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European Society of Thoracic Surgeons expert consensus recommendations on technical standards of segmentectomy for primary lung cancer

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INTRODUCTION

The recent findings from the JCOG0802 and CALGB randomized control trials [1, 2] have corroborated previous observational reports series [3–8] showing favourable short-term and long-term results of segmentectomy in patients operated for peripheral (outer third of the lung), early-stage non-small-cell lung cancer (NSCLC) (2 cm or less).

This has generated a growing interest in this procedure, which is however considered technically more challenging compared to lobectomy, especially when performed via closed-chest surgery.

This renewed interest coupled with the implementation of lung screening programs with the increased detection of early-stage lung cancer [9] will likely lead to a progressive wider adoption of this procedure. During this phase, it is important to ensure

that the oncologic principles will be respected and that practice variation will be minimized to guarantee patients' safety and appropriate cancer treatment [10].

Recent publications have shown that the current adherence to pre-defined quality measures occurred in only <13% of all segmentectomies at a national level [11]. In addition, 20% of reported segmentectomies may actually not meet the criteria for true segmental resection [12]. Poor quality standards have been associated with poorer survival [11].

With the aim to provide guidance to safely implement the adoption of segmentectomy as a curative resection for early-stage lung cancer patients, the European Society of Thoracic Surgeons designed an expert consensus project aiming at defining quality technical criteria of segmentectomies, whose results are herein reported.

METHODS

A modified Delphi approach was used to generate this European expert consensus on technical standards of segmentectomies.

A Delphi technique can be employed to achieve a complete consensus position or modified to illustrate where agreement and disagreement exist; understanding areas of disagreement can inform the feasibility of future research topics [13]. This is especially true when the available level of evidence is low.

A core group of 5 surgeons (Alessandro Brunelli, Rene Petersen, Dominique Gossot, Herbert Decaluwe, Michel Gonzalez) with expertise in sublobar resections, minimally invasive surgery and guideline developments met and discussed the current evidence on quality standards of segmentectomy and identify the following key topics:

- Definition of segmentectomy,
- Preoperative planning,
- Surgical approach,
- Procedural steps,
- Intraoperative lymph node management,
- Intraoperative management of intersegmental planes (ISPs),
- Management of positive resection margins and
- Management of unsuspected positive lymph nodes and spread through air space (STAS).

These topics were used to initially generate 20 consensus statements (Table A1) for testing across a wider group of panellists. The statements were collated into a questionnaire, which was electronically sent by email to a group of 29 panellists (5 core group experts and additional 24 experts) using a commercially available platform (www.surveymonkey.com). The additional 24 European panellists included in the final panel group were selected among European Society of Thoracic Surgeons (ESTS) members if they met 1 or more of the following criteria:

- contributing >50 segmentectomies to the ESTS database in the last 3 years,
- members of the ESTS Minimally Invasive Thoracic Surgery Interest Group,
- members of the ESTS Robotic working group and contributing to the ESTS database and
- renown experience in the field of segmentectomy as documented by participation as faculty to specific educational events or publication author.

Two additional members were invited but did not reply to the invitation.

The project was approved by the ESTS Board in September 2022.

Respondents were offered a 4-point Likert scale to rate their agreement with each statement, ranging across 'strongly disagree', 'disagree', 'agree' and 'strongly agree'.

The questionnaire requested to indicate name and affiliation for the purpose of authorship which were treated confidentially.

Completed questionnaires were collated and analysed to produce an arithmetic agreement score for each statement.

The steering group pre-defined *a priori* threshold of consensus of 75% or greater. Consensus was defined as 'very high' at ≥90% [13, 14].

After the first round, panellists' comments were discussed and taken into account to made edits to the original statements or add new statements as appropriate. A second round of questionnaire was distributed to the whole panel by email. The final list of statements is shown in Table 1.

Panellists were given 2-week time period to complete each round of their survey. The final round was completed as of November 2022.

No patients were involved in this study and Institutional Review Board approval was not necessary.

Statistical analysis

Descriptive statistics were used to summarize the results, and a summary of results was circulated to panellists to inform the second round of the survey.

There were no missing answers since all the answers were mandatory. There was no confidential information required for this study. Data were reported as frequency, number and percentage. Data were collected prospectively. The analysis was performed using Stata 15.1 statistical software (Stata Corp., College Station, TX, USA).

