REVIEW PAPER

DOI: https://doi.org/10.5114/kitp.2023.131943

Segmentectomy versus lobectomy. Which factors are decisive for an optimal oncological outcome?

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Kardiochirurgia i Torakochirurgia Polska 2023; 20 (3): 179-186

Abstract

Low-dose computed tomography is being used for lung cancer screening in high-risk groups. Detecting lung cancer at an early stage improves the chance of optimal treatment and increases overall survival. This article compares segmentectomy vs. lobectomy as surgical options, in the case of stage I non-small cell lung carcinoma, ideally IA. To compare the 2 previously referred strategies, data were collected from articles (40 studies were reviewed), reviews, and systematic analyses in PubMed Central, as well as reviewing recent literature. Segmentectomy could be an equal alternative to lobectomy in early-stage NSCLC (tumour < 2 cm). It could be preferred for patients with a low cardiopulmonary reserve, who struggle to survive a lobectomy. As far as early-stage NSCLC is concerned, anatomic segmentectomy is an acceptable procedure in a selective group of patients. For better tumour and stage classification, a systematic lymph node dissection should be performed.

Key words: lobectomy, non-small-cell lung carcinoma, recurrence, overall survival, segmentectomy, disease-free survival.

Introduction

Ginsberg and Rubenstein made the first comparison in 1995 [1] and published the results of a randomized Lung Cancer Study Group (LCSG) trial. They randomized 276 patients with T1N0 non-small cell lung cancer (NSCLC), of whom 247 were eligible for analysis. In detail, 40 patients who underwent wedge resection were randomized to 40 patients who underwent lobectomy, and 82 patients who underwent segmental resection were randomized to 85 patients who underwent lobectomy. The statistical analysis showed that in patients who underwent a sublobar resection, there was an observed 75% increase in the recurrence rate (0.101 versus 0.057), and the overall death rate was 30% higher compared to lobectomy patients. The authors advocated for lobectomy with systematic hilar and mediastinal lymph node (LN) sampling or dissection. However, despite the higher risk of locoregional recurrence, they suggested that sublobar resection should be performed in patients with impaired preoperative pulmonary function, especially in patients with a contralateral pneumonectomy [1].

For several years after this study, lobectomy was the procedure of choice because most thoracic surgeons had been sceptical of segmentectomy and wedge resection. However, the study also received criticism. D' Andrilli *et al.* [2] criticized the selected patients as being more or less under-staged because of non-proper preoperative staging. Furthermore, it is important to note that for tumours smaller than 2 cm, recurrence and death rates were not statistically analysed separately. Additionally, one out of three patients in the sublobar resection group underwent a wedge resection, which may have implications for the adequacy of resection margins and the omission of hi-

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Received: 27.04.2023, **accepted:** 25.06.2023.

lar lymph node dissection in these patients. The authors of this paper suggested a segmentectomy for peripheral tumours smaller than 2 cm that did not affect the intersegmental fissure, and they highlighted that more than one segment could be resected but with a questionable benefit over lobectomy. Finally, they suggested a systematic hilar and mediastinal LN dissection to avoid understaging and to reveal possible occult metastases [2].

Patient selection for segmental resection

Selecting patients for a segmentectomy is currently under discussion. As far as NSCLC is concerned, possible indications include functional parenchyma sparing in multimorbid patients, older age, poor preoperative cardiopulmonary status, small tumours without LN involvement, and multiple synchronous or metachronous tumours. Landreneau *et al.* [3] advocate anatomical segmentectomy in multimorbid patients with a small, peripheral (stage Ia) NSCLC to spare lung function and reduce morbidity. The authors also suggested that segmentectomy should be completed with interlobar, hilar, and mediastinal LN sampling/dissection to avoid under-staging. Similarly, Zeng *et al.* [4] recommend segmentectomy in elderly patients with low cardiopulmonary reserve and comorbidities. The authors highlighted the importance of the number of lymph nodes examined as a prognostic factor in node-negative NSCLC and suggested that more than 7 LNs should be dissected. Additionally, they argue that older age does not dictate segmentectomy.

Bilgi and Swanson [5] underlined that segmentectomy in patients with small tumour size (< 2 cm, Stadium Ia), adequate resection margins, and LN dissection leads to comparable outcomes with lobectomy, while Filosso *et al.* [6] recommended non-anatomic resections, such as wedge resections, for patients with low cardiopulmonary reserves or patients with multiple synchronous or metachronous tumours.

Meacci *et al.* [7] suggested that segmentectomy is indicated for small (< 1 cm) ground glass opacity (GGO) lesions, tumours less than 2 cm in diameter without thoracic lymph node involvement (T1N0), and benign disease, as a lung-sparing procedure. This allows a second or third future surgical resection for a newly diagnosed NSCLC and suggests interventional and non-interventional procedures for intraoperative tumour localization.

Technical issues

The sequence of surgical steps, selection between anatomical resection of a segment or resection of the adjacent segments, identification of difficult-to-resect segments, possible intraoperative pitfalls, and subxiphoid versus intercostal access in the thoracoscopic procedures have been examined. Pham *et al.* [8] examined indications and techniques of frequently performed segmental resections. The authors suggested segmentectomy for resection of primary NSCLC, pulmonary metastases, and benign conditions, such as fungal disease, and underlined that the most commonly performed procedures include lingula sparing upper lobectomy, lingulectomy, superior segmentectomy, and basilar segmentectomy. The authors advise against thoracoscopic segmentectomy if sufficient resection margins cannot be obtained, if a preoperative N2 or N3 situation is present, or if single lung ventilation cannot be achieved. They are also sceptical about T2 tumours, N1 disease, and a history of thoracic irradiation or induction therapy. After ligation of the segmental pulmonary vein, visible hilar LNs adjacent to the segmental bronchus and artery can be removed, and afterward, the segmental bronchus and artery can be stapled. The parenchymal resection should follow the intersegmental fissures, and a systematic mediastinal LN dissection should complete the operation. If the tumour is located close to the intersegmental fissures, a bi- or trisegmentectomy should be performed. In the same direction, Hernandez-Arenas *et al.* [9] have described the surgical technique in uniportal video-assisted thoracoscopic (VATS) segmentectomies. The authors advocate the inflation and deflation method before the final stapling of the segmental bronchus. While the segmental bronchus is clamped, the anaesthetist insufflates the remaining parenchyma. If the remaining segments can expand properly, the selected segment(s) can be removed.

