Lung function assessment before anatomical lung resections—is everything so clear?—a narrative review

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Background and Objective: Several aspects of the influence of the lung resection to the lung function still remain unclear. As the reliable prediction of postoperative complications, especially in patients at risk, may be challenging, a non-systematic review of the literature on the topic of the influence of the lung resections to the postoperative lung function was done.

Methods: Inclusion and exclusion criteria: The analysis included adult patients who underwent anatomical lung resections with curative intent (segmental resection, lobectomy, bilobectomy and pneumonectomy), independently of the operative approach—video-assisted thoracic surgery (VATS)/thoracotomy. Studies on combined benign and malignant pathology were included provided the majority of the included patients had lung cancer. Both retrospective and prospective studies were included, review articles, case reports and case series with less than 10 patients were excluded. Within the search strategy, the following terms were combined: lung resection, lobectomy, pneumonectomy, lung function, forced expiratory volume in the first second (FEV_1), small airways, diffusion, oxygen consumption, lung function prediction, postoperative, complications, mortality, diaphragm motion and outcome.

Key Content and Findings: The prediction of the postoperative lung function after the lung resection is currently the standard in most of the centers. Both the postoperative lung function loss and recovery are well documented and both should be taken into account during the lung function prediction. In patients with chronic obstructive pulmonary disease (COPD) patients the predicted postoperative lung function parameters may be initially underestimated *vs.* non-COPD patients, but COPD patients have the limited capacity of later lung function improvement. The prediction of the postoperative lung function after lobectomy is reliable in many aspects, but the influence of the upper *vs.* lower lobectomy either independently, or depending of the side of the operation, requires further analysis. Issues related to pneumonectomy are sufficiently evidence-based and combining of lung function analysis and cardiorespiratory risk assessment is now an accepted standard.

Conclusions: The existing guidelines should be adhered in the everyday practice. However, some evidence gaps and specific situations given in the review should be taken into consideration as well.

Keywords: Lobectomy; segmentectomy; lung function; prediction; postoperative

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Introduction

Several aspects of the influence of the lung resection to the lung function still remain unclear. After the lung resection, the lung function recovers till some point, but it may take 1–2 weeks to more than 2 months to reach the desired/predicted value (1,2). The main problem, despite all available hi-tech methods of the lung function assessment and prediction, still remains the impossibility to reliably predict the probability of complications during that period, especially in patients at risk (3). A non-systematic review of the literature on the topic of the influence of the lung resections to the postoperative lung function is performed with the following aims: first, to avoid unjustified upfront rejection from surgery of some patients that at first sight may seem as unfit for surgery; second, to avoid offering surgery to patients, who are under the functional limit for safe surgery according to the existing evidence. I present the following article in accordance with the Narrative Review reporting checklist (available at https://amj.amegroups.com/article/view/10.21037/amj-22-19/rc).

Methods

This is a non-systematic review of the literature on the topic of the influence of the lung resections to the postoperative lung function.

Inclusion criteria

The analysis included adult patients who underwent anatomical lung resections with curative intent (segmental resection, lobectomy, bilobectomy and pneumonectomy), independently of the operative approach—video-assisted thoracic surgery (VATS)/thoracotomy. Studies on combined benign and malignant pathology were included provided the majority of the included patients had lung cancer. Both retrospective and prospective studies were included, review articles, case reports and case series with less than 10 patients were excluded.

Search strategy

The searching included only journals (without language restrictions) cited in the following databases: Medline, Current contents (CC), Science Citation Index (SCI) and Science Citation Index expanded (SCIE) after 1995. References published before 1995. were included exceptionally and only as key-references for the understanding of the particular sub-topic. Within the search strategy, the following terms were combined: lung resection and lung function and prediction; lung function and lobectomy and segmentectomy; operative morbidity and lobectomy and pneumonectomy and segmentectomy; forced expiratory volume in the first second (FEV_1), and prediction; diffusion and lobectomy and pneumonectomy; oxygen consumption and pneumonectomy and complications; lobectomy and pneumonectomy and mortality, diaphragm motion lung function.

Titles and abstracts of potentially eligible studies were initially screened and the eligibility of the full texts was assessed depending on whether the particular study covered at least one of the following study endpoints: differences between the measured and predicted values of FEV_1, vital capacity (VC), diffusion capacity (DLco), oxygen consumption in effort (VO_2); differences in preoperative *vs.* postoperative lung function parameters depending on site and type of lobectomy (upper *vs.* lower); differences in the lung function parameters depending on operative approach (VATS *vs.* open surgery); differences between preoperative and postoperative FEV_1 and VC in patients with chronic obstructive pulmonary disease (COPD) *vs.* non-COPD patients. Studies addressing at least one of the listed end-points were included, provided the bias was low, as assessed on the basis of the size of the reported series, consistency and precision of the reported data, study limitations as presented by the authors and on the basis of the 30 years of specialist experience of the author of the present review.

The search strategy is summarized on *Table 1*. The main characteristics of the analysed studies are presented on Table S1 (3-23).

The evidence synthesis followed a stepwise process: subdividing each article into different research topics; grouping the evidence about the same research topic together; identifying similar or opposite findings; based on personal experience in the field, identifying research gasps whose clarifying could be of practical benefit.

Results

Based on the performed literature survey, the following areas of interest were identified: (I) the pattern of the early and late postoperative lung function recovery; (II) the differences in postoperative lung function between VATS and open surgery; (III) some specificities in COPD *vs.* non-COPD patients and (IV) the influence

Table 1 Search strategy summary

Items	Specification
Date of search	07/05/2022
Databases and other sources searched	PubMed and Google search
Search terms used (including MeSH and free text search terms and filters) (Table S1)	Lobectomy, pneumonectomy (MeSH), Segmentectomy, Spirometry (MeSH), postoperative complications (MeSH), prediction
Timeframe	1995–2022
Inclusion and exclusion criteria	Inclusion: anatomical lung resection with curative intent; exclusion: combined benign-malignant pathology in case that the majority of patients did not have lung cancer; review articles, case reports and case series with less than 10 patients
Selection process	The entire selection process was performed by the corresponding author

of the type of lobectomy; (V) accuracy of the lung function prediction methods; (VI) functional aspects of segmentectomy. These topics represent the primary study end-point. Secondly, the aim of this review is to underline strengths and limits of different methods of the postoperative lung function prediction, to identify some gaps in the existing evidence and to suggest the areas for future research.

Early postoperative lung function recovery

Different lung function parameters do not recover after the lung resections in the same way. In patients with lobectomy and without postoperative complications, it was demonstrated that forced vital capacity (FVC) and %VC recovered rapidly between two weeks and one month after surgery, whilst the recovery of FEV_1 was greater 1 to 3 months after surgery, with Tiffeneau index (FEV_1/FVC ×100) remaining unchanged after surgery (4). Similar findings were reported in other studies, suggesting that the postoperative recovery within 30 postoperative days might be due to the repair of surgical injury to the chest wall and the resulting pain alleviation (24).

It was also demonstrated that the trend of the postoperative lung function recovery persists in patients with postoperative complications as well. In a group of 60 patients at increased risk, in patients with respiratory complications, the improvement between days three and 7 was greater than in patients of other types of complications and without complications, independently of patient- and tumor-related factors and extent of resection (17). Concerning oxygenation in the arterial blood, partial pressure of oxygen (pO_2) was decreasing during the first three postoperative days in a similar way in patients with respiratory, surgical complications and in patients without complications. In patients with cardiac complications, a steep drop occurred at the moment of the complication onset. A slight hypercapnia registered on the first postoperative day was gradually abolished in all groups except in patients with cardiac complications (17). These results incline to some extent to support the decision to offer surgery to some patients with borderline cardiorespiratory reserve.

