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Minimally invasive approaches for *en-bloc* anatomical lung and chest wall resection

En-blok anatomik akciğer ve göğüs duvarı rezeksiyonu için minimal invaziv yaklaşımlar

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ABSTRACT

Background: The aim of this study was to evaluate the feasibility of *en-bloc* anatomical lung and chest wall resection via minimally invasive surgery.

Methods: Between January 2013 and December 2021, a total of 22 patients (18 males, 4 females; mean age: 63±6.9 years; range, 48 to 78 years) who underwent anatomical lung and chest wall resection using minimally invasive surgery for non-small cell lung cancer were retrospectively analyzed. Demographic, clinical, intra- and postoperative data of the patients, recurrence, metastasis, mortality, and overall survival rates were recorded.

Results: The surgical technique was robot-assisted thoracic surgery in two, multiport video-assisted thoracoscopic surgery in 18, and uniport video-assisted thoracoscopic surgery in two patients. Upper lobectomy was performed in 17 (77.3%) patients, lower lobectomy in three (13.6%) patients, and upper lobe segmentectomy in two (9.1%) patients. Five different techniques were used for chest wall resection. Nine (40.9%) patients had one, eight (36.4%) patients had two, four (18.2%) patients had three, and one (4.5%) patient had four rib resections. Chest wall reconstruction was necessary for only one of the patients. The mean operation time was 114±36.8 min. Complete resection was achieved in all patients. Complications were observed in seven (31.8%) patients without mortality. The mean follow-up was 24.4±17.9 months. The five-year overall survival rate was 55.3%.

Conclusion: Segmentectomy/lobectomy and chest wall resection with minimally invasive surgery are safe and feasible in patients with non-small cell lung cancer. In addition, the localization of the area where chest wall resection would be performed should be considered the most crucial criterion in selecting the ideal technique.

Keywords: Chest wall resection, minimally invasive surgery, robot-assisted thoracic surgery, robotic surgery, video-assisted thoracoscopic surgery.

ÖZ

Amaç: Bu çalışmada minimal invaziv cerrahi ile *en-blok* anatomik akciğer ve göğüs duvarı rezeksiyonunun uygulanabilirliği değerlendirildi.

Çalışma planı: Ocak 2013 - Aralık 2021 tarihleri arasında küçük hücreli dışı akciğer kanseri nedeniyle minimal invaziv cerrahi ile anatomik akciğer ve göğüs duvarı rezeksiyonu yapılan toplam 22 hasta (18 erkek, 4 kadın; ort. yaş: 63±6.9 yıl; dağılım, 48-78 yıl) retrospektif olarak incelendi. Hastaların demografik, klinik, ameliyat sırası ve ameliyat sonrası verileri, nüks, metastaz, mortalite ve genel sağkalım oranları kaydedildi.

Bulgular: Cerrahi teknik olarak iki hastada robot yardımlı toraks cerrahisi, 18 hastada multi-portal video yardımlı torakoskopik cerrahi ve iki hastada uniportal video yardımlı torakoskopik cerrahi uygulandı. On yedi (%77.3) hastaya üst lobektomi, üç (%13.6) hastaya alt lobektomi ve iki (%9.1) hastaya üst lob segmentektomi yapıldı. Göğüs duvarı rezeksiyonu için beş farklı teknik kullanıldı. Dokuz (%40.9) hastaya bir, sekiz (%36.4) hastaya iki, dört (%18.2) hastaya üç ve bir (%4.5) hastaya dört kosta rezeksiyonu uygulandı. Yalnızca bir hastada göğüs duvarı rekonstrüksiyonu gerekti. Ortalama ameliyat süresi 114±36.8 dk. idi. Tüm hastalarda komplet rezeksiyon sağlandı. Hastaların yedisinde (%31.8) mortalite olmaksızın komplikasyon gelişti. Ortalama takip süresi 24.4±17.9 ay idi. Beş yıllık genel sağkalım oranı %55.3 idi.

