up to 10 cm in size may not require reconstruction because the scapula and shoulder ensure adequate support and rigidity (30,51).

Materials selection for chest wall reconstruction

In complex cases, the surgical team should be very familiar with/experienced in chest wall reconstruction techniques using all materials as well as muscle flaps. With the improvement of surgical techniques as well as technology, the standards for materials have also been enhanced (52). Currently, ideal materials for chest wall reconstruction should have these properties:

(I) Rigidity to eliminate paradoxical movement;
(II) Ductility, modifiable in size and shape;
(III) Allows for tissue in-growth;
(IV) Radiolucency;
(V) Non-carcinogenicity, chemical inertness, sterility, and nonallergenic;
(VI) Decrease the likelihood of rejection and reduce internal environmental impact;
(VII) Reasonable price.

The different materials (see *Figure 1*) for surgical reconstruction of the chest wall can be categorized into synthetic, bioprosthetic, and biosynthetic materials (BSM) (50). Different materials have different characteristics. Synthetic materials generally have higher tensile strength but are more susceptible to foreign body reactions and have a higher risk of infection (40,53,54).

Bioprosthetic materials have advantages in reducing the risk of foreign body infection, promoting the healing of wounds and long-term stable performance, and having fewer postoperative complications. These are worthy of consideration for pediatric patients (55). However, they have been criticized for being costly and not strong enough, as the graft is absorbed over time, leading to instability of the chest wall (56-58). Finally, a BSM is a material that combines biological and synthetic components. It has specific indications in wounds with a high risk of contamination (59-61).

It remains controversial whether rigid prostheses should be used for chest wall reconstruction in pre-developing and developing adolescents (62,63). Due to physiological chest wall expansion and growth, surgeons need to consider long-term treatment strategies in such cases, as well as the possibility of secondary surgical repair.

The use of new materials and technologies is ongoing and

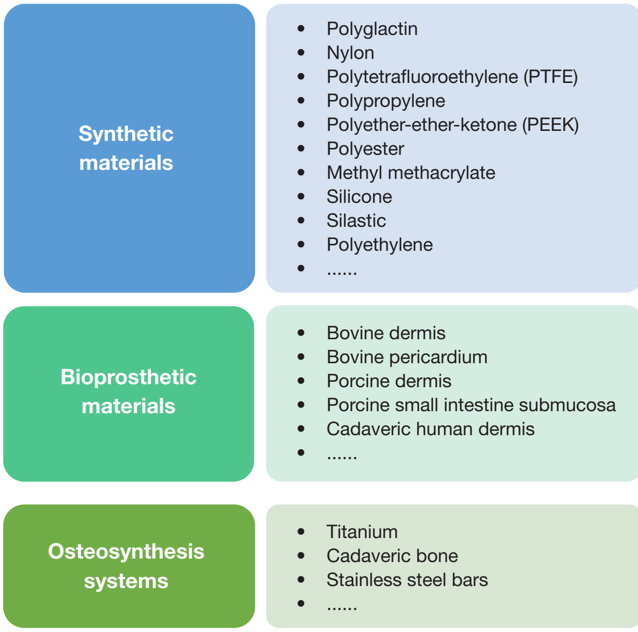

Figure 1 Display of different types of reconstruction materials.

may expand the clinical indications for chest wall resection and reconstruction while reducing overall costs and improving long-term patient outcomes. As a result, more patients requiring chest wall reconstruction may benefit.

The use of new technologies, such as 3D printing (64), 3D visualization combined with virtual reality (VR) (65), Software-assisted 4D dynamic-ventilation CT images (66), etc. will contribute to the future of accurate reconstruction, expand the indications for minimally invasive techniques, and even assist in the education of young surgeons.

However, each prosthetic material used for reconstruction has its advantages and disadvantages. There is no optimal material and procedure for reconstruction. It is usually the surgeon's preference and skill that determines the method of reconstruction (40,42,67). It is common to use a combination of these materials, and the goal is to achieve the best possible effect of the reconstruction. Ultimately, material selection is also about cost (51).