Late postoperative lung function recovery

After both lobectomy and pneumonectomy, a certain definitive lung function defect persists. Although values vary across studies, after pneumonectomy, the FVC may decrease by 30% from preoperative values, FEV_1 by 28%, whilst the reported decreases for DLco and peak oxygen consumption are 39% and 28%, respectively; after lobectomy, the definitive FVC loss was reported to be 13%, whilst FEV_1 drops of only 8% of the preoperative value were reported; the permanent DLco and peak oxygen consumption drops are around 20% and 12%, respectively (25).

Similar data were obtained in other studies, with 23% FEV_1 decrease after pneumonectomy and 8% after lobectomy and decreases in exercise capacity by 16% after pneumonectomy and 13% after lobectomy (26).

Some studies demonstrated even smaller lung function losses after lobectomy—for FVC by 7%—and for maximal oxygen consumption only by 1% of preoperative values (22). In line with these reports, the study measuring the lung function preoperatively and more than 6 months postoperatively, showed that in patients with lobectomy, 6 months after surgery, VC and FEV_1 loss was around 10%, whilst the maximal oxygen consumption per square meter recovered to 86.7% (2).

The relatively low reported loss in FEV_1 after lobectomy may lead to the underestimation of the value of the postoperative lung function prediction (see later) and misleading decisions in preoperative patient selection in a way that "almost every patient should tolerate a lobectomy". Rare studies specifically addressing differences in postoperative lung function changes between COPD and non-COPD patients help to avoid this pitfall. The average loss of FEV1 was about 8.6–19.0% after lobectomy for non-COPD patients, whilst the postoperative change of FEV1 in patients with COPD was between −18.3% and 5%. COPD (27). Such an interval of values can be explained by the quality of the resected lung tissue. Indeed, patients with a low preoperative FEV1 and COPD index >1.2 may have restrictive diseases and can be expected to sustain a 5% to 20% loss of function (FEV1) after lobectomy. Unlike them, patients with a COPD index <1.0, in whom the nonfunctioning lobe has remained, seem to lose higher percentage of their FEV1 with resection of a functioning lobe (26). It was also demonstrated that the_reduction in FEV1 was lower in COPD *vs.* non-COPD patients (6% *vs.* 13%, P=0.0002), but residual postoperative FEV1 values were lower in COPD patients as well (62% *vs.* 74%, P<0.0001), despite much lower FEV1 loss compared with preoperative values (28). The presented data clearly confirm the need to take all these elements into account during the preoperative patient selection.

Concerning differences in the postoperative lung function recovery between COPD and non-COPD patients, a study on 76 patients with the lung function assessment preoperatively and up to one year postoperatively, showed that postoperative FEV_1 values significantly increased only in non-COPD patients (29). The postoperatively measured DLco up to one year after surgery was again significantly higher in non-COPD than in COPD patients. This improvement was not observed after thoracotomy.

VATS vs. thoracotomy

The most of the studies on sufficient number of patients showed the functional advantage of VATS *vs.* thoracotomy. In a study on 51 patients with VATS and with 52 with postero-lateral thoracotomy, the FVC and the shoulder function recovered significantly better in the VATS group after 7 days, one and three months, whilst the FEV_1 recovery was also better in the VATS group, but without the statistical significance (7).

Similar results were obtained by some other studies, like the one by Nakata *et al.* that found that peak flow rates, FEV_1, and FVC were higher at one and two weeks after VATS lobectomy than after thoracotomy (30). Another study demonstrated that the recovery rates were dependent on the postoperative pain, being significantly lower in the VATS group on the day of operation and on the first, 7^{th} and 14^{th} postoperative days (31).

Unlike these reports, a study on two well matched VATS and thoracotomy groups with 60 patients each, found no significant differences in the recovery of FEV_1, FVC, or of the peak flow rate between VATS and thoracotomy group during the 1 year follow up (5). Similarly, several small series have suggested that the outcomes after VATS lobectomies in COPD patients could be similar to those in non-COPD patients (32,33).

It should be mentioned that the above reports refer to full thoracotomy, so that firm conclusions concerning the influence of the operative approach should not be extended to other types of thoracotomy, like mini-thoracotomy (up to 10 cm incision with small rib spreader), limited antero-lateral or axillar incision with sparing of the muscles, whose impact on the postoperative lung function could be different.

COPD patients

Several authors have reported that the loss in FEV_1 in COPD patients was smaller or was even improved postoperatively compared with FEV_1 changes in non-COPD patients (20-22), especially during 3 first postoperative months, probably due to some kind of the lung volume reduction (LVR) effect (1).

A trend of the measured postoperative FEV_1 to exceed the predicted value was reported in COPD-patients 1 month after surgery (P=0.06), but without a subsequent increase (17). Unlike that, the postoperative FEV_1 in the non-COPD patients corresponded to the predicted value 1 month after surgery, but it significantly increased till 6 months, and remained approximately the same after 1 year (85.1% of the preoperative value) (17).

Bobbio and colleagues reported that the maximal oxygen consumption decreased by 20% three months after

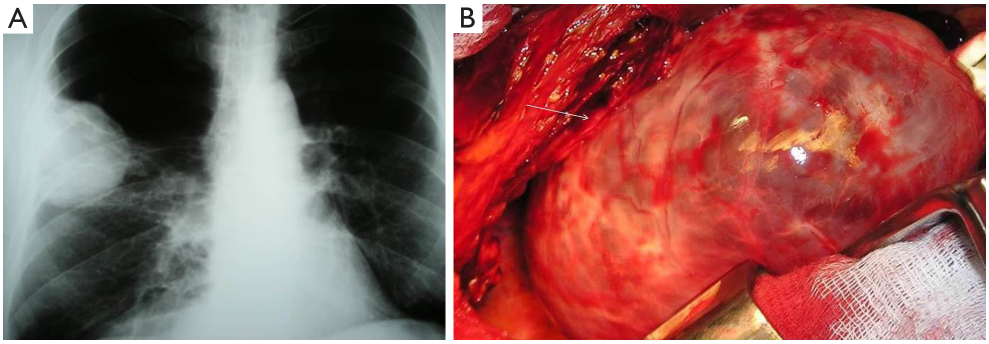


Figure 1 Primary lung cancer and a big bulla in the same lobe. (A) Preoperative PA radiography: right upper lobe with a big bulla and carcinoma invading the chest wall; (B) operative view: a big bulla protruding through the thoracotomy incision; arrow: area of the initial extrapleural dissection, subsequently extended to partial rib resection because of the direct rib invasion. PA, postero-anterior.

lobectomy in COPD-patients (34).

The problem within these considerations is that there is not sufficient data to distinguish between the true LVR effect of lobectomy in patients with clear bullous emphysema and accordingly expected LVR effect postoperatively (*Figure 1*) and patients with chronic obstructive bronchitis.

In patients with a pneumonectomy, a definitive remodeling of the chest exists, with mediastinal shift and sometimes a major lung hernia towards the operated side. Overdistension of the remaining lung occurs as an adaptive response. It was demonstrated that patients with a low body mass index (BMI) (<20 kg/m^2) showed a significantly greater degree of lung herniation towards the operative side than those with a high BMI (≥20 kg/m^2) (9). Although COPD itself has no effect on lung herniation, in COPD patients this can cause an LVR effect, whilst in non-COPD patients a vicariate emphysema occurs. Of practical importance is the report that COPD patients with a pneumonectomy may have the smaller postoperative FEV_1 drop and greater decrease in hyperinflation than non-COPD patients (8). These findings may be helpful in preoperative patient selection.