Sonuç: Minimal invaziv cerrahi ile segmentektomi/lobektomi ve göğüs duvarı rezeksiyonu küçük hücreli dışı akciğer kanseri hastalarında güvenli ve uygulanabilirdir. Ayrıca göğüs duvarı rezeksiyonu yapılacak bölgenin lokalizasyonu, ideal tekniğin seçiminde en önemli kriter olarak düşünülmelidir.

Anahtar sözcükler: Göğüs duvarı rezeksiyonu, minimal invaziv cerrahi, robot yardımlı toraks cerrahisi, robotik cerrahi, video yardımlı torakoskopik cerrahi.

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Surgery provides the best chance to cure Stage I-II non-small cell lung cancer (NSCLC) patients. Minimally invasive surgery (video-assisted thoracoscopy [VATS] and robot-assisted thoracic surgery [RATS]) for lung resection compared to thoracotomy is associated with less postoperative pain, shorter hospital stay, lower postoperative morbidity and mortality, and more rapid return to daily life.[1] Therefore, lung resection with VATS is considered the standard surgical approach for Stage I-II NSCLC. Currently, 50 to 70% of patients at this stage are operated with VATS.[2,3]

Chest wall invasion is detected in 5% of patients with lung cancer.[4] Surgical resection is the preferred treatment option for patients with the invasion of the chest wall.[1] Although Widmann et al.[5] performed the first lung and chest wall resection with VATS in 2000, few studies have been published on this surgery over the past two decades. Chest wall invasion is considered one of the relative contraindications for VATS lung resection; therefore, transition to thoracotomy is recommended.[2,6] However, chest wall resection can be safely performed in some certain experienced centers using minimally invasive techniques.[7,8]

In the present study, we aimed to evaluate the feasibility and results of the minimally invasive surgery techniques in patients undergoing lung and chest wall resection.

PATIENTS AND METHODS

This multi-center, retrospective study was conducted at the Department of Thoracic Surgery of three tertiary care centers between January 2013 and December 2021. Data of patients who underwent surgery for NSCLC were reviewed. A total of 1,746 patients underwent anatomic lung resection due to lung cancer in our clinics during the study period. Additional chest wall resection was performed in 102 patients. The VATS/RATS was performed in 22 of these patients. Finally, 22 patients (18 males, 4 females; mean age: 63±6.9 years; range, 48 to 78 years) were included. Exclusion criteria were as follows: undergoing lung resection with thoracotomy; conversion to thoracotomy during VATS/RATS; non-anatomic lung resection; and having no chest wall resection.

In the patients' clinical evaluation, positron emission tomography (PET)/computed tomography (CT) and cranial CT or magnetic resonance imaging (MRI) were performed in all patients to exclude the presence of distant metastasis. The mediastinal staging was done by the European Society of Thoracic Surgeons (ESTS) guideline recommendations.[9] Early-stage NSCLC patients were evaluated primarily for surgical treatment. The patients underwent surgical treatment, if they accepted and their cardiopulmonary functions were appropriate for surgery. Patients with non-early-stage NSCLC were evaluated by a multidisciplinary team. The decision to initiate neoadjuvant/induction therapy before surgery was made based on the presence of mediastinal lymph node metastases (N2) and the T stage. Chemotherapy consisted of at least two cycles of platinum-based therapy, and radiotherapy involved administering a dose of 45 to 66 Gy. Restaging after oncological treatment was done using CT or PET/CT. Patients without disease progression after treatment were evaluated as candidates for surgical treatment. Patients suspected to have N2 disease were assessed with invasive staging methods (endobronchial ultrasound, re-mediastinoscopy, and mediastinotomy), and lung resection was performed in patients without N2. Surgery was performed at least three weeks after chemotherapy and four to six weeks after chemoradiotherapy. Except for evaluating the suspicion of vertebral invasion, thoracic MRI was not performed to assess the presence of rib invasion. The surgical procedure which allowed for complete resection was used depending on the extent of the disease. Lung-sparing anatomic resection (sleeve lobectomy) and VATS/RATS were preferred over pneumonectomy and thoracotomy. Mediastinal lymph node dissection with an approach similar to open surgery was performed in all patients.