Possible complications of chest wall reconstruction

Table 3 summarizes the most important series on chest wall reconstruction (including the clinical outcomes). In a study of 100 NSCLC patients who underwent chest wall resection for CWI analyzed by Jones *et al.* (29), chest wall reconstruction was not associated with an increase in overall and major postoperative complications (grade III–V). A study by Spicer *et al.* (39), on the other hand, demonstrated that the type of reconstructive material did not appear to affect perioperative pulmonary or infectious wound complications. The number of ribs removed and concurrent parenchymal resection after chest wall resection can predict pulmonary morbidity.

Clinical factors associated with prognosis

The impact of resection margins

As early as 1999 (70), the need for complete surgery was articulated. Even R1 resection with minimal residual disease is unfavorable for the patient's prognosis. There is a significant difference in five-year survival between patients with complete resection and those with incomplete resection (24–32% *vs.* 4–13%) (70-72).

Complete resection (R0) and no N2-positive status are good prognostic factors for long-term survival in NSCLC patients with CWI, according to the study by Lee *et al.* (73). In previous studies, positive surgical margins were common in CWI patients (ranging from 14% to 31.2%) (71,72,74), significantly higher than 4.7% (75) of all-stage NSCLC patients from the National Cancer Database. Thus, pathological assessment of surgical margins is very important. The pathologist should individually review all margins sent by the surgeon intraoperatively and postoperatively and actively communicate with the surgeon to resolve any disputes to ensure accurate assessments of surgical margins.

Depth of chest wall involvement

Chapelier *et al.* (76) evaluated the potential factors that influence long-term survival after complete resection of CWI. The degree of histological differentiation and depth of chest wall involvement emerged as independent predictors of long-term survival after complete resection.

Whether outcomes differ in patients with rib versus parietal pleural invasion has been inconclusive in previous studies (20,77). Some studies (70,77,78) found no significant difference in survival between patients with parietal pleural and rib/intercostal involvement. However other studies (17,73,79) reach the opposite conclusion: CWI involving the ribs or intercostal muscles is an independent prognostic risk factor. The survival rate is lower in these patients than that of patients with only parietal pleural invasion.

A total of 703 patients who underwent chest wall resection were retrospectively analyzed by Wu *et al.* (80).

Table 3 Summary of the most important series of chest wall reconstruction in patients with NSCLC

Authors	Study period	Reconstruction materials	Number of reconstruction patients	Indications (percentage of lung cancer)	Chest wall defect size (cm^2)	Follow up
Gonfiotti *et al.* (35)	2013.10–2020.12	Cross-linked porcine dermal collagen matrix	105	Primary chest wall tumor: 52 (49.5%), secondary chest wall tumor: 29 (27.6%), and others (11.4% lung cancer)	–	Postoperative complications: 14 (13.3%). No 30-day mortality; 1-year and 2-year mortality was 8.4% and 16.8%
De Palma *et al.* (68)	2010.01–2014.12	Titanium plates system (Synthes®) with or without mersilene mesh/muscle flap	27	Primary chest wall tumor: 3; secondary chest wall tumor: 8 (5 infiltrating metastases by contiguity from primary lung cancer); and others	–	No 30-day post-operative mortality. Post-operative complications: 10 (37%) minor complications, 2 (7.4%) major complications. Long-term plates-related morbidity: 3
Giordano *et al.* (69)	2002.04–2016.01	SM: 95 (65.1%); ADM: 51 (34.9%)	146	Metastatic resection: 17 (11.6%) (lung cancer: not specified)	Mean 173.8 cm^2	Surgical-site complications: 39 (26.7%), 90-days mortality: 9 (6.2%)
Spicer *et al.* (39)	1998–2013	Rigid prosthesis: 82 (19%); flexible material 345 (81%)	427	Various indications, lung cancer: 81 (19.0%)	–	Pulmonary complications: 102 (24%). Thirty-day mortality: is 1% and 90-day mortality is 6%
Weyant *et al.* (40)	1995.01–2003.07	Rigid (polypropylene mesh/methyl methacrylate composite) 112 (42.7%); nonrigid (polytetrafluoroethylene or polypropylene mesh): 97 (37%)	209	Various indications, lung cancer: 85 (32%)	80 cm^2	30-day complication: rigid 43 (38.4%); nonrigid 26 (27.0%). Mortality: rigid 5 (4.5%); nonrigid 3 (3.1%)
Mansour *et al.* (41)	1975–2000	Prolene mesh, marlex mesh, methyl methacrylate sandwich, vicryl mesh, and polytetrafluoroethylene	200	Various indications, lung cancer: 75 (38%)	–	In-hospital complications: 57 (24%). In-hospital and 30-day survival was 93%

NSCLC, non-small cell lung cancer; SM, synthetic mesh; ADM, acellular dermal matrix.