Site of lobectomy and postoperative lung function

Despite certain amount of evidence (20,35,36), some aspects of the influence of the site of lobectomy are not absolutely clear. Although more lung volume is removed by lower lobectomy, the lung function after this operation was not inferior to that after upper lobectomy (37). In a study on 72 patients (33.3% COPD), the percent of FVC loss after the lower lobectomy was significantly higher compared with the upper lobectomy 6 months postoperatively, but this difference disappeared 12 months after surgery (6). Another study analyzed the duration of the postoperative air leak and demonstrated that the time necessary for the air leak to stop was shorter after lower and middle compared to upper lobectomy, thus in some way suggesting that the early functional consequences of the lower lobectomy must not always be inferior than those after upper lobectomy (19).

The understanding of this aspect is additionally complicated by some reports suggesting the influence of COPD. In fact, the postoperative FEV_1 was underestimated in COPD patients 1 and 6 months after upper lobectomy compared with non-COPD patients (38). It means that COPD might influence FEV_1% at both the early and late stages after upper lobectomy, making firm conclusions about the influence of the site of lobectomy even more difficult.

Prediction of the postoperative lung function

Several methods of the postoperative lung function prediction have been confirmed as reliable in terms of the FEV_1 prediction 3–6 months after surgery. However, it was demonstrated that the FEV_1 can be overestimated during the first postoperative days, when, in fact, the most of the severe complications may occur. Many years ago it was clearly demonstrated that in patients with lobectomy, the FEV_1 measured on the first postoperative day, may be 30% lower than predicted (3).

The choice of the postoperative lung function prediction depends not only of institutional protocols preferences,

Table 2 Accuracy of the postoperative lung function prediction-meta analysis of 17 studies

Author, year	No. of cases	Operation	Method of the lung function prediction	Measured outcome
Taube (39), 1980	27	Pneumonectomy	Perfusion scintigraphy	FEV_1
Egeblad (40), 1986	30	Lobectomy + pneumonectomy	Segment counting	FEV_1
Wu (41), 1994	38	Lobectomy + pneumonectomy	CT volume and density	FEV_1
Bolliger (42), 1995	22	Wedge, segmentectomy, lobectomy, pneumonectomy	Perfusion scintigraphy	FEV_1, DLco
Larsen (43), 1997	23	Lobectomy + pneumonectomy	Perfusion scintigraphy	FEV_1
Beccaria (44), 2001	62	Lobectomy + pneumonectomy	Segment counting	FEV_1
Wu (45), 2002	34	Lobectomy + pneumonectomy	Perfusion scintigraphy, CT volume and density	FEV_1
Wang (25), 2006	28	Segmentectomy, Lobectomy + pneumonectomy	Segment counting	DLco%
Sudoh (46), 2006	22	Lobectomy + segmentectomy	subsegment counting; SPECT-CT	FEV_1
Ohno (47), 2007	60	Lobectomy + pneumonectomy	Perfusion Scintigraphy; ventilation Scintigraphy; SPECT	FEV_1
Yoshimoto (48), 2009	37	Lobectomy	Segment counting; CT volume and density; SPECT	FEV_1
Yamashita (49), 2010	14	Lobectomy + pneumonectomy	Perfusion scintigraphy; CT perfusion	FEV_1
Yanagita (50), 2013	30	Lobectomy + pneumonectomy	SPECT; CT ventilation	FEV_1
Chae (51), 2013	51	Lobectomy + pneumonectomy	Perf. scintigraphy; CT perfusion	FEV_1
Ohno (52), 2015	60	Segmentectomy; Lobectomy; pneumonectomy	Segment counting; Perf. scintigraphy; CT volume and density	FEV_1
Yabuuchi (53), 2016	49	Lobectomy	Subsegment counting; CT volumetry; CT volume and density	Only FEV_1 change
Fourdrain (54), 2017	23	Lobectomy + pneumonectomy	Segment counting; subsegment counting; perfusion + ventilation scintigraphy	FEV_1

CT, computed tomography; SPECT, single-photon emission computed tomography; FEV_1, forced expiratory volume in the first second; DLco, diffusion capacity for carbon monoxide.

but of availability of modern technical equipment and of organizational issues as well.

A recent meta-analysis of 17 studies (*Table 2*) analyzed the accuracy of the postoperative FEV_1 prediction of different techniques: segment counting, subsegment counting, perfusion scintigraphy, ventilation scintigraphy, single photon-emission computer tomography (SPECT), computer tomography volume and density and computer tomography volume and partial density.

The prediction of FEV_1 after the lung resection was the most accurate when CT volume and density measures were combined, the minimum clinically important difference in FEV_1 being set up at 100 mL (10). This minimal cut off value means that, if the difference between the measured and predicted value is less than 100 mL, it should not be clinically noticeable (55). The evidence about the prediction of the postoperative DLco was weak, but the segment counting seems to be more accurate than perfusion scintigraphy.

Another study analysed the lung function preoperatively and 3–4 months postoperatively and demonstrated that volumetric CT was more accurate than segment counting or scintigraphy in terms of prediction of FEV_1, VC, DLco and peak oxygen uptake (11). However, both segment counting methods (Juhl-Frost and Nakahara), together with FEV_1 prediction by means of perfusion lung scintigraphy are still in the widespread use (56,57). The advantage of the Nakahara *vs.* Juhl-Frost method is taking into account the number of obstructed segments:

$$\text{ppoFFEV}_1 = \text{preopFEV}_1 \times \left[1-(\text{S}-\text{N})/(19-\text{N})\right] \quad [1]$$

(S= number of segments to be resected; N= number of obstructed or consolidated segments; 19= total number of segments in both lungs; ppo = predicted postoperative; preop = preoperative).

The method based on the perfusion lung scintigraphy is also suitable for clinical practice:

For lobectomy,

$$\text{ppoLoss in FEV}_1 = \text{preopFEV}_1 \times \%\text{ perfusion of the affected lung} \times \text{n/n1} \quad [2]$$

$$\text{ppoFEV}_1 = \text{preopFEV}_1 - \text{ppoLoss in FEV}_1 \quad [3]$$

(n= number of segments to be removed; n1= number of segments in the operated lung).

For pneumonectomy,

$$\text{ppoFEV}_1 = \text{preopFEV}_1 \times \%\text{ perfusion of the healthy lung} \quad [4]$$

The main concern with this method is that it uses only the percents of perfusion distribution between the right and left lung, not giving the insight into the quality of the perfusion itself. That is why the preoperative diffusion assessment is of the key importance and that is why the aforementioned volumetric (quantitative) CT by determining the extent of the lung zones with density ranging between −900 and −500 HU enables to determine the volume of the functioning lung tissue. The lung zones with the aforementioned density can be extracted by the appropriate software as proposed by Wu *et al.* (45). The removal of the lung zones outside the density range −910 to −500 HU is not expected to cause a major lung function loss.

In recent years, several methods of the postoperative lung function prediction have been reported, like SPECT, 4-dimensional CT ventilation, positron emission tomography/CT or dynamic contrast-enhanced perfusion magnetic resonance imaging. However, the correlation coefficients between measured and predicted postoperative FEV_1, ranging from 0.81 to 0.99, do not favor them over volumetric CT (58-61). In addition, they are less-accessible and, in some cases, involve additional radiation for the patient.

Independently on the used postoperative lung function prediction technique, the common goal is to assess whether the calculated ppoFEV_1 value exceeds or not 30–35% for the particular extent of resection. This cut of value represents the limit under which surgery should not be offered to the patient.