RESULTS

The survey was sent to 29 experts in 2 rounds. The second round was informed by the aggregate and anonymized results from the first round. All 29 experts responded to all statements in both rounds.

The results of the first round are shown in the Appendix. No statement was removed after round 1. However, the wording of 5 statements (statements 8, 13, 15, 19 and 20) was modified based on the comments received in the first round. In addition, statement 15 (concerning the definition of the ISP and the adequate resection margin) was broken down into 2 separate statements (15 and 15a). Similarly, statement 20 (concerning the unexpected finding of positive lymph nodes at definitive pathology) was broken down into 3 separate statements reflecting the nodal stations involved (statements 20, 20a and 20b). Moreover, other 3 statements were added to the original survey taking into account suggestions from the panel (statements 5a, 9a and 20c). Table 2 shows the results of the second and final survey including all 26 statements.

Table 1: Final statements included in round 2 survey

Statements	
1	A segmentectomy should be defined as an anatomic lung resection lesser than a lobectomy and including the dissection and division of the corresponding segmental artery/arteries, bronchi and veins. In some cases, segments may not require the individual division of the segmental vein as venous tributaries are divided along the intersegmental plane
2	This panel discourages the classification of simple versus complex segmentectomy which appears arbitrary
3	Segmentectomies should be classified based on the number of anatomic segments removed into single or multiple segmentectomies (>1 segment removed)
4	The functional benefit of segmentectomies involving >2 segments (i.e. left upper division, basilar segmentectomy) is uncertain and requires further research
5	Preoperative 3D reconstruction is highly recommendable in most cases to better define the location of the tumour, possible anatomic vascular variants and to ensure that adequate resection margins would be achieved with that specific segmentectomy
5a	The availability of a 3D model does not prevent from a precise intraoperative localization of the tumour, whenever it is possible
6	Segmentectomies should be preferably performed by minimally invasive techniques (VATS or robotic) to maximize their functional benefit over larger resections
7	Strategy of the procedure is partly based on the anatomical landmarks as seen in the preoperative 3D reconstruction
8	The availability of a 3D model does not prevent from a precise and extended dissection of the broncho-vascular elements.
9	Control of arteries and bronchus follows the anatomical landmarks.
9a	Before division of the segmental bronchus, it is recommended to use any of the available methods to confirm that you have controlled the correct bronchus (i.e. selective clamping and re-ventilation of the lung; ventilation of the lung-clamping of the selected bronchus and deflation; intraoperative bronchoscopy)
10	Except simple and clear anatomy, the control of the vein is best done within the parenchyma and not at the hilum level as a segmental vein can drain >1 segment.
11	All lymph node stations draining the target segment(s) should be removed. Lymphadenectomy at this level facilitates exposure of the segmental hilar structures.
12	A systematic or lobe-specific lymph node dissection should be performed in all segmentectomies according to the ESTS guidelines for intraoperative lymph node staging. A removal of stations 7, 9, 10 and 11 for segmentectomies of the right and left lower lobes; R4, 7, 10 and 11 in case of right upper lobe segments; 5, 6, 7, 10 and 11 in case of segments of the left upper lobe are recommended as the minimum acceptable extent of nodal dissection
13	Frozen section of the lymph nodes at the foot of the corresponding segmental bronchus should be performed to exclude N1 disease, with these exceptions: pure GGO or compromised segmentectomies (due to poor cardiopulmonary capacity or comorbidities) where a completion lobectomy would not be tolerated
14	In case any lymph node station is found positive for cancer at frozen section examination, a lobectomy should be performed instead of segmentectomy to reduce the risk of local recurrence
15	Intersegmental planes should be identified and defined based on the anatomy of the segment
15a	The location of the tumour should determine the extent of resection (single segment, multiple segments, extended segmentectomy or lobectomy). The recommended distance between the tumour and the intersegmental plane is at least 1 cm or an *M/T* ratio of at least 1
16	The identification of the intersegmental plane can be performed preferably by vascular (i.e. systemic ICG) delineation. If not available, bronchial (inflation/deflation technique) may be used
17	The division of the intersegmental plane should be performed by using staplers to decrease bleeding and postoperative air leak
18	In case of positive margin at intraoperative examination, the segmentectomy should be extended to the adjacent segment or the lobe
19	In case of positive or uncertain margin (tumour seen at the margin when the stapled line is removed by the pathologist) detected only on the final pathological report, the case should be discussed at the Tumour Board and reoperation for completion lobectomy may be considered whenever possible and if reasonable
20	In case of unexpected positive station 11 and 12 lymph node found only on the final pathological report, the patient should be referred to adjuvant chemotherapy and NOT for completion lobectomy
20a	In case of unexpected positive station 10 lymph node found only on the final pathological report, the patient should be referred to adjuvant chemotherapy and NOT for completion lobectomy
20b	In case of unexpected positive mediastinal (pN2) station lymph node found on the final pathological report, the patient should be referred to adjuvant chemotherapy and NOT for completion lobectomy
20c	In case of the presence of STAS detected at definitive pathology, the case should be re-discussed at the Tumour Board and reoperation for completion lobectomy may be an option whenever possible and if reasonable.