Due to arterial and bronchial anatomy, not all segments can be anatomically resected, as Zheng *et al.* [10] have underlined. The apical right upper segment, posterior segment, dorsal right lower segment, posterior left upper segment plus anterior (inherent upper), and the lingual and left posterior dorsal segments are considered resectable. In contrast, the upper anterior and basilar segments are classified as anatomically challenging to resect.

In general, it is of utmost importance to identify the anatomical structures (vein, artery, bronchus) and the intersegmental planes to perform an anatomical segmentectomy or sublobar anatomical resection. Therefore, administering indocyanine green (ICG) intravenously or with air injection in the segmental bronchus helps identify the intersegmental planes. According to Yotsukura *et al.* [11], ICG might demarcate the intersegmental plane more restricted to the target segment than air. The anatomical and technical aspects of segmentectomy are thoroughly described by Nomori and Okada in their book titled "Illustrated Anatomical Segmentectomy for Lung Cancer" [12].

Operational access and incisions

Regarding surgical access and incisions, Abdellateef *et al.* [13] compared subxiphoid uniportal video-assisted thoracoscopic (SVATS) segmentectomy and intercostal uniportal VATS segmentectomy (UVATS). In the SVATS group the operative time was longer and more blood was lost intraoperatively. However, the postoperative pain score was lower, and the postoperative quality of life score was higher during the first postoperative year. UVATS segmentectomy was found to cost less than SVATS segmentectomy. Regarding postoperative drainage, duration of chest tube, postoperative hospital stay, conversion rate, or postoperative complications, no significant differences were found between the 2 groups. After completion of SVATS and UVATS, the surgical margins were evaluated, and the specimen was sent for frozen section analysis. A lobectomy should be performed if the lesion cannot be palpated or the margins are inadequate. LN sampling from at least 3 N2 stations was also performed. More LNs were sampled in the UVATS group, but more LNs were dissected in the SVATS group. Therefore, SVATS segmentectomy can be a safe surgical option for stage IA NSCLC. However, as the authors have suggested, it should be avoided in the case of a history of cardiac disease or cardiac arrhythmia and patients with left-sided lesions [13]. Segmentectomy indications, as presented by Hirji and Swanson [14], include peripheral T1N0 lesions and, at the same time, low cardiopulmonary reserve, synchronous lung primary tumours, or the possibility for metachronous primary tumours, for instance, following a small contralateral lesion. The authors also suggested that an additional resection of adjacent segments can be performed depending on the spatial location of the tumour.

Effect on pulmonary function

As previously stated, segmental resection has been considered a surgical option in patients with impaired cardiopulmonary reserve. Postoperative changes in pulmonary function values after segmentectomy and lobectomy have been assessed in studies presented subsequently. Donington *et al.* [15] favour lobectomy with systematic mediastinal LN evaluation as the gold standard for stage I NSCLC. However, they stated that one in four patients with stage I NSCLC are not eligible for lobectomy because they are multimorbid. If lobectomy cannot be tolerated, sublobar resection followed by adjuvant intraoperative brachytherapy, in order to reduce recurrence in the involved lobe, can be an alternative. Bedat *et al.* [16] compared postoperative complications between VATS lobectomy and VATS segmentectomy. Minor or major complications appeared in 33.3% of segmentectomies and 38% of lobectomies. The complications and severity rate correlated with American Society of Anesthesiologists (ASA) score, presence of chronic obstructive pulmonary disease (COPD), decreased forced expiratory volume (FEV_1), and diffusing capacity of the lung for carbon monoxide (DLCO). The length of hospital stay and drainage duration were shorter after segmentectomy. Segmentectomy preserves lung function better than lobectomy because the function of the ipsilateral non-operated lobe is increased. However, this type of operation is more technically demanding, requiring more extensive and deeper dissection into the hilum and division of intersegmental planes. Using staplers to divide intersegmental planes can induce compression of the adjacent parenchyma, atelectasis, and pneumonia of the non-operated lobe, possibly more often in patients with COPD. Dissection of hilar and mediastinal LN was performed in both procedures, but systematic LN dissection was more often performed in lobectomy patients.

Factors that predict recurrence

Rami-Porta *et al.* [17] suggested that complete resection is linked to free-of-tumour margins, proven microscopically and systematically, or lobe-specific systematic LN dissection without tumour extension outside the nodal capsule. If the highest mediastinal LN dissected is positive, if there is carcinoma in situ at the bronchial margin, even though there is no residual tumour macroscopically, or if pleural lavage cytology is positive, the resection is considered incomplete. In the same direction, Schuchert *et al.* [18] showed that the factors influencing recurrence in stage I NSCLC include increased size and grade, vessel and LN invasion, and decreased tumour inflammation. The authors suggested that the risk of overall complications is lower in segmentectomy. In this study, the risk of recurrence did not differ statistically between segmentectomy and lobectomy, as resection margins were examined intraoperatively and found to be adequate. The suggested margin-to-tumour ratio should be higher than one. If this condition cannot be fulfilled, the operation must be converted to lobectomy.