However, even if ppoFEV_1 slightly exceeds this cut-off value, it does not mean that the patient will not be exposed to the increased risk of postoperative complications. This should always be kept in mind in surgical candidates with limited lung function. The prediction of postoperative oxygen consumption (VO_2) better reflects this type of risk. It can be determinated by combining the preoperative measured VO_2 and percent of perfusion of particular lung lobe: max.ppoVO_2 = max.preop.VO_2 × (1 − *fr*), where *fr* means fraction of the function of the part of the lung to be removed. With the maximal ppoVO_2 being <10 mL/kg/min. the risk of operative mortality is unacceptably high (42).

Many years ago it was demonstrated that that the pattern of the DLco increase in effort is the most reliable in terms of complications prediction. With <10% DLco increase in effort (from rest to 70% of maximal workload) the complication rate is 100%, *vs.* 10% complication rate in case of >10% DLco increase (62). By using the same equations as for FEV_1 prediction by means of perfusion lung scintigraphy (see above), the postoperative DLco can be predicted as well.

The ERS/ESTS guidelines for fitness for surgery address the above issues in a practice-oriented way with calculation methods that are suitable for practical use (63).

Functional aspects of anatomical segmentectomy

Before presenting the evidence about functional effects of anatomical segmentectomy, it should be mentioned that, since the publication of the Lung Cancer Study Group Trial, dealing primarily with oncological aspects of segmentectomy *vs.* lobectomy, it has been suggested that segmentectomy brings nonsignificant, if any, functional advantage over lobectomy (64). In fact, in that trial there were no significant differences only in postoperative FVC between patients with lobectomies *vs.* limited resections, whilst a significant benefit of limited resection in preserving FEV_1 was demonstrated. Despite this, the authors' conclusion that there was no functional advantage of limited resection compared with lobectomy, continued to be widely accepted. A similar conclusion appeared after the study of Takizawa and coworkers who compared patients with segmentectomy and lobectomy and found that the choice of the procedure had no effect on postoperative FVC at 12 months, although a significant impact on postoperative

FEV_1 was demonstrated (65). Both of these studies have suggested that lobectomy should remain the procedure of choice despite the slight functional advantage in favor of limited resection.

During the past 20 years anatomical segmentectomy is in the widespread use for stage one lung cancer smaller than 2 cm in diameter and is considered as advantageous *vs.* lobectomy because it preserves the lung function, and allows patients to benefit from eventual future resection in case of metachronous lung cancer as well (66). The pool of evidence about functional effects of segmentectomy increases and in general supports such a statement, although some conflicting and opposite results were also reported.

In the study of Tane and co-workers with well-matched groups (74 VATS segmentectomies and 74 VATS lobectomies), the postoperative lung function was significantly better preserved in the segmentectomy than in the lobectomy group (61). The same study demonstrated that after both segmentectomy and lobectomy, the regional FEV_1 of the ipsilateral non-affected lobe was increased in comparison with the preoperative value, whereas that of the residual lobe rescued by segmentectomy was decreased. Interestingly, the preservation rate of the residual lobe inversely correlated with the extent of the resected segment, possibly because of inflation of_the unaffected ipsilateral lobe causing limited expansion of the residual lobe. Conversely, the preservation rate of the unaffected lobe directly correlated with the extent of the resected segment. In other words, the larger the extent of resection of the segment, the greater the increase in the lung function of the ipsilateral nonaffected lobe.

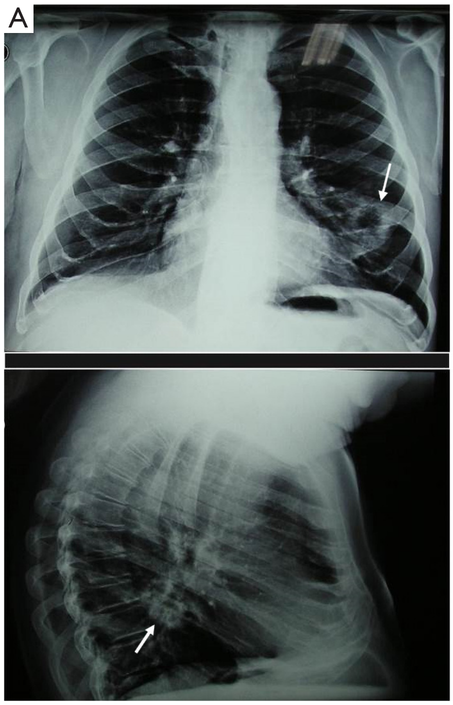
The similar functional advantage of segmentectomy was demonstrated in the study on 147 patients with lobectomy and 54 patients with segmentectomy for stage I non-small cell lung cancer, where the preoperative lung function was significantly worse in the segmentectomy group (FEV_1 75.1% versus 55.3%; P<0.001) (42). After 1 year, in the lobectomy group, significant drops in forced VC (85.5% to 81.1%), FEV_1 (75.1% to 66.7%), maximum voluntary ventilation (72.8% to 65.2%), and DLco (79.3% to 69.6%) existed, whilst in the segmentectomy group, the only significant change was a decline in DLco.

Some other reports are in line with the aforementioned results. In one study, the suitability of segmentectomy for <2 cm peripheral T1N0M0 lung cancers was suggested based on the small postoperative decline in lung function—only 11.3% in FVC and 13.4% in FEV_1 (67). Another study on 103 patients with segmentectomy and the same number with lobectomy showed that the lung function was significantly better preserved after segmentectomy, because the operated lobe retained 48%±21% of the preoperative function. Furthermore, the function of the ipsilateral non-operated lobe increased only after segmentectomy (14).

Some reports, although not denying the functional effects of segmentectomy, express some concerns. Firstly, according to the available evidence, the mean decrease in FEV_1 seems to range from −9% to −24% of the preoperative value after two months and −3 to −12% 12 months after segmentectomy (68). Despite the significantly lower lung function reduction than after lobectomy, segmentectomy saves only a few percents of the preoperative FEV_1 value, so that the question arises about the real benefit of this procedure. Moreover, the published data do not clearly confirm the functional benefit of segmentectomy in patients with poor lung function (68). Secondly, it was also demonstrated that, although the lung function was better after segmental resection than after lobectomy after 6 months, the actual lung function did not reach the predicted-postoperative value at 1 month after surgery (15). It means that after segmentectomy, the early postoperative pulmonary function may be significantly less than the expected value.

In some studies no functional advantage for segmentectomy could be demonstrated, like in the study on 37 patients with segmentectomy and 33 patients with lobectomy for T1aN0M0 non-small cell lung cancer. In this study, no statistically significant difference was demonstrated neither for recovery ratios of the FVC nor of the FEV_1 (16). Similarly, the recovery ratios for radiologic lung volume and weight followed the similar pattern in both groups (P=0.46 and P=0.22).