All patients were placed in the lateral decubitus position. A segmentectomy or lobectomy in addition to *en-bloc* chest wall resection was performed using one of the following methods:

a. *Multiportal approach without an additional incision:* Resection using two 12-mm access ports opened in the eighth or ninth intercostal space (ICS) in the midaxillary line plus a 4-cm utility incision at the fifth ICS anterior to the involved ribs.[10]

b. *Hybrid resection:* As described by Berry et al.,[11] an incision was made over the invaded site of thoracic wall. The resection was performed through this incision by direct view and with the help of videothoracoscopic camera.

c. *Uniportal resection:* Introduced by Gonzales-Rivas et al.[12,13] in 2013. Firstly, a 2.5 to 5 cm incision was made over the fourth or fifth ICS. Pulmonary resection and lymph node dissection

were performed. The surgical margins for chest wall resection were defined before a second incision according to the planned resection. The chest wall resection was performed after pulmonary resection.

d. *The Bayarri technique:* A single port incision was made to confirm and identify the chest wall invasion of the tumor.[14] Chest wall invasion was confirmed by direct visualization and dissection. The tumor margins invading the thorax were marked by needles inserted through the skin. The chest wall was resected through those marked sites. Anatomic resection was completed through the single incision allowing an *en-bloc* resection of the tumor with the invaded chest wall.

e. *Robot-assisted chest wall and anatomic lung resection:* The patient was slightly tilted anteriorly in the lateral decubitus position. The surgical table was repositioned at 30° to the perpendicular axis of the room of the surgical robot (da Vinci SI Systems Intuitive Surgical, Sunnyvale, CA, USA). After the camera port was placed through the eighth ICS in the posterior axillary line, other arms were placed with the help of a 30° camera. One arm was placed from the anterior axillary line in the fifth ICS, and the other arm was placed from 8 to 10 cm behind the posterior axillary line in the eighth ICS. The working area was expanded with carbon dioxide (CO_2) insufflation at a pressure of 6 to 8 mmHg and a flow rate of 6 to 10 L/min. ProGrasp™ forceps (Intuitive Inc., CA, USA) were preferred in the robotic left arm, and a Maryland dissector (Intuitive Inc., CA, USA) was selected for the right arm. Spatula was preferred to mark and cauterize the ribs to be resected in both arms, if necessary. After completion of marking of the area to be resected in the chest wall, we performed the anatomical resection first. After completion of the anatomical resection, an appropriate incision was performed of the area planned to be resected.

For pain management, all patients received an epidural catheter before surgery, or muscle and nerve block after induction anesthesia which was administered by the anesthesiologist. All patients also received oral and/or intravenous non-steroidal anti-inflammatory drugs. Medications were gradually reduced during four weeks in accordance with standard of care at the study departments until complete cessation of pain. For pain evaluation, we used an 11-point Numeric Rating Scale.

Perioperative mortality was defined as death occurring within the first 30 days after surgery or during hospitalization for the respective lung resection surgery. An air leak lasting more than seven days was considered prolonged air leak (PAL). Postoperative complications included PAL, pneumonia, atelectasis, insufficient pulmonary expansion of the remaining lung, dyspnea, paradoxical breathing, surgical wound infection, empyema, bronchopleural fistula, and hemorrhage.[15] Other possible complications stated in the consent forms prepared by the Turkish Society of Thoracic Surgery were recorded.[16] A multidisciplinary team re-evaluated patients according to the pathological stage. Adjuvant therapy was recommended for patients with high-risk factors for recurrence.[1]

All patients were followed with thoracic CT every three months following surgery in the first two years. Local recurrence for patients was defined as ipsilateral pleural, hilar, or mediastinal recurrence. Distant recurrence was defined as contralateral lung, mediastinal, or hilar and extrathoracic metastatic disease.[17] Overall survival was defined as the time from surgery to death or the last follow-up.

Statistical analysis

All the statistical analyses were performed using IBM SPSS version 23.0 software (IBM Corp., Armonk, NY, USA). In descriptive statistics, the numerical data were presented as mean ± standard deviation (SD), and the categorical data were presented as numbers and percentages. Overall survival was calculated as the time between the surgery date and the death date or last available follow-up. Survival analysis was performed using the Kaplan-Meier method.