Sawabata *et al.* [19] evaluated the presence of malignancy in resection margins. In the negative malignancy sample (61% of total) group, the maximum tumour diameter was smaller, the margin distance was bigger, lesions were located in easily resected parenchyma regions, and more often only stapling was required. This study presented maximum tumour diameter and margin distance as independent factors of recurrence. Margin distance higher than 2 cm and margin distance greater than maximum tumour diameter has led to surgical margins negative for malignancy in 100% of cases in this study and was considered to prevent local recurrence.

Ensuring sufficient resection margins might be associated with the exact tumour location. Sato *et al.* [20] suggested virtual-assisted lung mapping as a technique that aids in identifying the location of lesions in the lung parenchyma. Indigo carmine was injected into the targeted bronchus under bronchoscopic guidance to mark the tumour's location. This technique was used to identify and resect 209 lesions, including mixed and pure ground glass nodules and solid nodules. Consequently, 190 of 209 lesions were identified, and 178 were successfully resected. The authors concluded that their technique could target lung lesions. However, the successful resection rate did not reach their primary goal. It underlined that insufficient depth of resection margin is the main reason for unsuccessful removal of the lesion.

Okada *et al.* [21] analysed the 5- and 10-year survival rates in the case of segmentectomy and lobectomy for tumours < 2 cm and > 2 cm. If the tumour size was smaller than 2 cm, the 5-year survival rate was 83% for segmentectomy and 81% for lobectomy, and the 10-year survival rate was 83% and 64%, respectively. In the case of tumours larger than 2 cm, the 5-year survival rate was 58% for segmentectomy and 78% for lobectomy, and the 10-year survival rate was 58% and 60%, respectively. The authors suggested that histological type and tumour size could determine if an intentional segmentectomy or an intentional lobectomy is performed, and that segmentectomy should be performed in NSCLC stage IA. In the same direction, Zheng *et al.* [10] compared patients treated with segmentectomy and lobectomy. Age, sex, pulmonary function, tumour size, local recurrence, the incidence of postoperative complications, 5-year OS, and DFS did not differ significantly among the 2 groups. The authors suggested that tumour size is an independent prognostic factor of disease-free survival (DFS) in stage IA NSCLC (≤ 2 cm) and advocated segmentectomy with resection margins ≥ 2 cm in this group of patients.

Baig *et al.* [22] studied survival differences between segmentectomy and lobectomy. Lobectomy was associated with improved 5-year survival. Adenocarcinoma histology and the number of sampled LNs had a favourable effect on survival, while age and male sex were linked to worse survival outcomes. Interestingly, married status was associated with better survival. Neuroendocrine tumours were associated with worse survival after wedge resection or segmentectomy than after lobectomy. Small (≤ 2 cm) peripheral but high-grade tumours are linked to better survival after lobectomy than segmentectomy. In addition, in this study, it was demonstrated that lobectomy is preferred over segmentectomy in young patients with aggressive tumour histology and clinical N1/N2 disease, as the risk of developing metachronous, recurrent, or second primary lung cancer is estimated at 1–2% per year. Therefore, the authors advocate appropriate patient selection in both segmentectomy and lobectomy.

Nodal status

Histologically positive nodal status is linked to a higher possibility of recurrence, especially in inaccurate nodal staging. Detection of metastatic hilar or mediastinal LNs, which are thought to be disease-free, has been described as nodal upstaging after surgery for NSCLC during the final histopathological evaluation. According to the Cancer and Leukaemia group B prospective clinical trial, nodal upstaging occurs in 28% of clinical stage I patients (CALGB 9761). Positive hilar and mediastinal LN can be detected radiologically through a chest computed tomography (CT) or positron emission tomography (PET) scan and proven/verified through mediastinoscopy, endobronchial ultrasound (EBUS), or VATS.

Inaccurate nodal staging might occur in patients with tuberculosis, rheumatoid arthritis, and diabetes mellitus, as stated by Toker *et al.* [23]. In these cases, especially interlobar LNs are closely attached to the pulmonary artery and its branches, and therefore dissection is more challenging. Van Schil *et al.* [24] stated that patients with ipsilateral hilar or intrapulmonary lymph-node metastases (N1) should be treated with a combination of surgery and adjuvant chemotherapy, and patients with ipsilateral mediastinal lymph-node metastases (N2) should primarily be treated with chemoradiation. If downstaging takes place after induction therapy, surgery becomes an option. Patients with contralateral mediastinal or supraclavicular lymph node involvement (N3) are not treated surgically because of poor prognosis. However, cases of possible curative concepts after a successful neoadjuvant therapy have been described.

Regarding suspicious lymph nodes, 28% of patients with N2 disease were diagnosed by mediastinoscopy, although EBUS was negative. National Comprehensive Cancer Network (NCCN) guidelines refer to the results of the ACOSOG Z0030 randomized trial that compared mediastinal LN sampling versus total LN dissection in N0 (no demonstratable metastasis to regional LN) or N1 (ipsilateral peribronchial and hilar region metastasis) NSCLC patients [25]. The trial did not show an additional survival benefit of total mediastinal LN resection over systematic LN sampling in patients with early NSCLC and negative nodes (in the frozen section) in systematic sampling. For right-sided cancers, NCCN guidelines propose sampling of stations 2R, 4R, 7, 8, and 9, whereas for left-sided cancers, sampling of 4L, 5, 6, 7, 8, and 9 stations is suggested. At least 3 mediastinal LN stations should be sampled. In the case of suspected nodal disease, the NCCN additionally suggests EBUS for 2R/2L, 4R/4L, 7, and 10R/10L station biopsies, and EUS for 5,7,8, and 9 station biopsies, and mediastinoscopy in the case of the positive mediastinal nodes in PET and/or CT, but negative in EBUS. NCCN guidelines conclude that surgical strategy in early-stage (IA and IB) patients should involve tumour resection, adjacent tissue exploration, and mediastinal LN dissection or sampling. If LNs positive for disease are found, radiation therapy or chemotherapy are options depending on the disease stage [25].