Unlike lobectomy, anatomical segmentectomy has some technical points that may cause differences between predicted und actual lung function of the residual lobe and these points are addressed in the literature as well (12). Developing the intersegmental plane by using electrocautery and stapler may cause the restricted the reexpansion of the preserved segments. Similarly, in order to achieve tumor-free margins, dissection of the parenchyma is directed towards the residual segment, thus additionally restricting its function. Finally, because of the segmental anatomy, resection of the 6^{th} segment, as technically less complicated (well defined, only one intersegmental surface), is more likely to cause better preservation of the residual lobe's



B

	4. V	16. V	23. V
	During the preoperative therapy		
FEV_1 %	53	**38**	65
Tiff.	58.4	**48.5**	56.3
FEF_{50} %	21	**12**	24
FEF_{25} %	17	**12**	14
pO_2	8.6	8.6	9.2
pCO_2	5.4	5.5	5.3

Figure 2 Transitory lung function worsening during the preoperative bronchodilation treatment. (A) Postero-anterior (above) and lateral view (below): excavating tumour centrally in the left lower lobe (arrows). (B) From left to right: transitory worsening and recovery of the ventilatory parameters during the preoperative therapy; no synchronous worsening of the preexisting slight hypoxaemia, clear improvement at the end of the therapy. FEV_1, forced expiratory volume in the first second; Tiff, Tiffeneau index ($100FEV_1$/vital capacity); FEF_{50}, FEF_{25}, forced respiratory flows at 50% and 25% of vital capacity; pO_2, partial pressure of oxygen in the arterial blood in kPa; pCO_2, partial pressure of carbon monoxide in the arterial blood in kPa.

function, compared with posterior-basal segmentectomy, requiring dissection at multiple surfaces at an acute angle and with deeply located point of divergence of the bronchus and vessels.

Finally, by considering these functional effects of segmentectomy, it should be remembered that preservation of lung function makes sense only if these patients will not be exposed to an increased risk of local or regional recurrence. In only one report both aspects were synchronously analyzed (13). Segmentectomy was also reported as associated with longer mean operative time (270±70 *vs.* 202±67 min) and more frequent postoperative complications (19.6% *vs.* 6.5%, P=0.03) compared with lobectomy (69) and it should be kept in mind in preoperative patient selection.

Some specific considerations

As the above considerations relate to patients with borderline respiratory reserve (mostly COPD), it is useful to remind that sometimes, transitory worsening of the lung function may occur in form of unexpected FEV_1 drops during the combined bronchodilation treatment (*Figure 2*). This is a phenomenon known as paradoxical response to bronchodilation (70). Although it is attributed to transitory decrease of the small airways' wall tonus and subsequent collapse during the forced expiration under this type of therapy, the exact mechanisms are not clear. They include incorrect inhaler use, bronchospasm from the propellant or the benzalkonium chloride, chlorofluorocarbons, and oleic acid contained in inhalers were suggested as possible causes (71-73). Airway thickness is significantly increased in the paradoxical bronchodilator response group, and may reduce the response to bronchodilators (74). Paradoxical bronchoconstriction after short-acting beta-agonists was suggested as a possible mechanism as well (75). These patients should be carefully monitored, rather than being upfront rejected from surgery.

	Before OP	p.op. d. 1	p.op. d. 5
pO_2	8.2 kPa	9.7	13.2
pCO_2	5.7 kPa	7.1	6.9
pH	7.44	7.36	7.39

	Before bronchodilatation	After bronchodilatation
FEV_1	1.72 (69%)	2.19 (87%)
FVC	3.28 (111%)	3.72 (126%)
FEF_{50}	**0.51 (13%)**	**1.11 (29%)**
FEF_{25}	**0.13 (9%)**	**0.36 (24%)**

Figure 3 Unexpected oxygenation worsening despite reversible bronchoobstruction, good responding to preoperative bronchodilation therapy. Upper row left: postero-anterior radiography showing a tumour in the right upper lobe; upper row right: oxygenation before and after lobectomy—refractory preoperative hypoxaemia disappeared after surgery; lower row: lung function parameters before (left) and after bronchodilation therapy (right). p.op. d. 1, postoperative day one; p.op. d. 5, postoperative day 5; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; FEF_{50}, FEF_{25}, forced respiratory flows at 50% and 25% of vital capacity; pO_2, partial pressure of oxygen in the arterial blood; pCO_2, partial pressure of carbon monoxide in the arterial blood; pH, potential of hydrogen, quantitative measure of acidity or alkalinity.

Similarly, despite a good therapeutic response to preoperative bronchodilation treatment in patients with mild to moderate COPD, a refractory and unexpected hypoxemia may occur during the treatment, putting into question the planned surgery. Here again, the reversibility of the bronchoconstriction is an important argument to offer surgery to these patients provided the diffusion problems and embolism are excluded. Such a scenario can be partly explained by the impaired function of the small airways-forced expiratory flow at 50% and 25% of the VC (FEF_{50} and FEF_{25}), as can be seen on *Figure 3*. The function of the small airways is usually not so much in focus during the postoperative lung function prediction. A single center series of 35 COPD and 47 non-COPD patients confirmed the importance of synchronous improvement of the small airways' function after preoperative bronchodilation treatment (76).

In candidates for pneumonectomy, a so called "functional effect of pneumonectomy" may exist preoperatively. In this case, the measured spirometry values may be very low, corresponding to severe mixed or purely restrictive disorders and as such at first sight not allowing a pneumonectomy. In these patients either the main bronchus may be completely occluded by the tumor, both lobar bronchi may be occluded by the extraluminal compression, or only one lobar bronchus may be occluded from outside in presence of a big tumor in another lobe (*Figure 4*). The correct interpretation of the endoscopic aspect will qualify these patients for pneumonectomy, because their preoperative lung function in fact corresponds to that after the operation.

Furthermore, the preservation *vs.* scarifying of the phrenic nerve during surgery has for a long time been considered as non-relevant for the postoperative lung function. However, the study from Ugalde *et al.* (in 2008) nicely demonstrated that the postoperative FEV_1 in patients with preserved phrenic nerve was significantly higher *vs.* patients with both immobile diaphragm and patients with paradoxical diaphragm movements (18).

Finally, diaphragm motion should be always taken into consideration before the planned lung resection. In a prospective pilot-study on 27 patients, we demonstrated that diaphragm movements may influence the accuracy of the postoperative lung function prediction (23). It can be easily checked either by ultra-sound or under fluoroscopy.

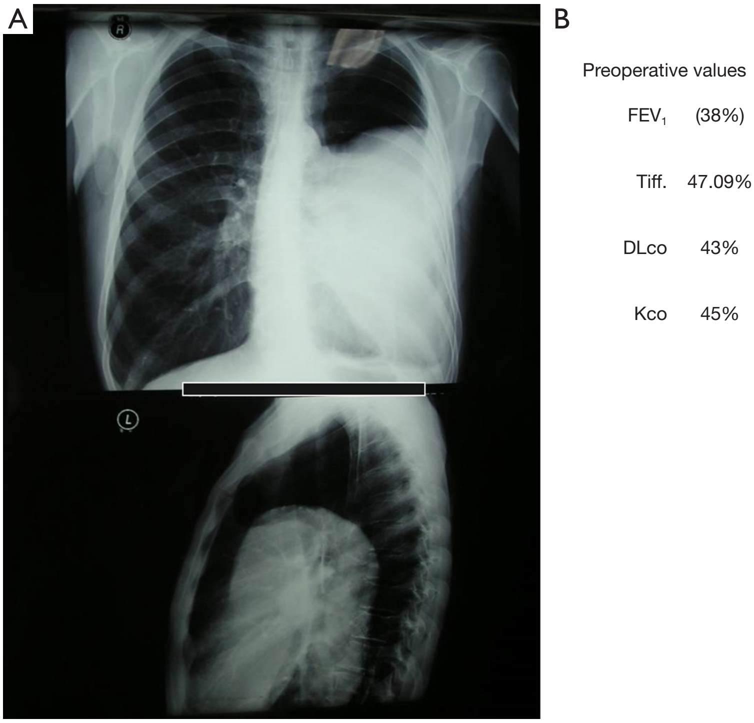


Figure 4 Functional effect of pneumonectomy before surgery. (A) Postero-anterior (above) and lateral view (below)—big tumour of the left lung with occlusion of both lobar bronchi. (B) Preoperative ventilatory parameters and diffusion values. FEV_1, forced expiratory volume in the first second; Tiff, Tiffeneau index ($100FEV_1$/vital capacity); DLco, diffusion capacity for carbon monoxide; Kco, diffusion coefficient (DLco/effective alveolar surface).