GGO: ground-glass opacity; ICG: indocyanine green; VATS: video-assisted thoracic surgery.

Nineteen statements reached a high consensus (≥90% of responders agreed or strongly agreed), 4 reached a consensus (between 75% and 90% of responders agreed or strongly agreed), whereas <75% of responders agreed to 3 statements (statements 2, 20 and 20c) (Tables 3–5). However, the 3 statements with the lowest consensus still reached a 69% agreement level.

DISCUSSION

The objective of this study was to define a set of expert consensus-based principles to assist surgeons in safely implementing the use of segmentectomies in patients with early-stage lung cancer. For most of these topics, the evidence base is lacking or is of a low-quality level. In this context, expert consensus recommendations are legitimate and may address existing evidence gaps by creating a base knowledge for future research in the field. Most importantly, they may assist in safeguarding technical quality standards, ensuring the delivery of oncologically sound operations to our patients by minimizing variation in surgical care.

Definition of segmentectomy (statements 1–4)

A pulmonary segment is the base unit of the lung and has a distinct hilum with a bronchial and vascular supply. Isolation and

Table 2: Results of the second round of the Delphi process (28 responders)

Statements	Strongly agree	Agree	Disagree	Strongly disagree
1	24	4	0	0
2	7	12	9	0
3	18	10	0	0
4	14	14	0	0
5	22	5	1	0
5a	20	7	1	0
6	22	5	1	0
7	16	11	1	0
8	23	5	0	0
9	22	6	0	0
9a	13	14	1	0
10	13	14	1	0
11	26	2	0	0
12	19	7	2	0
13	10	11	7	0
14	16	11	1	0
15	19	9	0	0
15a	12	13	3	0
16	15	12	1	0
17	19	9	0	0
18	26	2	0	0
19	15	12	1	0
20	7	12	7	2
20a	7	15	6	0
20b	16	9	3	0
20c	7	12	9	0

Results are expressed as number of responders in each category.

division of the segmental bronchus/bronchi and artery/arteries ensure adequate resection margins and sampling of lymph nodes [15, 16]. Venous drainage is generally less consistent and segmental veins may optionally be divided along with the parenchyma unless their division at the segmental hilum is necessary to gain exposure to the other structures. Acknowledging a proper definition of segmentectomy is an important quality point to prevent the erroneous classification of wedge resections into this category [12]. This panel agreed with a very high consensus on the above definition of segmentectomy. In addition, the panel agreed with very high consensus on the concept of distinguishing the segmentectomies into single segmentectomies (removal of a single segment) and multiple segmentectomies (removal of >1 segment). This definition has also a functional implication as studies have shown that the maximal functional preservation after segmentectomy is obtained when <2 segments are removed [17]. Recent randomized control trials have shown that segmentectomies are associated with a statistically significant smaller functional loss compared to lobectomies [1, 2], but the median reduction of Forced Expiratory Volume in one second (FEV1) at 6 months was only 3% less after segmentectomy compared to lobectomy. This may be explained by the fact that single and multiple segmentectomies were all grouped together when in fact they may have different functional implications.

Finally, the panel did not reach an agreement on considering the classification into complex segmentectomies as arbitrary. There is indeed an anatomic background to classify a segmentectomy as complex which is when segmentectomy requires a multiplanar development of the ISPs [18].

Consensus-based recommendations:

- Segmentectomies should be defined as lung resections including the dissection and division of at least the corresponding segmental artery/arteries and bronchi. Veins can optionally be divided along the ISP.
- Segmentectomies should be classified into single (removal of only 1 segment) or multiple segmentectomies.