ESTS recommends CT, PET scan, and endoscopic ultrasound (EUS) or EBUS over surgical staging as the initial procedure as far as mediastinal nodal staging is concerned [26]. If EUS/EBUS does not reveal nodal involvement, surgical staging via mediastinoscopy is suggested as the next step. Surgeons are advised to assess mediastinal and hilar nodal stations and to sample at least 3 different nodal stations (4R, 4L, 7) if CT and/or PET show nodal involvement [26]. American College of Chest Physicians (ACCP) guidelines underline that NSCLC resection should include at least lymph node sampling [27]. In stages I and II, mediastinal lymph node sampling or dissection at the time of anatomic resection is suggested over selective or no sampling for accurate pathologic staging. In the case of anatomic resection for stage I disease in patients who have undergone hilar and mediastinal lymph node staging (intraoperative N0 status), completion of the procedure with a mediastinal lymph node dissection does not provide a survival benefit. Conversely, in patients with stage II NSCLC undergoing anatomic resection, mediastinal lymph node dissection may provide additional survival benefits over mediastinal LN sampling. Darling *et al.* [25] explain in detail how mediastinal lymph node dissection (LND) is performed and prove that in cases of early-stage NSCLC, if mediastinal and hilar nodes at LN sampling are negative, mediastinal lymph node dissection does not improve survival. For right-sided tumours, LN stations 2R (upper paratracheal) and 4R (lower paratracheal) between the right upper lobe bronchus, innominate artery, superior vena cava, and trachea should be removed. If the tumour is left-sided, LNs between the phrenic and vagus nerves up to the left main stem bronchus should be removed (stations 5 and 6). LNs of the aortopulmonary window should also be removed without damaging the recurrent nerve. Also, subcarinal nodes adjacent to the carina, right, and left main bronchi are removed (station 7). Lymph nodes from stations 8 (paraesophageal) and 9 (inferior pulmonary ligament) are extracted. Finally, at the end of the procedure, the main bronchi, posterior pericardium, and oesophagus should lack lymphatic tissue. The preoperative mediastinal evaluation involves identifying mediastinal LN ≥ 1 cm in the short axis in a CT scan or increased uptake in an 18F-Fluordesoxyglucose (FDG) PET scan. These LNs are intraoperatively biopsied. Lackey and Donington [28] present cervical mediastinoscopy and anterior mediastinotomy (Chamberlain procedure) as procedures used to evaluate N2 disease, especially in patients with large tumours, central tumours, PET avidity in the ipsilateral hilum, or bilateral synchronous primary tumours. The authors advocate systematic mediastinal LN sampling. Lopez Guerra *et al.* [29] suggest that harvesting more than 6 LNs during surgery leads to the observation of more nodal metastases in the examination at the pathology laboratory and significantly higher 3-year RFS than when harvesting less than 6 LNs during surgery, while Osarogiagbon *et al.* [30] state that the lowest mortality risk occurs in dissecting and examining 18–21 LNs. If LN status is inadequately examined, there is a high risk of underestimating long-term mortality and ignoring candidates for postoperative adjuvant therapy. In that case, a corrective intervention is suggested.

Lobectomy was associated with better overall survival (OS) and disease-free survival (DFS), as Wang *et al.* [31] demonstrated. Regarding OS, bilateral mediastinal lymphadenectomy (BML) is superior to systematic nodal dissection (SND) and lobe-specific systematic node dissection (L-SND), which have an advantage over systematic nodal sampling (SNS) or selected lymph node biopsy (SLNB). Regarding DFS, BML or SND have been proven to be superior to LSND, SNS, or SLNB. After propensity score matched (PSM) comparative analysis the authors concluded that lobectomy with SND, compared with lobectomy with SNS or SLNB, resulted in more favourable OS and DFS. However, there was no survival benefit in different types of lymph node resection in sublobar resection. LN involvement in any tumour size, metastasis, and micrometastasis could be missed in the case of sublobar resection or inadequate LN resection. It was proven that SND stages NSCLC more accurately because all possible metastatic tissue is resected, and BML aids most in examining the nodal status [31].

Fan *et al.* [32] are sceptical about segmentectomy, and instead they advocate lobectomy. In this study, lobectomy and segmentectomy presented higher conditional survival rates (CSR) than wedge resection. CSR in segmentectomy is lower if the tumour grade is higher. Additionally, CSR in segmentectomy is lower than CSR in lobectomy for the first 2 years but becomes higher after the third year. The authors have attributed this difference in CSR to inadequate hilar LN resection and, therefore, tumour under-staging, recurrence, and metastasis in the case of segmentectomy. In this study, male patients younger than 65 years-old and grade I NSCLC who underwent segmentectomy presented comparable CSR compared to the group of patients with similar demographic characteristics who underwent lobectomy. However patients with adenocarcinoma and female patients who underwent segmentectomy presented lower CSR in the early postoperative period compared to the group which underwent lobectomy respectively. Therefore, the authors concluded that age, sex, tumour histological features, and type of operation can affect the OS [32].