Study limitations

There are three main limitations of this study. The first one is a non-systematic type of the review, making the evidence quality assessment unreliable. The second limitation is the aim of the study, that was focused not only to the existing evidence, but to the evidence gaps as well. The problem is to define what are "evidence gaps"—are those only topics with insufficient data or those with sufficient, but conflicting data as well? Furthermore, our awareness of gaps depends also on the preference of particular teams, in a way that some of them are more inclined to get the update information about a particular surgical technique, relying upon the functional assessment by pulmonologists. Finally, as in recent years the percentage of studies dealing with modern noninvasive techniques steadily increases, functional aspects were not frequently specifically addressed, but rather (if at all) as a part of the presented data, usually including one or two analyzed parameters. That is why the structure of the papers included in this study does not adequately mirrors the real percentage of evidence covering a particular topic, like, for example for diaphragm-related issues with only a couple of studies that could be benefit for the everyday practice.

Conclusions

The prediction of the postoperative lung function after the lung resection is currently the standard in most of the centers. Both the postoperative lung function loss and recovery are well documented and both should be taken into account during the lung function prediction. In COPD patients the predicted postoperative lung function parameters may be initially underestimated *vs.* non-COPD patients, but COPD patients have the limited capacity of later lung function improvement. The prediction of the postoperative lung function after lobectomy is reliable in many aspects, but the influence of the upper *vs.* lower lobectomy either independently, or depending of the side of the operation, requires further analysis. Issues related to pneumonectomy are sufficiently evidence-based and combining of lung function analysis and cardiorespiratory risk assessment is now an accepted standard. The cut-off values for safe surgery given in the existing guidelines should be adhered, taking into account the above-mentioned evidence gaps and issues given under “specific considerations” of this text. In brief, the preoperative lung function assessment is a dynamic process and the published data should be used cautiously, with the awareness of the presented evidence gaps, uncertainties and controversial data as well.

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Footnote

Reporting Checklist: The author has completed the Narrative Review reporting checklist. Available at https://amj.amegroups.com/article/view/10.21037/amj-22-19/rc

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

References

1. Brunelli A, Refai M, Salati M, et al. Predicted versus observed FEV1 and DLCO after major lung resection: a prospective evaluation at different postoperative periods. Ann Thorac Surg 2007;83:1134-9.
2. Nezu K, Kushibe K, Tojo T, et al. Recovery and limitation of exercise capacity after lung resection for lung cancer. Chest 1998;113:1511-6.
3. Varela G, Brunelli A, Rocco G, et al. Predicted versus observed FEV1 in the immediate postoperative period after pulmonary lobectomy. Eur J Cardiothorac Surg 2006;30:644-8.
4. Nagamatsu Y, Maeshiro K, Kimura NY, et al. Long-term recovery of exercise capacity and pulmonary function after lobectomy. J Thorac Cardiovasc Surg 2007;134:1273-8.
5. Park TY, Park YS. Long-term respiratory function recovery in patients with stage I lung cancer receiving video-assisted thoracic surgery versus thoracotomy. J Thorac Dis 2016;8:161-8.
6. Seok Y, Jheon S, Cho S. Serial changes in pulmonary function after video-assisted thoracic surgery lobectomy in lung cancer patients. Thorac Cardiovasc Surg 2014;62:133-9.
7. Pu Q, Ma L, Mei J, et al. Video-assisted thoracoscopic surgery versus posterolateral thoracotomy lobectomy: A more patient-friendly approach on postoperative pain, pulmonary function and shoulder function. Thorac Cancer 2013;4:84-9.
8. Luzzi L, Tenconi S, Voltolini L, et al. Long-term respiratory functional results after pneumonectomy. Eur J Cardiothorac Surg 2008;34:164-8.
9. Fujimoto T, Matsui T, Hanawa T, et al. Lung herniation as an anatomic consequence of pneumonectomy. Thorac Cardiovasc Surg 2002;50:292-5.
10. Oswald NK, Halle-Smith J, Mehdi R, et al. Predicting Postoperative Lung Function Following Lung Cancer Resection: A Systematic Review and Meta-analysis. EClinicalMedicine 2019;15:7-13.
11. Fernández-Rodríguez L, Torres I, Romera D, et al. Prediction of postoperative lung function after major lung resection for lung cancer using volumetric computed tomography. J Thorac Cardiovasc Surg 2018;156:2297-2308.e5.
12. Tane S, Nishio W, Nishioka Y, et al. Evaluation of the Residual Lung Function After Thoracoscopic Segmentectomy Compared With Lobectomy. Ann Thorac Surg 2019;108:1543-50.
13. Keenan RJ, Landreneau RJ, Maley RH Jr, et al. Segmental resection spares pulmonary function in patients with stage I lung cancer. Ann Thorac Surg 2004;78:228-33; discussion 228-33.

14. Nomori H, Shiraishi A, Cong Y, et al. Differences in postoperative changes in pulmonary functions following segmentectomy compared with lobectomy. Eur J Cardiothorac Surg 2018;53:640-7.
15. Saito H, Nakagawa T, Ito M, et al. Pulmonary function after lobectomy versus segmentectomy in patients with stage I non-small cell lung cancer. World J Surg 2014;38:2025-31.
16. Suzuki H, Morimoto J, Mizobuchi T, et al. Does segmentectomy really preserve the pulmonary function better than lobectomy for patients with early-stage lung cancer? Surg Today 2017;47:463-9.
17. Ercegovac M, Subotic D, Zugic V, et al. Postoperative complications do not influence the pattern of early lung function recovery after lung resection for lung cancer in patients at risk. J Cardiothorac Surg 2014;9:92.
18. Ugalde P, Miro S, Provencher S, et al. Ipsilateral diaphragmatic motion and lung function in long-term pneumonectomy patients. Ann Thorac Surg 2008;86:1745-51; discussion 1751-2.
19. Kushibe K, Kawaguchi T, Kimura M, et al. Influence of the site of lobectomy and chronic obstructive pulmonary disease on pulmonary function: a follow-up analysis. Interact Cardiovasc Thorac Surg 2009;8:529-33.
20. Sekine Y, Iwata T, Chiyo M, et al. Minimal alteration of pulmonary function after lobectomy in lung cancer patients with chronic obstructive pulmonary disease. Ann Thorac Surg 2003;76:356-61; discussion 362.
21. Baldi S, Ruffini E, Harari S, et al. Does lobectomy for lung cancer in patients with chronic obstructive pulmonary disease affect lung function? A multicenter national study. J Thorac Cardiovasc Surg 2005;130:1616-22.
22. Edwards JG, Duthie DJ, Waller DA. Lobar volume reduction surgery: a method of increasing the lung cancer resection rate in patients with emphysema. Thorax 2001;56:791-5.
23. Subotic DR, Stevic R, Gajic M, et al. Diaphragm motion and lung function prediction in patients operated for lung cancer--a pilot study on 27 patients. J Cardiothorac Surg 2013;8:213.
24. Miyoshi S, Yoshimasu T, Hirai T, et al. Exercise capacity of thoracotomy patients in the early postoperative period. Chest 2000;118:384-90.
25. Wang JS, Abboud RT, Wang LM. Effect of lung resection on exercise capacity and on carbon monoxide diffusing capacity during exercise. Chest 2006;129:863-72.
26. Korst RJ, Ginsberg RJ, Ailawadi M, et al. Lobectomy improves ventilatory function in selected patients with severe COPD. Ann Thorac Surg 1998;66:898-902.
27. Ueda K, Tanaka T, Hayashi M, et al. Compensation of pulmonary function after upper lobectomy versus lower lobectomy. J Thorac Cardiovasc Surg 2011;142:762-7.
28. Pompili C, Brunelli A, Refai M, et al. Does chronic obstructive pulmonary disease affect postoperative quality of life in patients undergoing lobectomy for lung cancer? A case-matched study. Eur J Cardiothorac Surg 2010;37:525-30.
29. Kushibe K, Takahama M, Tojo T, et al. Assessment of pulmonary function after lobectomy for lung cancer--upper lobectomy might have the same effect as lung volume reduction surgery. Eur J Cardiothorac Surg 2006;29:886-90.
30. Nakata M, Saeki H, Yokoyama N, et al. Pulmonary function after lobectomy: video-assisted thoracic surgery versus thoracotomy. Ann Thorac Surg 2000;70:938-41.
31. Şimşek Veske N, Sökücü SN, Günlüoğlu G, et al. Place of vibration response imaging in preoperative lung cancer patients. Tuberk Toraks 2014;62:279-85.
32. Garzon JC, Ng CS, Sihoe AD, et al. Video-assisted thoracic surgery pulmonary resection for lung cancer in patients with poor lung function. Ann Thorac Surg 2006;81:1996-2003.
33. Demmy TL, Curtis JJ. Minimally invasive lobectomy directed toward frail and high-risk patients: a case-control study. Ann Thorac Surg 1999;68:194-200.
34. Bobbio A, Chetta A, Carbognani P, et al. Changes in pulmonary function test and cardio-pulmonary exercise capacity in COPD patients after lobar pulmonary resection. Eur J Cardiothorac Surg 2005;28:754-8.
35. Larsen KR, Svendsen UG, Milman N, et al. Cardiopulmonary function at rest and during exercise after resection for bronchial carcinoma. Ann Thorac Surg 1997;64:960-4.
36. Bolliger CT, Jordan P, Solèr M, et al. Pulmonary function and exercise capacity after lung resection. Eur Respir J 1996;9:415-21.
37. Wei S, Chen F, Liu R, et al. Outcomes of lobectomy on pulmonary function for early stage non-small cell lung cancer (NSCLC) patients with chronic obstructive pulmonary disease (COPD). Thorac Cancer 2020;11:1784-9.
38. Kim HK, Lee YJ, Han KN, et al. Pulmonary Function Changes Over 1 Year After Lobectomy in Lung Cancer. Respir Care 2016;61:376-82.
39. Taube K, Konietzko N. Can the effect of pneumonectomy on cardiopulmonary function be anticipated? (author's