Knowledge gaps:

- The functional benefit of multiple segmentectomies is uncertain and requires further research.
- The scientific and practical merit of classification into simple and complex segmentectomies should be further investigated.

Preoperative planning (statements 5 and 5a)

Pulmonary segmentectomy requires a surgeon to have the full understanding of the anatomy of the lung segment. Therefore, the chest computed tomography (CT) should be carefully reviewed prior to surgery to localize the pulmonary nodule and identify the anatomy of the targeted segments, blood vessels and bronchi. This remains an essential and fundamental step in the preoperative planning of the procedure. Surgeons should become familiar with the radiologic segmental anatomy, especially in relation to the segmental vascular branches. In fact, variations in the anatomy of vessels and bronchi within the lung are frequent and pose new surgical challenges. Thus, knowledge of these variations plays an important role in the planning and implementation of segmentectomy.

Three-dimensional reconstruction can convert 2D images of the pulmonary vessels and bronchi from the chest CT scan into 3D images facilitating the location of the lesion and the identification of the broncho-vascular variations. This panel agreed with a very high consensus that 3D reconstruction can accurately help understand the anatomic structure, clarify the division of the pulmonary segments and determine the location of the lesion and the spatial relationship with the target segment, to decrease the intraoperative risks, improve the safety of the surgery and achieve complete resection. In addition, the use of 3D images may simulate resection margins [19–22].

Several software packages are commercially available that allow free rotation of the 3D images and interactive visualization and relationship between the blood vessels, bronchi and the lesion, including the indication of optimal resection margin [23]. The virtual safety margin (the distance between the edge of the tumour and ISP) can be measured by 3D-CT images to obtain a sufficient surgical margin to prevent loco-regional recurrence [24, 25]. Recent software developments allow precise identification of 98% of pulmonary artery branches and of all vascular variations. According to these studies, the few undetected pulmonary arteries were consistently 1–2 mm in diameter [26–29].

Recent studies have reported shorter operative time, decreased bleeding, smaller rates of postoperative complications and shorter length of drainage when using 3D planning [30–33].

However, the panel recommends careful interpretation of the 3D model. Some small vessels may be missed, or even misinterpreted as a pulmonary vein or artery because most 3D reconstructions are based on a single-phase enhanced CT scan. In

Table 3: Statements that achieved high consensus (≥90%)

Statements	Level of agreement (%)
1. A segmentectomy should be defined as an anatomic lung resection lesser than a lobectomy and including the dissection and division of the corresponding segmental artery/arteries, bronchi and veins. In some cases, segments may not require the individual division of the segmental vein as venous tributaries are divided along the intersegmental plane	100
3. Segmentectomies should be classified based on the number of anatomic segments removed into single or multiple segmentectomies (>1 segment removed)	100
4. The functional benefit of segmentectomies involving >2 segments (i.e. left upper division, basilar segmentectomy) is uncertain and requires further research	100
5 Preoperative 3D reconstruction is highly recommendable in most cases to better define the location of the tumour, possible anatomic vascular variants and to ensure that adequate resection margins would be achieved with that specific segmentectomy	96
5a. The availability of a 3D model does not prevent from a precise intraoperative localization of the tumour, whenever it is possible	96
6. Segmentectomies should be preferably performed by minimally invasive techniques (VATS or robotic) to maximize their functional benefit over larger resections	96
7. Strategy of the procedure is partly based on the anatomical landmarks as seen in the preoperative 3D reconstruction	96
8. The availability of a 3D model does not prevent from a precise and extended dissection of the broncho-vascular elements	100
9. Control of arteries and bronchus follows the anatomical landmarks	100
9a. Before division of the segmental bronchus, it is recommended to use any of the available methods to confirm that you have controlled the correct bronchus (i.e. selective clamping and re-ventilation of the lung; ventilation of the lung-clamping of the selected bronchus and deflation; intraoperative bronchoscopy)	96
10. Except simple and clear anatomy, the control of the vein is best done within the parenchyma and not at the hilum level as a segmental vein can drain >1 segment	96
11. All lymph node stations draining the target segment(s) should be removed. Lymphadenectomy at this level facilitates exposure of the segmental hilar structures	100
12. A systematic or lobe-specific lymph node dissection should be performed in all segmentectomies according to the ESTS guidelines for intraoperative lymph node staging. A removal of stations 7, 9, 10 and 11 for segmentectomies of the right and left lower lobes; R4, 7, 10 and 11 in case of right upper lobe segments; 5, 6, 7, 10 and 11 in case of segments of the left upper lobe are recommended as the minimum acceptable extent of nodal dissection	92
14. In case any lymph node station is found positive for cancer at frozen section examination, a lobectomy should be performed instead of segmentectomy to reduce the risk of local recurrence	96
15. Intersegmental planes should be identified and defined based on the anatomy of the segment	100
16. The identification of the intersegmental plane can be performed preferably by vascular (i.e. systemic ICG) delineation. If not available bronchial (inflation/deflation technique) may be used	96
17. The division of the intersegmental plane should be performed by using staplers to decrease bleeding and postoperative air leak	100
18. In case of positive margin at intraoperative examination the segmentectomy should be extended to the adjacent segment or the lobe	100
19. In case of positive or uncertain margin (tumour seen at the margin when the stapled line is removed by the pathologist) detected only on the final pathological report, the case should be discussed at the Tumour Board and reoperation for completion lobectomy may be considered whenever possible and if reasonable.	96