Qu *et al.* [33] presented segmentectomy with proper, thorough lymph node dissection or sampling as an excellent alternative to lobectomy. In segmentectomy, fewer LNs are typically dissected than in lobectomy, which may lead to higher recurrence. In segmentectomy, removing more than 3 regional LN stations is technically challenging. Conversely, in lobectomy, more than 3 regional stations of LNs are typically removed. A higher number of resected LNs is linked to more accurate staging and fewer cases of false negative stage I NSCLC. Khullar *et al.* [34] concluded that the median OS for lobectomy, segmentectomy, and wedge resection was at 100, 74, and 68 months, respectively. They explained that patients treated with sublobar resection were more likely to have inadequate LN resection (< 3 LNs) and positive tumour resection margins. Al-Shahrabani *et al.* [35] advocate lobectomy with mediastinal lymph node dissection (MLND) or systematic lymph node sampling (SLNS) in operable patients. MLND or SLNS stage disease more accurately, but studies have shown that MLND reduces local and systemic recurrence significantly because it stages disease more accurately than SLNS and aids thorough examination of LNs and detection of skip metastasis and micrometastasis. The authors of this paper also state that the improved outcome after MLND might be attributed to the Will Rogers phenomenon [36] by some researchers. In detail, technological advances are responsible for high sensitivity in tumour spread, stage migration, and survival improvement. In the same paper, sublobar resection in early-stage NSCLC in patients with low cardiopulmonary reserve, tumour size < 2 cm, N0 LN status, and free resection margins in the frozen section are suggested. The oncological outcome and efficacy of LN dissection in thoracoscopic segmentectomy are comparable to thoracoscopic lobectomy, as presented by Shapiro *et al.* [37]. Additionally, Zheng *et al.* [10] concluded that in the case of stage I NSCLC, VATS segmentectomy is safe and effective and can be used to remove 1 or 2 segments. At the same time, systematic LN dissection, including peribronchial, segmental, and subsegmental (12, 13, 14 stations), can also be performed by VATS segmentectomy.

Okada *et al.* [21] present extended segmentectomy as an alternative for patients with cT1N0M0 non-small cell lung cancer of 2 cm or less. Extended resection includes the removal of both the affected segment and adjacent subsegments and exploring mediastinal and hilar lymph nodes, which were examined pathologically as intraoperative frozen sections. If the intraoperative frozen section proves LN involvement, the procedure should be converted to lobectomy with complete hilar LN dissection to resect possible satellite lesions and involved LN. According to the author, intrapulmonary metastases or involved interlobar nodes (1.4% possibility) at the segment with the primary tumour might be hidden in the remaining lung parenchyma [21].

Effect on survival

According to Villamizar et al. [38], preserving lung function through limited resections should certainly be considered in elderly patients, in patients with compromised cardiopulmonary status, and in cases of synchronous or metachronous cancers which may require multiple resections over the years, as these patient groups could potentially benefit from the preservation of lung parenchyma in terms of survival and quality of life. The likelihood of a second primary cancer occurring is 3% per year. If a patient survives 5 or more years after the first operation, there is a 9% risk for second cancer. The authors have suggested that lobectomy is associated with a lower recurrence rate and longer disease-free interval, and that LN metastasis in case of clinical Stage IA NSCLC can occur in 10% of patients, attributing this to possible infiltration by cancer cells of station 13 LNs of segments adjacent to the resected segment. Koike *et al.* [39] showed that 5-year OS and DFS rates are not significantly different between lobectomy and limited resection. However, median postoperative/preoperative FEV_1 and postoperative/preoperative FVC ratios were significantly higher in the limited resection group. Therefore, the authors concluded that both procedures have similar oncologic outcomes, but if limited resection is performed, postoperative lung function is better preserved. The survival advantage of lobectomy over segmentectomy for tumours greater than 3 cm was presented by Koike *et al.* [40]. The authors reported that locoregional recurrence after segmentectomy was found in 22.7% of patients versus 4.9% after lobectomy, and therefore follow-up of these patients is highly suggested. Deng *et al.* [41] found that segmentectomy and lobectomy present comparable hospital stays, mean OS, and DFS time in T1a NSCLC. However, lobectomy has a slight advantage over segmentectomy regarding OS and DFS in T1b NSCLC. Both procedures were completed by mediastinal lymphadenectomy. The authors found that the impact of PET did not differ significantly after segmentectomy or lobectomy, suggesting that lobectomy with mediastinal lymphadenectomy should be performed in patients with stage IA NSCLC, especially in T1b cases. Lobectomy is preferred for large or right-sided tumours, high maximum standardized uptake value (SUV_{max}), tumours invading lymphatic, vascular, or pleural structures, and lymph node metastasis, according to Okada *et al.* [21]. Three-year recurrence-free survival (RFS) was higher after segmentectomy than lobectomy, but the 3-year OS did not significantly differ. In PSM analysis, 3-year OS and RFS after segmentectomy and lobectomy were comparable. Therefore, the authors advocate segmentectomy in clinical stage IA NSCLC, even in low-risk patients.

On the other hand, Liu *et al.* [42] performed a meta-analysis and concluded that sublobar resection (wedge resection and segmentectomy) is linked to lower OS than lobectomy in stage IA NSCLC patients. Additionally, according to the same meta-analysis, OS in the case of segmentectomy is also lower than in lobectomy. Liang *et al.* [43] compared actuarial cancer-specific survival (ACS) rates and conditional cancer-specific survival (CCS) rates linked to lobectomy, sublobar resection, radiation, and observation in a retrospective study of 27,116 patients with stage I NSCLC. The ACS rate in lobectomy decreased from 86.9% (3^{rd} year) to 73.6% (8^{th} year), while the CCS rate increased from 86.9% (3^{rd} year) to 91.7% (8^{th} year). The ACS rate in sublobar resection decreased from 80.8% (3^{rd} year) to 62.2% (8^{th} year), and CCS increased from 80.8% to 86.4%. The smallest increase in CCS3 among the 4 groups was noted in the lobectomy group because ACS decreased at the slowest rate in this group. The ACS rate in patients who did not receive treatment decreased sharply. After PSM, the authors concluded that lobectomy shows an advantage regarding survival, especially if healthy patients are selected, enough lymph nodes are dissected, and improved technology is used [43].