The overall rate of survival for patients with involvement of the ribs (N=237) was lower compared with that for patients with involvement of the parietal pleura (N=466, P=0.004) and patients with pT4 stage (P=0.037). Furthermore, tumor size may have a prognostic significance for different subgroups. Patients with parietal pleural involvement and tumors larger than 5 cm and those with pT4 tumors do not have a statistically different survival. This means that upstaging from pT3 to pT4 may be appropriate for patients with parietal pleural invasion and a tumor size of 5 to 7 cm. Regardless of propensity score matching (PSM), patients with rib involvement had the lowest survival in a study (20) of 521 patients with resected stage 3–4 NSCLC. Reclassifying rib invasion as pT4 disease may have provided a potential survival predictive benefit (P<0.001). The analysis of 6,479 T2b–4N0–2M0 NSCLC patients in the Surveillance, Epidemiology, and End Results database (SEER) by Chen *et al.* (81) showed that the rib involvement group's outcome of survival was comparable to that of the pT4 group. R0 resection and receipt of neo/adjuvant therapy were not independent risk factors for survival in cases of rib invasion. For NSCLC with rib invasion, the potential benefit of surgery or different surgical techniques is still under investigation.

Lymph node status

After surgery, the status of the lymph nodes is strongly associated with the patient's long-term outcome. Increasing nodal involvement significantly reduces survival. In a study by Scarnecchia *et al.* (82), 54 patients with NSCLC CWI underwent an *en-bloc* resection with the chest wall. In patients who undergo surgery, N0 status and negative surgical margins are favorable prognostic factors for postoperative survival and the role of surgery in patients with N1 or N2 disease is controversial.

In T3–4N0–1 NSCLC, surgery is considered the mainstay of treatment, but for N2 involvement, surgical reevaluation after neoadjuvant chemotherapy may be a valuable option. A preoperative lymph node examination is necessary. Mediastinoscopy (83) and endobronchial ultrasound-guided transbronchial needle aspiration (EBUS-TBNA) (84) may be considered for the preoperative evaluation of patients with a suspicion of nodal involvement.

Strengths and limitations

(I) Strengths: this review focuses on NSCLC patients (non-SST tumors) that invade the chest wall, and comprehensively covers preoperative diagnosis, preoperative treatment, surgical planning, technical points of resection and reconstruction surgery, and prognostic factors for patients. It may provide readers with a basic understanding of the historical development and latest clinical advances in the diagnosis and treatment (chest wall resection and possible chest wall reconstruction) of a subset of NSCLC patients that invade the chest wall.

(II) Limitations: based on the nature of the narrative review, this review did not conduct a quantitative analysis of the specific literature searched. It only conducted basic screening based on the evidence level of the literature and did not implement strict quality control assessment.