ICG: indocyanine green; VATS: video-assisted thoracic surgery.

Table 4: Statements that achieved consensus (≥75%)

Statements	Level of agreement (%)
13. Frozen section of the lymph nodes at the foot of the corresponding segmental bronchus should be performed to exclude N1 disease, with these exceptions: pure GGO or compromised segmentectomies (due to poor cardiopulmonary capacity or comorbidities) where a completion lobectomy would not be tolerated	75
15a. The location of the tumour should determine the extent of resection (single segment, multiple segments, extended segmentectomy or lobectomy). The recommended distance between the tumour and the intersegmental plane is at least 1 cm or an *M/T* ratio of at least 1	89
20a. In case of unexpected positive station 10 lymph node found only on the final pathological report, the patient should be referred to adjuvant chemotherapy and NOT for completion lobectomy	79
20b. In case of unexpected positive mediastinal (pN2) station lymph node found on the final pathological report, the patient should be referred to adjuvant chemotherapy and NOT for completion lobectomy	89

GGO: ground-glass opacity.

addition, 3D reconstruction is based on a CT that has been performed with a fully ventilated lung, and the model does not reflect the state of the deflated lung during surgery. This may lead to underestimation of the resection margins and artefacts such as a non-accurate length and/or diameter of a vessel.

During surgery, the confirmation by digital palpation of the exact location of the pulmonary nodule on the lung surface may be difficult due to deeper location within the parenchyma or ground-glass opacity (GGO) composition. Currently, various methods of pulmonary nodule localization [hookwire, coil,

Table 5: Statements that achieved low consensus (<75%)

Statements	Level of agreement (%)
2. This panel discourages the classification of simple versus complex segmentectomy which appears arbitrary	68
20. In case of unexpected positive station 11–12 lymph node found only on the final pathological report, the patient should be referred to adjuvant chemotherapy and NOT for completion lobectomy.	68
20c. In case of the presence of STAS detected at definitive pathology, the case should be re-discussed at the Tumour Board and reoperation for completion lobectomy may be an option whenever possible and if reasonable.	68

methylene blue, indocyanine green (ICG) or lipiodol] have been described with excellent results for intraoperative identification and low associated morbidity [34].

This panel proposes additional intraoperative identification when a nodule is deeply located, not palpable (GGO) or bordering adjacent segments.

Consensus-based recommendations:

- Preoperative 3D reconstruction is highly recommended to better define the location of the tumour, to ensure adequate resection margin and to identify broncho-vascular variants.

Knowledge gaps:

- More research is needed to identify reliable and consistent methods for precise intraoperative localization of the tumour.

Surgical approach (statement 6)

Video-assisted thoracic surgery (VATS) is now the preferred approach for patients with clinical stage I NSCLC. Current data suggest that the VATS approach for lobectomy is associated with better perioperative outcomes, decreased pain, better quality of life [35, 36] and equivalent oncological results in comparison to open resection [37].

Segmentectomy differs from lobectomy in terms of surgical difficulty, and there is limited information about the use of VATS for segmentectomy in lung cancer patients. In a multicentre study comparing VATS segmentectomy ($n = 240$) and VATS lobectomy ($n = 450$), postoperative complication rates were similar (33.3% vs 38%, $P = 0.73$). However, VATS segmentectomy was associated with a shorter length of stay and drainage duration, suggesting that neither the dissection of the ISP nor the parenchymal compression during segmentectomy increased the risk of pulmonary complications [38].