Present and future

The JCOG0802 study [44] was the first randomized, controlled, non-inferiority trial at 70 institutions in Japan that showed at least non-inferiority of segmentectomies vs. lobectomies for clinical stages of IA NSCLC tumours. The results were compared among 1006 patients who had undergone a segmentectomy (n = 552) vs. a lobectomy (n = 554) for a clinical stage IA NSCLC. This study demonstrated a better 5-year OS for the segmentectomy group (94.3%) vs. 91.1% for the lobectomy group. However, the local relapse was almost 2 times higher for the segmentectomy group (10.5%) and 5.4% for lobectomy. Nevertheless, this first high-volume study suggests that segmentectomy should be the standard surgical procedure for clinical stages of IA NSCLC tumours. Another interesting study from Altorki *et al.* [45] compared lobectomy with sublobar resection in patients with clinical stage IA NSCLC with a tumour size of 2 cm or less, showing a non-inferiority of sublobar resection regarding 5-year DFS (disease-free survival) and OS in comparison to the lobectomy group after a median follow-up of 7 years.

Moreover, 3D modelling techniques, such as Visible Patient and Synapse 3D, have revolutionized preoperative planning and intraoperative guidance for segmentectomy. These advanced imaging technologies allow for the creation of highly accurate and detailed 3-dimensional representations of the patient's anatomy, facilitating a better understanding of complex pulmonary segmental structures. Surgeons can use these models to precisely identify intersegmental planes, evaluate vascular and bronchial anatomy, and simulate surgical resection strategies. This enhanced visualization aids in optimizing surgical outcomes and minimizing the risk of complications during segmentectomy procedures.

Furthermore, robotic surgery has emerged as a valuable tool in performing segmentectomy with increased precision and dexterity. The da Vinci Surgical System and other robotic platforms offer enhanced visualization, ergonomic advantages, and fine instrument control. Robotic-assisted segmentectomy enables surgeons to access challenging anatomical locations with improved manoeuvrability and range of motion. This approach enhances the surgeon's ability to navigate within the pulmonary parenchyma, facilitates meticulous dissection of vessels and bronchi, and promotes accurate reconstruction of the lung parenchyma. Robotic segmentectomy has demonstrated promising results, including reduced blood loss, shorter hospital stays, and faster postoperative recovery.

These advancements represent significant strides towards personalized surgical approaches, improved patient outcomes, and refined surgical techniques.

Conclusions

Segmentectomy can be performed for older and/or multimorbid patients as a parenchyma-sparing procedure for small (≤ 2 cm) peripheral tumours without LN involvement and synchronous or metachronous tumours. Additionally, segmental resection can be performed for GGO lesions ≤ 1 cm and histologically confirmed benign tumours. Segmental resection is technically challenging due to arterial and bronchial anatomy. If sufficient resection margins cannot be obtained, for instance when the tumour invades the intersegmental plane or if anatomic variations complicate the operation, a bi- or trisegmentectomy can be performed. Both thoracoscopic intercostal and subxiphoid access could be used depending on the tumour location and surgeons' experience.

Segmental resection can be performed to preserve pulmonary function, but special attention is needed to avoid technical pitfalls. The proper patient selection for this procedure is of utmost importance. Factors associated with recurrence are macro- and microscopic malignant infiltration of resection margins, extracapsular extension, LN involvement, and low differentiation grade. Ensuring a margin to tumour ratio higher than 1 and sufficient LN dissection/sampling are crucial. Otherwise, conversion of segmental to lobar resection is mandatory according to oncological principles. Careful assessment of nodal status is linked with a lower possibility of recurrence because understaging can be avoided. Hilar and mediastinal dissection/sampling is suggested. Mediastinal sampling should be completed by sampling at least 3 LN stations, but always the subcarinal LNs. Systematic dissection aids a more thorough nodal examination than systematic sampling because of the detection of skip metastasis and micrometastasis. However, NCCN, ESTS, and ACCP guidelines have not excluded systematic sampling. Finally, sublobar resection shows similar OS and DFS rates to lobectomy in selected patients.

Disclosure

The authors report no conflict of interest.