RESULTS

Five (22.7%) patients were administered neoadjuvant chemoradiotherapy (three patients received chemoradiotherapy, and two had chemotherapy). Two (9.1%) patients underwent RATS, while 18 (81.8%) patients and two (9.1%) patients underwent multi-portal and uniportal VATS, respectively. Seventeen (77.2%) patients had upper lobectomy (n=7 left, n=10 right), whereas three (13.6%) patients and two (9.1%) patients underwent lower lobectomy and segmentectomy, respectively. One rib was resected in nine (40.9%), two, three, and four ribs were removed in eight (36.4%), four (18.2%), and one (4.5%) patient, respectively. Chest wall reconstruction was performed in only one patient. The mean operation

Table 1. Pre- and postoperative characteristics of patients

Case	Age/Sex	Surgery	Technique	Neoadjuvant/ Induction treatment	Lung resection	Number of rib resection	Chest wall reconstruction	Operation time	Comp.	Chest drain	Stage	Adjuvant treatment
1	48/M	RATS	No Ad Inc	Cht-RT	RUL	2	No	80	No	2	T3N0M0	Cht
2	69/M	VATS	Hybrid (Bayarri)	No	LUL	1	No	55	No	7	T3N0M0	Cht
3	71/M	VATS	No Ad Inc	No	Seg.	2	No	65	No	5	T3N0M0	No
4	60/F	VATS	Hybrid	No	LUL	3	No	90	PAL	9	T3N0M1	Cht
5	69/M	RATS	Hybrid	Cht-RT	LUL	4	No	140	No	3	T4N0M0	Cht
6	62/M	VATS	Hybrid	No	RUL	2	No	90	PAL/ pneumonia	14	T3N0M0	Cht
7	61/M	VATS	Hybrid	No	RUL	3	No	90	PAL/ pneumonia	14	T4N1M0	Cht
8	67/M	VATS	No Ad Inc	No	RUL	1	No	120	No	3	T3N0M0	No
9	62/M	VATS	No Ad Inc	No	RUL	1	No	100	No	4	T3N0M0	No
10	65/F	VATS	Hybrid	Cht	LLL	2	No	120	No	3	T3N0M0	Cht
11	62/M	VATS	Hybrid	Cht-RT	LUL	2	No	100	No	5	T3N0M0	No
12	58/M	VATS	Hybrid (Uniport)	No	RLL	1	No	105	Pneumonia	12	T3N0M0	No
13	58/F	VATS	Hybrid (Uniport)	No	RUL	1	No	100	No	4	T3N0M0	No
14	57/M	VATS	Hybrid	Cht	LUL	2	No	95	PAL	21	T3NOM1	Cht
15	56/M	VATS	Hybrid	No	RUL	3	No	180	No	3	T3N0M0	Cht
16	75/M	VATS	No Ad Inc	No	LUL	1	No	120	No	4	T3N0M0	No
17	64/M	VATS	No Ad Inc	No	RUL	2	No	160	No	4	T3N0M0	Cht
18	67/M	VATS	No Ad Inc	No	LUL	1	No	90	No	4	T3N0M0	No
19	78/M	VATS	Hybrid	No	RLL	3	No	130	PAL	8	T3N1M0	No
20	67/M	VATS	Hybrid	No	RUL	1	No	140	Hematoma	3	T3N0M0	No
21	55/F	VATS	Hybrid	No	Seg.	1	No	140	No	3	T4N0M0	Cht-RT
22	67/M	VATS	No Ad Inc	No	RUBL	2	Yes	210	No	5	T3N0M0	No

Chest drain: Chest tube drainage time; Comp.: Complications; RATS: Robot-assisted thoracic surgery; No Add Inc: No addition incision; Cht-RT: Chemoradiotherapy; RUL: Right upper lobectomy; Cht: Chemotherapy; VATS: Video-assisted thoracoscopy; LUL: Left upper lobectomy; Seg: Segmentectomy; PAL: Prolonged air leak; LLL: Left lower lobectomy; RLL: Right lower lobectomy; RUBL: Right upper Bi-lobectomy.