It remains unclear whether VATS segmentectomy may preserve lung function better than VATS lobectomy. A recent prospective observational study comparing VATS segmentectomy ($n = 321$) and VATS lobectomy ($n = 338$) reported that the pulmonary function loss was significantly lower than expected after VATS lobectomy but greater than expected after VATS segmentectomy. These results suggest that less lung parenchyma resected under VATS would not necessarily translate into better pulmonary function preservation. These results could be explained by incomplete re-expansion of the residual lobe after segmentectomy or by better compensation of the remaining lobes after lobectomy [39]. The panel agreed that the pulmonary function benefit after segmentectomy is clinically modest in terms of FEV1 and further studies are necessary to establish the functional consequences of segmentectomy and whether FEV1 is the most accurate parameter to estimate function and well-being after surgery.

A systematic review including 7 studies comparing VATS and open segmentectomy concluded that VATS segmentectomy was technically feasible, and associated with shorter length of hospital stay, decreased postoperative complication rates and shorter duration of chest tube for VATS approach [40].

A recent meta-analysis included 10 articles comparing outcomes of VATS segmentectomy with VATS lobectomy in patients with stage IA NSCLC. The postoperative complication rates were similar with no significant differences between the 2 groups in terms of overall survival and disease-free survival. However, VATS segmentectomy was associated with a shorter length of stay and fewer harvested lymph nodes [41]. The panel agreed with a high level of consensus that despite increased technical complexity, segmentectomies are technically feasible by VATS and are associated with at least similar postoperative outcomes to lobectomies. Therefore, this approach should be preferred to thoracotomy.

Recently, robotic-assisted thoracic surgery (RATS) has increasingly been used for segmentectomy. It may present several advantages, including high-definition three-dimensional vision, improved ergonomics, less steep learning curve, tremor suppression and better manoeuvrability of instruments, which can be useful during segmentectomy. However, recent studies did not report any clinical or oncological advantage of RATS over VATS, with the exception of a greater number of lymph nodes or nodal stations sampled [42, 43]. This panel is therefore unable to recommend 1 approach over the other and further studies are necessary to determine their full advantage profiles [44, 45].

Consensus-based recommendations:

- Segmentectomies should be preferably performed by minimally invasive approach to improve postoperative outcomes.

Knowledge gaps:

- More investigations are needed to determine the relative benefits of the type of minimally invasive approach (VATS or RATS).
- The functional benefits of minimally invasive segmentectomy over minimally invasive lobectomy are not well reflected in the measurement of perioperative FEV1. More investigations are needed taking into account additional functional parameters or patient-reported outcomes to clarify this point.

Procedural steps (statements 7–10)

A detailed description of the technical steps of each individual segmentectomy is outside the scope of this project. The panel agreed on a few high-level statements covering this topic with the aim to provide guidance to ensure an oncologically sound and safe procedure. All 4 procedural steps statements (no. 7–10) reached high consensus. In particular, they emphasize the concept of performing a meticulous dissection of the segmental hilar structures which would prevent the division of erroneous structures and ensure the preservation of those pertinent to the remaining segments. Although different segmentectomies may entail different technical steps or approaches (fissure-based or fissure-last), this principle of a precise exposure of the hilar structures (arteries, bronchus and possibly veins) should be maintained.

As mentioned, the use of 3-D reconstruction is of great assistance in identifying the segmental hilar vessels and bronchi and the presence of variations. However, 3-D reconstruction should not prevent the surgeon to adopt a meticulous broncho-vascular dissection following the anatomic landmarks of the segment.

In addition to a precise dissection, the surgeon should ensure before definitive transection that the isolated segmental bronchus is the one afferent to the target segment to be removed. Different methods are available for this purpose (i.e. selective clamping and re-ventilation of the lung; ventilation of the lung-clamping of the selected bronchus and deflation; intraoperative bronchoscopy).

The panel is not able to recommend one over the other method but advise their use prior to bronchial division.