transl). Prax Klin Pneumol 1980;34:548-54.
40. Egeblad K, Aunsholt NA, Funder V, et al. A simple method for predicting pulmonary function after lung resection. Scand J Thorac Cardiovasc Surg 1986;20:103-7.
41. Wu MT, Chang JM, Chiang AA, et al. Use of quantitative CT to predict postoperative lung function in patients with lung cancer. Radiology 1994;191:257-62.
42. Bolliger CT, Wyser C, Roser H, et al. Lung scanning and exercise testing for the prediction of postoperative performance in lung resection candidates at increased risk for complications. Chest 1995;108:341-8.
43. Larsen KR, Lund JO, Svendsen UG, et al. Prediction of post-operative cardiopulmonary function using perfusion scintigraphy in patients with bronchogenic carcinoma. Clin Physiol 1997;17:257-67.
44. Beccaria M, Corsico A, Fulgoni P, et al. Lung cancer resection: the prediction of postsurgical outcomes should include long-term functional results. Chest 2001;120:37-42.
45. Wu MT, Pan HB, Chiang AA, et al. Prediction of postoperative lung function in patients with lung cancer: comparison of quantitative CT with perfusion scintigraphy. AJR Am J Roentgenol 2002;178:667-72.
46. Sudoh M, Ueda K, Kaneda Y, et al. Breath-hold single-photon emission tomography and computed tomography for predicting residual pulmonary function in patients with lung cancer. J Thorac Cardiovasc Surg 2006;131:994-1001.
47. Ohno Y, Koyama H, Takenaka D, et al. Coregistered ventilation and perfusion SPECT using krypton-81m and Tc-99m-labeled macroaggregated albumin with multislice CT utility for prediction of postoperative lung function in non-small cell lung cancer patients. Acad Radiol 2007;14:830-8.
48. Yoshimoto K, Nomori H, Mori T, et al. Prediction of pulmonary function after lung lobectomy by subsegments counting, computed tomography, single photon emission computed tomography and computed tomography: a comparative study. Eur J Cardiothorac Surg 2009;35:408-13.
49. Yamashita CM, Langridge J, Hergott CA, et al. Predicting postoperative FEV1 using spiral computed tomography. Acad Radiol 2010;17:607-13.
50. Yanagita H, Honda N, Nakayama M, et al. Prediction of postoperative pulmonary function: preliminary comparison of single-breath dual-energy xenon CT with three conventional methods. Jpn J Radiol 2013;31:377-85.
51. Chae EJ, Kim N, Seo JB, et al. Prediction of postoperative lung function in patients undergoing lung resection: dual-energy perfusion computed tomography versus perfusion scintigraphy. Invest Radiol 2013;48:622-7.
52. Ohno Y, Seki S, Koyama H, et al. 3D ECG- and respiratory-gated non-contrast-enhanced (CE) perfusion MRI for postoperative lung function prediction in non-small-cell lung cancer patients: A comparison with thin-section quantitative computed tomography, dynamic CE-perfusion MRI, and perfusion scan. J Magn Reson Imaging 2015;42:340-53.
53. Yabuuchi H, Kawanami S, Kamitani T, et al. Prediction of post-operative pulmonary function after lobectomy for primary lung cancer: A comparison among counting method, effective lobar volume, and lobar collapsibility using inspiratory/expiratory CT. Eur J Radiol 2016;85:1956-62.
54. Fourdrain A, De Dominicis F, Lafitte S, et al. Quantitative computed tomography to predict postoperative FEV1 after lung cancer surgery. J Thorac Dis 2017;9:2413-8.
55. Nagahiro I, Andou A, Aoe M, et al. Pulmonary function, postoperative pain, and serum cytokine level after lobectomy: a comparison of VATS and conventional procedure. Ann Thorac Surg 2001;72:362-5.
56. Juhl B, Frost N. A comparison between measured and calculated changes in the lung function after operation for pulmonary cancer. Acta Anaesthesiol Scand Suppl 1975;57:39-45.
57. Nakahara K, Monden Y, Ohno K, et al. A method for predicting postoperative lung function and its relation to postoperative complications in patients with lung cancer. Ann Thorac Surg 1985;39:260-5.
58. Eslick EM, Bailey DL, Harris B, et al. Measurement of preoperative lobar lung function with computed tomography ventilation imaging: progress towards rapid stratification of lung cancer lobectomy patients with abnormal lung function. Eur J Cardiothorac Surg 2016;49:1075-82.
59. Piai DB, Quagliatto R Jr, Toro I, et al. The use of SPECT in preoperative assessment of patients with lung cancer. Eur Respir J 2004;24:258-62.
60. Ohno Y, Koyama H, Nogami M, et al. Postoperative lung function in lung cancer patients: comparative analysis of predictive capability of MRI, CT, and SPECT. AJR Am J Roentgenol 2007;189:400-8.
61. Brunelli A, Xiumé F, Refai M, et al. Evaluation of expiratory volume, diffusion capacity, and exercise tolerance following major lung resection: a prospective follow-up analysis. Chest 2007;131:141-7.
62. Wang JS, Abboud RT, Evans KG, et al. Role of CO