time was 114±36.8 (range, 55 to 210) min. Seven patients (31.8%) developed at least one complication. The most frequent complication was PAL which developed in five (22.7%) patients. The median chest tube drainage time was four (range, 2 to 21) days. Median length of hospital stay was five (range, 2 to 14) days. No readmission was necessary for any patients. Paradoxical breathing was not observed during postoperative follow-up in any of patients who did not have chest wall reconstruction. No 30-day mortality was observed. Surgical pathological stage was T3N0M0 in 16 (72.7%) patients, while it was T4N0M0, T4N1 and T3N1 in two (9.1%), one (4.5%), and one (4.5%) patient, respectively. Two patients (9.1%) were at stage T3N0M1. Demographic characteristics of the patients, the surgical data, and results are given in Table 1.

Complete resection was performed in all patients. Eleven patients (50%) received adjuvant chemotherapy/chemoradiotherapy. No patient developed severe chronic pain during a mean follow-up of 24±17.9 (range, 2 to 62) months. The five-year overall survival rate was 55.3%. Only one patient had local recurrence (hilar and ipsilateral mediastinal lymph nodes) at postoperative 16 months. This patient underwent upper lobe posterior and lower lobe superior bisegmentectomy and chest wall resection using the multiport VATS technique without neoadjuvant therapy. Adjuvant therapy was not given to the patient, who was staged as pathological T3N0. None of our patients had recurrence on the chest wall.

DISCUSSION

The standard approach for lung cancer invading chest wall has been thoracotomy for many years.[18] In this study, we showed that minimally invasive *en-bloc* chest wall resection with segmentectomy/lobectomy was safe and feasible. There are controversial issues regarding lung resection and chest wall resection, on which there is no consensus in the literature.[4,18] The ideal length of negative surgical margin has yet to be determined. One to 4 cm of clear margin from tumor has been oncologically accepted. When the tumor invades the parietal pleura, *en-bloc* chest wall resection is recommended.[19] Some authors have advocated parietal pleural resection with the tumor, while chest wall resection seems to provide better survival and lesser recurrence.[20] However, there is no randomized trial on this subject and the evidence supporting chest wall resection needs to be confirmed. If the tumor can be completely dissected with the adjacent parietal pleura, chest wall resection can be spared.[17,19] A chest wall resection is deemed to be necessary, when frozen-section analysis of the surface of the parietal pleura during surgery discloses positive margins.[8,17] A chest wall reconstruction must follow in critical situations following chest wall resection, for not all resection. In general, chest wall defects smaller than 5 cm can be managed without reconstruction. Posterior chest wall defects under the scapula do not necessitate reconstruction, unless the resection would cause scapular tip entrapment.[17,19] The role of neoadjuvant therapy in patients with chest wall invading tumors other than superior sulcus tumors is yet to be identified.[17,19] A Phase II trial concluded that neoadjuvant chemoradiotherapy was safe and increased complete resection rate in patients with tumor invading the chest wall.[21] However, all patients with T3 tumors were advised to have adjuvant chemotherapy after complete resection.[19] We performed complete chest wall resection with a surgical margin of at least 1 cm in all patients. Patients who underwent extrapleural resection were not included in the study. We evaluated all patients for adjuvant chemotherapy after surgery by the multidisciplinary team.

Widmann et al.[5] first reported an *en-bloc* a wedge resection with resection of two ribs to treat primary lung cancer with chest wall invaded via VATS. However, the generally accepted approach is that chest wall invasion is a contraindication for minimally invasive surgery, and thoracotomy should be performed in these patients.[2] On the other hand, chest wall resection has not been accepted as a contraindication for VATS by some others, although relevant data are derived from small case series.[4] The typical features of the cases performed for chest wall resection by VATS in the literature are as follows: most of the tumor is apical and posteriorly, the number of ribs invaded is four ribs or less, chest wall defect is under the scapula, and small tumor size.[13,22] Our cases had similar features. We believe that this surgery can be preferred in patients without mediastinal lymph node metastasis and who are candidates for complete resection with VATS.