Conclusions

Surgery plays an important role in treating NSCLC patients with CWI. Actually, in light of the tremendous success of immune- and checkpoint-inhibition therapies, the role of surgery might be modified in the near future. A collaborative, experienced MDT, therefore, is an even more essential component of the successful treatment of CWI with lung cancer. In the future, more high-quality clinical research is needed to focus on CWI patients so that patients can receive more effective treatment options and better clinical prognosis.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. Birchard SJ, Schertel ER. Chapter 167 - Principles of Thoracic Surgery. In: Birchard SJ, Sherding RG, editors. Saunders Manual of Small Animal Practice. Third Ed. Saint Louis: W.B. Saunders; 2006:1723-31.
2. Pairolero PC. Extended resections for lung cancer. How far is too far? Eur J Cardiothorac Surg 1999;16 Suppl 1:S48-50.
3. Pearson FG. Non-small cell lung cancer: role of surgery for stages I-III. Chest 1999;116:500S-3S.
4. Voltolini L, Rapicetta C, Luzzi L, et al. Lung cancer with chest wall involvement: predictive factors of long-term survival after surgical resection. Lung Cancer 2006;52:359-64.
5. Stoelben E, Ludwig C. Chest wall resection for lung cancer: indications and techniques. Eur J Cardiothorac Surg 2009;35:450-6.
6. Lanuti M. Surgical Management of Lung Cancer Involving the Chest Wall. Thorac Surg Clin 2017;27:195-9.
7. Doddoli C, D'Journo B, Le Pimpec-Barthes F, et al. Lung cancer invading the chest wall: a plea for en-bloc resection but the need for new treatment strategies. Ann Thorac Surg 2005;80:2032-40.
8. Poland A. Deficiency of the pectoral muscles. Guys Hosp Rep 1841;6:191-3.
9. Coleman FP. Primary Carcinoma of the Lung, with Invasion of the Ribs: Pneumonectomy and Simultaneous Block Resection of the Chest Wall. Ann Surg 1947;126:156-68.
10. Smith DE, Dietrich A, Nicolas M, et al. Conversion during thoracoscopic lobectomy: related factors and learning curve impact. Updates Surg 2015;67:427-32.
11. Samson P, Guitron J, Reed MF, et al. Predictors of conversion to thoracotomy for video-assisted thoracoscopic lobectomy: a retrospective analysis and the influence of computed tomography-based calcification assessment. J Thorac Cardiovasc Surg 2013;145:1512-8.
12. Glazer HS, Duncan-Meyer J, Aronberg DJ, et al. Pleural and chest wall invasion in bronchogenic carcinoma: CT evaluation. Radiology 1985;157:191-4.
13. Bandi V, Lunn W, Ernst A, et al. Ultrasound vs. CT in detecting chest wall invasion by tumor: a prospective study. Chest 2008;133:881-6.
14. Tahiri M, Khereba M, Thiffault V, et al. Preoperative assessment of chest wall invasion in non-small cell lung cancer using surgeon-performed ultrasound. Ann Thorac Surg 2014;98:984-9.
15. Padovani B, Mouroux J, Seksik L, et al. Chest wall invasion by bronchogenic carcinoma: evaluation with MR imaging. Radiology 1993;187:33-8.
16. Bueno J, Lichtenberger JP 3rd, Rauch G, et al. MR Imaging of Primary Chest Wall Neoplasms. Top Magn Reson Imaging 2018;27:83-93.
17. Kawaguchi K, Mori S, Usami N, et al. Preoperative evaluation of the depth of chest wall invasion and the extent of combined resections in lung cancer patients. Lung Cancer 2009;64:41-4.
18. Motono N, Iwai S, Yamagata A, et al. Risk factors of chest wall invasion in non-small cell lung cancer. J Thorac Dis 2021;13:824-30.
19. Ramnath N, Dilling TJ, Harris LJ, et al. Treatment of stage III non-small cell lung cancer: Diagnosis and management of lung cancer, 3rd ed: American College of Chest Physicians evidence-based clinical practice guidelines. Chest 2013;143:e314S-40S.</bok>
20. Zhao M, Wu J, Deng J, et al. Proposal for Rib invasion as an independent T descriptor for non-small cell lung cancer: A propensity-score matching analysis. Lung Cancer 2021;159:27-33.
21. Yutaka Y, Terada K, Tanaka S, et al. Prognostic impact of pathologically confirmed rib invasion in patients with lung cancer requiring chest wall resection. J Thorac Dis 2022;14:4660-8.
22. Sato K, Nakamura S, Kadomatsu Y, et al. Neoadjuvant Therapy for Patients With Non-small Cell Lung Cancer Complicated With Chest Wall Invasion. Anticancer Res 2022;42:5539-46.
23. Kawaguchi K, Yokoi K, Niwa H, et al. Trimodality therapy for lung cancer with chest wall invasion: initial results of a phase II study. Ann Thorac Surg 2014;98:1184-91.
24. Kawaguchi K, Yokoi K, Niwa H, et al. A prospective,