References

1. Ginsberg RJ, Rubinstein LV. Randomized trial of lobectomy versus limited resection for T1 N0 non-small cell lung cancer. Lung Cancer Study Group. Ann Thorac Surg 1995; 60: 615-622.
2. D'Andrilli A, Rendina EA. POINT: should segmentectomy rather than lobectomy be the operation of choice for early-stage-non-small cell lung cancer? Yes. Chest 2018; 153: 590-592.
3. Landreneau RJ, Schuchert MJ. Is segmentectomy the future? J Thorac Dis 2019; 11: 308-318.
4. Zeng W, Zhang W, Zhang J, You G, Mao Y, Xu J, Yu D, Peng J, Wei Y. Systematic review and meta-analysis of video-assisted thoracoscopic surgery segmentectomy versus lobectomy for stage I non-small cell lung cancer. World J Surg Oncol 2020; 18: 44.
5. Bilgi Z, Swanson SJ. Current indications and outcomes for thoracoscopic segmentectomy for early-stage lung cancer. J Thorac Dis 2019; 11: S1662-S1669.
6. Filosso PL, Sandri A, Oliaro A, Filippi AR, Cassinis MC, Ricardi U, Lausi PO, Asioli S, Ruffini E. Emerging treatment options in the management of non-small cell lung cancer. Lung Cancer (Auckl) 2011; 2: 11-28.
7. Meacci E, Nachira D, Zanfrini E, Triumbari EKA, Iaffaldano AG, Congedo MT, Ciavarella LP, Pogliani L, Chiappetta M, Porziella V, Gonzalez-Rivas D, Vita ML, Margaritora S. Uniportal VATS approach to sub-lobar anatomic resections: literature review and personal experience. J Thorac Dis 2020; 12: 3376-3389.
8. Pham D, Balderson S, D'Amico TA. Technique of thoracoscopic segmentectomy. Oper Techn Thorac Cardiovasc Surg 2008; 13: 188-203.
9. Hernandez-Arenas LA, Purmessur RD, Gonzalez-Rivas D. Uniportal video-assisted thoracoscopic segmentectomy. J Thorac Dis 2018; 10: S1205-S1214.
10. Zheng YZ, Zhai WY, Zhao J, Luo RX, Gu WJ, Fu SS, Wu D, Yuan LX, Jiang W, Tsutani Y, Liao HY, Li XQ. Oncologic outcomes of lobectomy vs. segmentectomy in non-small cell lung cancer with clinical T1N0M0 stage: a literature review and meta-analysis. J Thorac Dis 2020; 12: 3178-3187.
11. Yotsukura M, Okubo Y, Yoshida Y, Nakagawa K, Watanabe SI. Indocyanine green imaging for pulmonary segmentectomy. JTCVS Tech 2021; 6: 151-158.
12. Nomori H, Okada M. Segmentectomy of the right lower lobe. In: Illustrated Anatomical Segmentectomy for Lung Cancer. Springer Japan, Tokyo 2016.
13. Abdellateef A, Ma X, Chen Z, Wu L, Cai J, Jiang L. Subxiphoid uniportal thoracoscopic pulmonary segmentectomy for stage I non-small cell lung cancer: Feasibility, quality of life and financial worthiness. Thorac Cancer 2020; 11: 1414-1422.
14. Hirji SA, Swanson SJ. T1a lung carcinoma: the place of segmentectomy in the treatment array. J Thorac Dis 2018; 10: S1151-S1156.
15. Donington J, Ferguson M, Mazzone P, Handy J, Schuchert M, Fernando H, Loo Jr B, Lanuti M, de Hoyos A, Detterbeck F, Pennathur A, Howington J, Landreneau R, Silvestri G; Thoracic Oncology Network of the American College of Chest Physicians and the Workforce on Evidence-Based Surgery of the Society of Thoracic Surgeons. American College of Chest Physicians and Society of Thoracic Surgeons consensus statement for evaluation and management for high-risk patients with stage I non-small cell lung cancer. Chest 2012; 142: 1620-1635.
16. Bédat B, Abdelnour-Berchtold E, Perneger T, Licker MJ, Stefani A, Krull M, Perentes JY, Krueger T, Triponez F, Karenovics W, Gonzalez M. Comparison of postoperative complications between segmentectomy and lobectomy by video-assisted thoracic surgery: a multicenter study. J Cardiothorac Surg 2019; 14: 189.
17. Rami-Porta R, Wittekind C, Goldstraw P. Complete resection in lung cancer surgery: proposed definition. Lung Cancer 2005; 49: 25-33.
18. Schuchert MJ, Normolle DP, Awais O, Pennathur A, Wilson DO, Luketich JD, Landreneau RJ. Factors influencing recurrence following anatomic lung resection for clinical stage I non-small cell lung cancer. Lung Cancer 2019; 128: 145-151.
19. Sawabata N, Miyaoka E, Asamura H, Nakanishi Y, Eguchi K, Mori M, Nomori H, Fujii Y, Okumura M, Yokoi K; Japanese Joint Committee for Lung Cancer Registration. Japanese lung cancer registry study of 11,663 surgical cases in 2004: demographic and prognosis changes over decade. J Thorac Oncol 2011; 6: 1229-1235.
20. Sato M, Kobayashi M, Kojima F, Tanaka F, Yanagiya M, Kosaka S, Fukai R, Nakajima J. Effect of virtual-assisted lung mapping in the acquisition of surgical margins in sublobar lung resection. J Thorac Cardiovasc Surg 2018; 156: 1691-1701.e5.