diffusing capacity during exercise in the preoperative evaluation for lung resection. Am J Respir Crit Care Med 2000;162:1435-44.
63. Brunelli A, Charloux A, Bolliger CT, et al. ERS/ESTS clinical guidelines on fitness for radical therapy in lung cancer patients (surgery and chemo-radiotherapy). Eur Respir J 2009;34:17-41.
64. 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;60:615-22; discussion 622-3.
65. Takizawa T, Haga M, Yagi N, et al. Pulmonary function after segmentectomy for small peripheral carcinoma of the lung. J Thorac Cardiovasc Surg 1999;118:536-41.
66. Okada M, Koike T, Higashiyama M, et al. Radical sublobar resection for small-sized non-small cell lung cancer: a multicenter study. J Thorac Cardiovasc Surg 2006;132:769-75.
67. Yoshikawa K, Tsubota N, Kodama K, et al. Prospective study of extended segmentectomy for small lung tumors: the final report. Ann Thorac Surg 2002;73:1055-8; discussion 1058-9.
68. Charloux A, Quoix E. Lung segmentectomy: does it offer a real functional benefit over lobectomy? Eur Respir Rev 2017;26:170079.
69. Ohtsuka T, Kamiyama I, Asakura K, et al. Thirty-day outcomes after lobectomy or segmentectomy for lung cancer surgery. Asian Cardiovasc Thorac Ann 2015;23:828-31.
70. Shin HJ, Kim TO, Kim YI, et al. The paradoxical response to short-acting bronchodilator administration in patients with chronic obstructive pulmonary disease. J Thorac Dis 2021;13:511-20.
71. Nicklas RA. Paradoxical bronchospasm associated with the use of inhaled beta agonists. J Allergy Clin Immunol 1990;85:959-64.
72. "Inactive" ingredients in pharmaceutical products: update (subject review). American Academy of Pediatrics Committee on Drugs. Pediatrics 1997;99:268-78.
73. Spooner LM, Olin JL. Paradoxical bronchoconstriction with albuterol administered by metered-dose inhaler and nebulizer solution. Ann Pharmacother 2005;39:1924-7.
74. Bhatt SP, Wells JM, Kim V, et al. Radiological correlates and clinical implications of the paradoxical lung function response to β2 agonists: an observational study. Lancet Respir Med 2014;2:911-8.
75. Magee JS, Pittman LM, Jette-Kelly LA. Paradoxical Bronchoconstriction with Short-Acting Beta Agonist. Am J Case Rep 2018;19:1204-7.
76. Subotic DR, Mandaric DV, Eminovic TM, et al. Influence of chronic obstructive pulmonary disease on postoperative lung function and complications in patients undergoing operations for primary non-small cell lung cancer. J Thorac Cardiovasc Surg 2007;134:1292-9.

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Supplementary

Table S1 Characteristics of the analysed studies

Study ID	Type of research	Patients characteristics	Surgery type	Findings summary
Nagamatsu Y, 2007 (4)	Retrospective analysis of prospectively collected data	18 patients	Lobectomy	The recovery of exercise capacity was 95% 1 year after surgery
Park TY, 2016 (5)	Retrospective study	120 patients with primary lung cancer	60 VATS lobectomy, 60 open lobectomy	There were no significant differences in pulmonary function recovery during the late postoperative period in NSCLC patients receiving VATS versus thoracotomy
Seok Y, 2014 (6)	Prospective	72 patients with primary lung cancer	VATS lobectomy	The postoperative lung function depended on the lobe resected and presence of COPD
Pu Q, 2013 (7)	Prospective	103 patients with primary lung cancer	51 VATS and 52 open lobectomy	FEV_1 recovery was better in VATS group, but not significantly; VATS lobectomy generates less pain and preserves better the lung function in the early postoperative phase
Luzzi L, 2008 (8)	Retrospective	27 patients with lung cancer	Pneumonectomy	COPD patients with a pneumonectomy may have the smaller postoperative FEV_1 drop and greater decrease in hyperinflation than non-COPD patients
Fujimoto T, 2002 (9)	Retrospective cohort study	27 patients with lung cancer	Pneumonectomy	Patients with a low body mass index (BMI) (<20 kg/m^2), however, showed a significantly greater degree of lung herniation than those with a high BMI (≥20 kg/m^2)
Oswald NK, 2019 (10)	Meta-analysis of 17 studies	610 patients with lung cancer	Lobectomy, pneumonectomy, segmentectomy	FEV_1 prediction was the most accurate when CT volume and density measures were combined
Varella G, 2006 (3)	Prospective	161 patients with lung cancer	Lobectomy	in patients with lobectomy, the FEV_1 measured on the first postoperative day, may be 30% lower than predicted
Fernández-Rodríguez L, 2018 (11)	Retrospective	114 patients with lung cancer	Anatomical lung resections	volumetric CT was more accurate than segment counting or scintigraphy in terms of prediction of FEV_1, vital capacity, diffusion capacity and peak oxygen uptake
Tane S, 2019 (12)	Retrospective	148 patients with lung cancer	74 segmentectoimies,74 lobectomies	Segmentectomy preserved the lung function better than lobectomy
Keenan R, 2004 (13)	Retrospective	201 patients with lung cancer	54 segmentectomies, 147 lobectomies	segmental resection offers preservation of pulmonary function compared with lobectomy and does not compromise survival
Nomori H, 2018 (14)	Retrospective cohort study	392 patients with lung cancer	184 segmentectomies, 208 lobectomies	Segmentectomy preserves the lung function better than lobectomy; it also improves the function of non-operated lobe
Saito H, 2014 (15)	Retrospective	178 patients with lung cancer	52 segmentectomies, 162 lobectomies	Pulmonary function at 6 months after surgery is better after segmental resection than after lobectomy
Suzuki H, 2017 (16)	Retrospective	70 patients with lung cancer	37 segmentectomies, 33 lobectomies	No functional advantage for segmentectomy was observed during long-term follow-up
Ercegovac M, 2014 (17)	Prospective cohort study	60 patients with lung cancer	5 sublobar resections, 41 lobectomies, 14 pneumonectomies	Extent of the lung resection and postoperative complications do not significantly influence the trend of the lung function recovery after lung resection for lung cancer
Ugalde P, 2008 (18)	Retrospective	88 patients with lung cancer	Pneumonectomy	Phrenic nerve preservation during pneumonectomy is of significant functional benefit postoperatively
Kushibe K, 2009 (19)	Retrospective	186 patients with lung cancer	Lobectomy	The time necessary for the air leak to stop was shorter after lower and middle- compared to upper lobectomy
Sekine Y, 2003 (20)	Retrospective	521 patients with lung cancer	Lobectomy	In patients with COPD who had lower or middle-lower lobectomies was better preserved than predicted
Baldi S, 2005 (21)	Retrospective	137 patients with lung cancer	Lobectomy	Patients with mild to severe chronic obstructive pulmonary disease could have a better late preservation of pulmonary function after lobectomy than healthy patients
Edwards JG, 2001 (22)	Retrospective	29 patients with lung cancer	Lobectomy	Effect of lobar volume reduction allows for an extension of the selection criteria
Subotic D, 2013 (23)	Prospective plot-study	27 patients with lung cancer	Lobectomy and pneumonectomy	The preoperative diaphragm motion influences the postoperative lung function prediction

NSCLC, non-small-cell lung cancer; VATS, video-assisted thoracic surgery; COPD, chronic obstructive pulmonary disease; FEV_1, forced expiratory volume in the first second.

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