multi-institutional phase II study of induction chemoradiotherapy followed by surgery in patients with non-small cell lung cancer involving the chest wall (CJLSG0801). Lung Cancer 2017;104:79-84.
25. Forde PM, Spicer J, Lu S, et al. Neoadjuvant Nivolumab plus Chemotherapy in Resectable Lung Cancer. N Engl J Med 2022;386:1973-85.
26. Bilfinger T, Keresztes R, Albano D, et al. Five-Year Survival Among Stage IIIA Lung Cancer Patients Receiving Two Different Treatment Modalities. Med Sci Monit 2016;22:2589-94.
27. Chiappetta M, Nachira D, Congedo MT, et al. Non-Small Cell Lung Cancer with Chest Wall Involvement: Integrated Treatment or Surgery Alone? Thorac Cardiovasc Surg 2019;67:299-305.
28. Sinn K, Mosleh B, Steindl A, et al. Neoadjuvant chemoradiotherapy is superior to chemotherapy alone in surgically treated stage III/N2 non-small-cell lung cancer: a retrospective single-center cohort study. ESMO Open 2022;7:100466.
29. Jones GD, Caso R, No JS, et al. Prognostic factors following complete resection of non-superior sulcus lung cancer invading the chest wall. Eur J Cardiothorac Surg 2020;58:78-85.
30. Thomas M, Shen KR. Primary Tumors of the Osseous Chest Wall and Their Management. Thorac Surg Clin 2017;27:181-93.
31. Huber RM, Ruysscher DD, Hoffmann H, et al. Interdisciplinary multimodality management of stage III nonsmall cell lung cancer. Eur Respir Rev 2019;28:190024.
32. Berry MF, Onaitis MW, Tong BC, et al. Feasibility of hybrid thoracoscopic lobectomy and en-bloc chest wall resection. Eur J Cardiothorac Surg 2012;41:888-92.
33. Kara HV, Balderson SS, D'Amico TA. Challenging cases: thoracoscopic lobectomy with chest wall resection and sleeve lobectomy-Duke experience. J Thorac Dis 2014;6:S637-40.
34. Gonfiotti A, Salvicchi A, Voltolini L. Chest-Wall Tumors and Surgical Techniques: State-of-the-Art and Our Institutional Experience. J Clin Med 2022;11:5516.
35. Gonfiotti A, Viggiano D, Vokrri E, et al. Chest wall reconstruction with implantable cross-linked porcine dermal collagen matrix: Evaluation of clinical outcomes. JTCVS Tech 2022;13:250-60.
36. Pairolero PC, Trastek VF, Payne WS. Treatment of bronchogenic carcinoma with chest wall invasion. Surg Clin North Am 1987;67:959-64.
37. David EA, Marshall MB. Review of chest wall tumors: a diagnostic, therapeutic, and reconstructive challenge. Semin Plast Surg 2011;25:16-24.
38. Wang L, Yan X, Zhao J, et al. Expert consensus on resection of chest wall tumors and chest wall reconstruction. Transl Lung Cancer Res 2021;10:4057-83.
39. Spicer JD, Shewale JB, Antonoff MB, et al. The Influence of Reconstructive Technique on Perioperative Pulmonary and Infectious Outcomes Following Chest Wall Resection. Ann Thorac Surg 2016;102:1653-9.
40. Weyant MJ, Bains MS, Venkatraman E, et al. Results of chest wall resection and reconstruction with and without rigid prosthesis. Ann Thorac Surg 2006;81:279-85.
41. Mansour KA, Thourani VH, Losken A, et al. Chest wall resections and reconstruction: a 25-year experience. Ann Thorac Surg 2002;73:1720-5; discussion 1725-6.
42. Deschamps C, Tirnaksiz BM, Darbandi R, et al. Early and long-term results of prosthetic chest wall reconstruction. J Thorac Cardiovasc Surg 1999;117:588-91; discussion 591-2.
43. World Health Organization. WHO Classification of Tumours of Soft Tissue and Bone: WHO Classification of Tumours, vol. 5. World Health Organization; 2013 [cited 2023 Nov 6]. Available online: http://apps.who.int/bookorders/anglais/detart1.jsp?codlan=1&codcol=70&codcch=4005&content=1</eref>
44. Liu M, Wampfler JA, Dai J, et al. Chest wall resection for non-small cell lung cancer: A case-matched study of postoperative pulmonary function and quality of life. Lung Cancer 2017;106:37-41.
45. Towe CW, Servais EL, Grau-Sepulveda M, et al. Impact of Chest Wall Resection on Mortality After Lung Resection for Non-Small Cell Lung Cancer. Ann Thorac Surg 2022;114:2023-31.
46. Tansini I. Sopra il mio nuovo processo di amputazione della mammella. Gazz Med Ital 1906;57:141-2.
47. Loi M, Mazzella A, Desideri I, et al. Chest wall resection and reconstruction for lung cancer: surgical techniques and example of integrated multimodality approach. J Thorac Dis 2020;12:22-30.
48. Azoury SC, Grimm JC, Tuffaha SH, et al. Chest Wall Reconstruction: Evolution Over a Decade and Experience With a Novel Technique for Complex Defects. Ann Plast Surg 2016;76:231-7.
49. Ito T, Suzuki H, Yoshino I. Mini review: surgical management of primary chest wall tumors. Gen Thorac Cardiovasc Surg 2016;64:707-14.
50. Khullar OV, Fernandez FG. Prosthetic Reconstruction of the Chest Wall. Thorac Surg Clin 2017;27:201-8.