21. Okada M, Mimae T, Tsutani Y, Nakayama H, Okumura S, Yoshimura M, Miyata Y. Segmentectomy versus lobectomy for clinical stage IA lung adenocarcinoma. Ann Cardiothorac Surg 2014; 3: 153-159.
22. Baig MZ, Razi SS, Weber JF, Connery CP, Bhora FY. Lobectomy is superior to segmentectomy for peripheral high-grade non-small cell lung cancer ≤ 2 cm. J Thorac Dis 2020; 12: 5925-5933.
23. Toker A, Özyurtkan MO, Kaba E. Nodal upstaging: effects of instrumentation and three-dimensional view in clinical stage I lung cancer. J Vis Surg 2017; 3: 76.
24. van Schil PE, Balduyck B, Waele M de, Hendriks JM, Hertoghs M, Lauwers P. Surgical treatment of early-stage non-small-cell lung cancer. EJC Suppl 2013; 11: 110-122.
25. Darling GE, Allen MS, Decker PA, Ballman K, Malthaner RA, Inculet RI, Jones DR, McKenna RJ, Landreneau RJ, Rusch VW, Putnam JB Jr. Randomized trial of mediastinal lymph node sampling versus complete lymphadenectomy during pulmonary resection in the patient with N0 or N1 (less than hilar) non-small cell carcinoma: results of the American College of Surgery Oncology Group Z0030 Trial. J Thorac Cardiovasc Surg 2011; 141: 662-670.
26. De Leyn P, Dooms C, Kuzdzal J, Lardinois D, Passlick B, Rami-Porta R, Turna A, Van Schil P, Venuta F, Waller D, Weder W, Zielinski M. Revised ESTS guidelines for preoperative mediastinal lymph node staging for non-small-cell lung cancer. Eur J Cardiothorac Surg 2014; 45: 787-798.
27. Yang CJ, Veeramachaneni N, Hurd J, Potter AL, Zheng L, Teman N, Blair S, Martin LW. A national survey of surgeons evaluating the accuracy of mediastinal lymph node identification. Clin Lung Cancer 2023; 24: 445-452.
28. Lackey A, Donington JS. Surgical management of lung cancer. Semin Intervent Radiol 2013; 30: 133-140.
29. Lopez Guerra JL, Gomez DR, Lin SH, Levy LB, Zhuang Y, Komaki R, Jaen J, Vaporciyan AA, Swisher SG, Cox JD, Liao Z, Rice DC. Risk factors for local and regional recurrence in patients with resected N0-N1 non-small-cell lung cancer, with implications for patient selection for adjuvant radiation therapy. Ann Oncol 2013; 24: 67-74.
30. Osarogiagbon RU, Ogbata O, Yu X. Number of lymph nodes associated with maximal reduction of long-term mortality risk in pathologic node-negative non-small cell lung cancer. Ann Thorac Surg 2014; 97: 385-393.
31. Wang W, Chen D, Xi K, Chen Y, Zhang X, Wen Y, Huang Z, Yu X, Wang G, Zhang R, Zhang L. Impact of different types of lymphadenectomy combined with different extents of tumor resection on survival outcomes of stage I non-small-cell lung cancer: a large-cohort real-world study. Front Oncol 2019; 9: 642.
32. Fan X, Liang Y, Bai Y, Yang C, Xu S. Conditional survival rate estimates of lobectomy, segmentectomy and wedge resection for stage IA1 non-small cell lung cancer: a population-based study. Oncol Lett 2020; 20: 1607-1618.
33. Qu X, Wang K, Zhang T, Shen H, Dong W, Liu Q, Du J. Long-term outcomes of stage I NSCLC (≤3 cm) patients following segmentectomy are equivalent to lobectomy under analogous extent of lymph node removal: a PSM based analysis. J Thorac Dis 2017; 9: 4561-4573.
34. Khullar OV, Liu Y, Gillespie T, Higgins KA, Ramalingam S, Lipscomb J, Fernandez FG. Survival after sublobar resection versus lobectomy for clinical stage ia lung cancer: an analysis from the national cancer data base. J Thorac Oncol 2015; 10: 1625-1633.
35. Al-Shahrabani F, Vallböhmer D, Angenendt S, Knoefel WT. Surgical strategies in the therapy of non-small cell lung cancer. World J Clin Oncol 2014; 5: 595-603.
36. Feinstein AR, Sosin DM, Wells CK. The Will Rogers phenomenon. Stage migration and new diagnostic techniques as a source of misleading statistics for survival in cancer. N Engl J Med 1985; 312: 1604-1608.
37. Shapiro M, Weiser TS, Wisnivesky JP, Chin C, Arustamyan M, Swanson SJ. Thoracoscopic segmentectomy compares favorably with thoracoscopic lobectomy for patients with small-stage I lung cancer. J Thorac Cardiovasc Surg 2009; 137: 1388-1393.
38. Villamizar N, Swanson SJ. Lobectomy vs. segmentectomy for NSCLC (T<2 cm). Ann Cardiothorac Surg 2014; 3: 160-166.
39. Koike T, Koike T, Sato S, Hashimoto T, Aoki T, Yoshiya K, Yamato Y, Watanabe T, Akazawa K, Toyabe SI, Tsuchida M; Niigata Chest Surgery Research Group. Lobectomy and limited resection in small-sized peripheral non-small cell lung cancer. J Thorac Dis 2016; 8: 3265-3274.
40. Koike T, Koike T, Yoshiya K, Tsuchida M, Toyabe SI. Risk factor analysis of locoregional recurrence after sublobar resection in patients with clinical stage IA non-small cell lung cancer. J Thorac Cardiovasc Surg 2013; 146: 372-378.
41. Deng B, Cassivi SD, Andrade M de, Nichols FC, Trastek VF, Wang Y, Wampfler JA, Stoddard SM, Wigle DA, Shen RK, Allen MS, Deschamps Cl, Yang P. Clinical outcomes and changes in lung function after segmentectomy versus lobectomy for lung cancer cases. J Thorac Cardiovasc Surg 2014; 148: 1186-1192.e3.
42. Liu Y, Huang C, Liu H, Chen Y, Li S. Sublobectomy versus lobectomy for stage IA (T1a) non-small-cell lung cancer: a meta-analysis study. World J Surg Oncol 2014; 12: 138.
43. Liang Y, Fan X, Bai Y, Huang D, Yang C. Conditional survival analysis of four treatment strategies for patients with stage I non-small cell lung cancer. Oncol Lett 2019; 18: 1089-1098.
44. Saji H, Okada M, Tsuboi M, Nakajima R, Suzuki K, Aokage K, Aoki T, Okami J, Yoshino I, Ito H, Okumura N, Yamaguchi M, Ikeda N, Wakabayashi M, Nakamura K, Fukuda H, Nakamura S, Mitsudomi T, Watanabe SI, Asamura H; West Japan Oncology Group and Japan Clinical Oncology Group. Segmentectomy versus lobectomy in small-sized peripheral non-small-cell lung cancer (JCOG0802/WJOG4607L): a multicentre, open-label, phase 3, randomised, controlled, non-inferiority trial. Lancet 2022; 399: 1607-1617.
45. Altorki N, Wang X, Kozono D, Watt C, Landrenau R, Wigle D, Port J, Jones DR, Conti M, Ashrafi AS, Liberman M, Yasufuku K, Yang S, Mitchell JD, Pass H, Keenan R, Bauer T, Miller D, Kohman LJ, Stinchcombe TE, Vokes E. Lobar or sublobar resection for peripheral stage IA non-small-cell lung cancer. N Engl J Med 2023; 388: 489-498.