There have been different approaches described for VATS chest wall resection:

a. Multiport VATS: Demmy et al.[10] performed multiport VATS chest wall resection in three patients and reported no recurrence in the patients during 6 to 26 months of follow-up. We utilized this approach in five patients in our series. Tumors were located below the scapula in four patients. Another patient had a tumor of 3 cm, located in the upper lobe of the right lung,

invading the chest wall very close to the utility incision. This patient underwent reconstruction after two rib resections with a two-port VATS approach. The necessity of long, small shafted rib-cutters can be deemed as a disadvantage of the method. The main advantage is, however, that it can be done without a larger additional incision. It can be recommended for patients with tumors located behind the scapula, not very close to the vertebra or around the utility incision.

b. *Hybrid:* It was first introduced by Berry et al.[11] It involves an additional incision over the tumor. This incision provides a direct view of tumor and invaded ribs. The chest wall resection can be performed via this additional incision. The authors compared 12 (11%) patients receiving hybrid resection of chest wall and 93 patients who underwent thoracotomy.[11] Seven patients received chest wall reconstruction using synthetic mesh. The complication rate was reported to be 42%. They reported that the hybrid technique was feasible and safe. It was our most preferred approach (54.5%). We prefer it, particularly in cases of Pancoast tumors and requiring disarticulation from paravertebral vertebrae.

c. *Uniport VATS technique:* The method was first described by Gonzales-Rivas et al.[12] We performed this method in two patients in our series. A utility incision was done at the fifth ICS. The chest wall margins of the tumors were delineated with electrocautery followed by a small counter incision performed immediately above the chest wall involvement. Under thoracoscopic guidance and direct vision, the intercostal muscles and neurovascular structures were dissected with an energy-sealing device. It can be performed with standard uniportal VATS instruments.[12,13]

d. *Bayarri Technique:* Bayarri et al.[14] started the procedure with a 1 to 2-cm port incision for VATS exploration of the tumor. After confirmation of chest wall invasion, the tumor site was marked with transthoracic needles inserted from outside. A chest wall resection was performed from the marked site. Lastly, pulmonary resection was performed through this incision via videothoracoscopy. In our series, this technique was used in one patient with a left upper lobe tumor. A lobectomy was performed via the resected chest wall defect after chest wall resection. The main advantage of this method is that it does not require extensive experience of chest wall resection with minimally invasive resection. However, careful preoperative planning is necessary for all patients.

Among the minimally invasive chest wall resection approaches described above, the ideal technique has not yet been defined, and the type of resection depends on the surgeon's experience and the localization of the area where chest wall resection is required. If an additional incision is not made, it is a disadvantage since special tools with long and thin bodies are needed to cut ribs. Recently, such tools have been produced by local and foreign companies and are easier to supply. Although different surgical techniques were used, none of our patients had severe/unmanageable/chronic postoperative pain. It can be speculated that all techniques are effective for the prevention of postoperative pain.

According to the literature data, the potential advantages of minimally invasive chest wall resection are as follows: *(i)* similar oncological outcomes; *(ii)* good postoperative recovery; *(iii)* low complication rates; *(iv)* short hospital stay; and *(v)* less postoperative pain,[4,22] consistent with our results. However, due to the prolonged operation time, small case series and the lack of comparative studies, debates on this issue still continue.

Nonetheless, there are some limitations to this study. First, we described 22 patients operated using five different techniques depending on the multiple operating surgeons in this study. Second, we were unable to compare our results with patients undergoing open surgery. Third, the Cancer and Leukemia Group B defines VATS lobectomy as no use of rib-spreading and a maximum length of 8 cm for the utility incision.[23] The incision length on some of our patients was greater than 8 cm.

In conclusion, our study results show that minimally invasive thoracic surgical resection of chest wall infiltrating tumors can be performed safely using different techniques. However, further comparative clinical trials are needed to evaluate the most optimal method. Based on our findings, minimally invasive thoracoscopic surgery for chest wall invading pulmonary tumors seems to be safe and feasible.

Ethics Committee Approval: The study protocol was approved by the Uludağ University Faculty of Medicine Clinical Research Ethics Committee (date: 27.07.2022, no: 07.2022.15-4). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: This study is retrospective and there was no need to obtain written informed consent from patients.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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