51. Seder CW, Rocco G. Chest wall reconstruction after extended resection. J Thorac Dis 2016;8:S863-71.
52. Miller DL, Force SD, Pickens A, et al. Chest wall reconstruction using biomaterials. Ann Thorac Surg 2013;95:1050-6.
53. Leber GE, Garb JL, Alexander AI, et al. Long-term complications associated with prosthetic repair of incisional hernias. Arch Surg 1998;133:378-82.
54. Bellón JM, Buján J, Contreras LA, et al. Comparison of a new type of polytetrafluoroethylene patch (Mycro Mesh) and polypropylene prosthesis (Marlex) for repair of abdominal wall defects. J Am Coll Surg 1996;183:11-8.
55. Bongiolatti S, Voltolini L, Borgianni S, et al. Short and long-term results of sternectomy for sternal tumours. J Thorac Dis 2017;9:4336-46.
56. Alaedeen DI, Lipman J, Medalie D, et al. The single-staged approach to the surgical management of abdominal wall hernias in contaminated fields. Hernia 2007;11:41-5.
57. Wiegmann B, Zardo P, Dickgreber N, et al. Biological materials in chest wall reconstruction: initial experience with the Peri-Guard Repair Patch. Eur J Cardiothorac Surg 2010;37:602-5.
58. Ge PS, Imai TA, Aboulian A, et al. The use of human acellular dermal matrix for chest wall reconstruction. Ann Thorac Surg 2010;90:1799-804.
59. Ferzoco SJ. Early experience outcome of a reinforced bioscaffold in inguinal hernia repair: A case series. Int J Surg Open 2018;12:9-11.
60. Parker MJ, Kim RC, Barrio M, et al. A novel biosynthetic scaffold mesh reinforcement affords the lowest hernia recurrence in the highest-risk patients. Surg Endosc 2021;35:5173-8.
61. Overbeck N, Nagvajara GM, Ferzoco S, et al. In-vivo evaluation of a reinforced ovine biologic: a comparative study to available hernia mesh repair materials. Hernia 2020;24:1293-306.
62. Lin SR, Kastenberg ZJ, Bruzoni M, et al. Chest wall reconstruction using implantable cross-linked porcine dermal collagen matrix (Permacol). J Pediatr Surg 2012;47:1472-5.
63. Tuggle DW, Mantor PC, Foley DS, et al. Using a bioabsorbable copolymer plate for chest wall reconstruction. J Pediatr Surg 2004;39:626-8.
64. Wang L, Cao T, Li X, et al. Three-dimensional printing titanium ribs for complex reconstruction after extensive posterolateral chest wall resection in lung cancer. J Thorac Cardiovasc Surg 2016;152:e5-7.
65. Thumerel M, Belaroussi Y, Prisciandaro E, et al. Immersive Three-dimensional Computed Tomography to Plan Chest Wall Resection for Lung Cancer. Ann Thorac Surg 2022;114:2379-82.
66. Yamashiro T, Moriya H, Tsubakimoto M, et al. Preoperative assessment of parietal pleural invasion/adhesion of subpleural lung cancer: advantage of software-assisted analysis of 4-dimensional dynamic-ventilation computed tomography. Eur Radiol 2019;29:5247-52.
67. Sanna S, Brandolini J, Pardolesi A, et al. Materials and techniques in chest wall reconstruction: a review. J Vis Surg 2017;3:95.
68. De Palma A, Sollitto F, Loizzi D, et al. Chest wall stabilization and reconstruction: short and long-term results 5 years after the introduction of a new titanium plates system. J Thorac Dis 2016;8:490-8.
69. Giordano S, Garvey PB, Clemens MW, et al. Synthetic Mesh Versus Acellular Dermal Matrix for Oncologic Chest Wall Reconstruction: A Comparative Analysis. Ann Surg Oncol 2020;27:3009-17.
70. Downey RJ, Martini N, Rusch VW, et al. Extent of chest wall invasion and survival in patients with lung cancer. Ann Thorac Surg 1999;68:188-93.
71. Magdeleinat P, Alifano M, Benbrahem C, et al. Surgical treatment of lung cancer invading the chest wall: results and prognostic factors. Ann Thorac Surg 2001;71:1094-9.
72. Pitz CC, Brutel de la Rivière A, Elbers HR, et al. Surgical treatment of 125 patients with non-small cell lung cancer and chest wall involvement. Thorax 1996;51:846-50.
73. Lee CY, Byun CS, Lee JG, et al. The prognostic factors of resected non-small cell lung cancer with chest wall invasion. World J Surg Oncol 2012;10:9.
74. Tandberg DJ, Kelsey CR, D'Amico TA, et al. Patterns of Failure After Surgery for Non-Small-cell Lung Cancer Invading the Chest Wall. Clin Lung Cancer 2017;18:e259-65.
75. Osarogiagbon RU, Lin CC, Smeltzer MP, et al. Prevalence, Prognostic Implications, and Survival Modulators of Incompletely Resected Non-Small Cell Lung Cancer in the U.S. National Cancer Data Base. J Thorac Oncol 2016;11:e5-16.
76. Chapelier A, Fadel E, Macchiarini P, et al. Factors affecting long-term survival after en-bloc resection of lung cancer invading the chest wall. Eur J Cardiothorac Surg 2000;18:513-8.
77. Kawaguchi K, Miyaoka E, Asamura H, et al. Modern surgical results of lung cancer involving neighboring structures: a retrospective analysis of 531 pT3 cases in a Japanese Lung Cancer Registry Study. J Thorac

Cardiovasc Surg 2012;144:431-7.
78. Lin YT, Hsu PK, Hsu HS, et al. En bloc resection for lung cancer with chest wall invasion. J Chin Med Assoc 2006;69:157-61.
79. Sakakura N, Mizuno T, Kuroda H, et al. The eighth TNM classification system for lung cancer: A consideration based on the degree of pleural invasion and involved neighboring structures. Lung Cancer 2018;118:134-8.
80. Wu LL, Li CW, Li K, et al. The Difference and Significance of Parietal Pleura Invasion and Rib Invasion in Pathological T Classification With Non-Small Cell Lung Cancer. Front Oncol 2022;12:878482.
81. Chen Y, Zhang J, Chen J, et al. Prognostic relevance of rib invasion and modification of T description for resected NSCLC patients: A propensity score matching analysis of the SEER database. Front Oncol 2022;12:1082850.
82. Scarnecchia E, Liparulo V, Capozzi R, et al. Chest wall resection and reconstruction for tumors: analysis of oncological and functional outcome. J Thorac Dis 2018;10:S1855-63.
83. Xiao R, Li Y, Zhao H, Li X, Wang X, Wang J. The value of mediastinoscopy in N staging of clinical N2 lung cancer. Mediastinum 2019;3:23.
84. Ye T, Hu H, Luo X, et al. The role of endobronchial ultrasound guided transbronchial needle aspiration (EBUS-TBNA) for qualitative diagnosis of mediastinal and hilar lymphadenopathy: a prospective analysis. BMC Cancer 2011;11:100.

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