One of the most challenging procedural steps during segmentectomy is the multiplanar division of the ISP. This is especially true in basilar segmentectomies where their pyramidal shape requires the reduction of a three-dimensional structure into a two-dimensional or linear structure for resection. This requires the use of a marking technique that precisely delineates the plane [such as infrared imaging (IRI)] and progressive and step-by-step stapling. An efficient dimensional reduction approach preserves the resection boundaries in line with the natural boundaries of the segment and ensures adequate resection margins.

Finally, statement 10 deals with the management of segmental veins. Among the hilar structures, segmental veins are the ones with the greatest frequency of variations. To prevent the division of a segmental vein draining also another segment this panel encourages the division of the vein as the very last structure (after division of the artery and bronchus) and at the most peripheral site as possible. For some types of segmentectomy, the initial division of the segmental vein at the segmental hilum may be useful to gain exposure of the other hilar elements (artery and bronchus). However, for most of the segmentectomies, the control of the vein can be and should be done within the parenchyma during the division of the ISP.

Consensus-based recommendations:

- Segmentectomies should be performed by adopting a meticulous, precise and peripheral dissection of the hilar elements of the target segment following the anatomic landmarks and assisted by 3-D reconstruction.
- Division of the segmental bronchus should be preceded by a measure to ascertain that the isolated bronchus corresponds to the target segment to be removed.
- Whenever possible the segmental veins should be divided as peripherally as possible and preferentially along the division of the ISP (not at the hilum).*

*Remark: The division of the segmental vein along the ISP whenever anatomically and surgically feasible should not prevent omission of a meticulous dissection and isolation of the segmental hilar structures which is a fundament of segmentectomy.

Intraoperative lymph node management (statements 11–14)

The loco-regional recurrence rate after segmentectomy is significantly higher than after lobectomy [1, 2]. Factors such as insufficient resection margins, inadequate lymph node dissection, presence of STAS or more locally aggressive behaviour of certain tumours may explain this finding [46].

Several authors have shown the importance of the total number of sampled lymph nodes [47].

In addition, some studies have shown that a larger number of sampled lymph nodes during segmentectomy is associated with a higher rate of metastatic lymph nodes (>6 nodes associated with 9.4% positive ones vs 6 or less nodes sampled associated with 1.5% positive nodes) and better survival at 5-year [48]. Similarly, in a series of 3916 patients operated on for stage I NSCLC by sublobar resections, the only prognostic factor for 5-year survival was the number of examined lymph nodes, while the extent of resection did not have a significant influence [49]. Similarly, in a series of 1991 lepidic adenocarcinomas submitted to either lobectomy or segmentectomy, survival was significantly better after lobectomy, except in the sublobar resections subgroup associated with lymph node dissection [50].

The panel agreed with a high level of consensus that a complete dissection of the segmental nodes adjacent to the target segment and an intraoperative hilar and mediastinal nodal staging according to the ESTS guidelines [51] should be performed during segmentectomy to ensure oncologic standards.

The panel agreed (75% consensus) that a frozen section examination on the lymph nodes located at the segmental bronchus of the target segment should be performed and if those lymph nodes turn out positive a lobectomy rather than segmentectomy should be performed. This is mostly based on observation that

40% of patients showing metastatic lymph nodes adjacent to the target segment have also hilar or mediastinal lymph node metastasis [52]. Performing a sublobar resection in the context of segmental nodal metastasis may increase the risk of local recurrence. On the other hand, some panel members expressed an opposite view focusing more on the fact that patients with nodal spread have a systemic disease that needs mostly a systemic treatment rather than a more extended local resection, which may in fact preclude the receipt of adjuvant chemotherapy in case of postoperative complications or poor performance status.

Logistic factors should also be taken into account such as the prolonged time necessary to perform frozen section examination in different hospitals. Another argument against systematic intraoperative assessment of segmental lymph nodes is the fact that frozen section is not completely reliable with a sensitivity of only 85% [53].

When a frozen section on the segmental nodes is systematically performed, authors have reported a conversion rate to lobectomy of about 5–7% [54, 55].

Consensus-based recommendations:

- During segmentectomy, a thorough lymphadenectomy including the lymph nodes draining the target segment and a systematic or lobe-specific hilar and mediastinal node dissection according to the ESTS guidelines should be performed.
- A frozen section on the segmental nodes should be performed in all cases (with the exception of pure GGO lesions or patient unfit for lobectomy), and in case of a positive node found at frozen section examination, the segmentectomy should be extended to lobectomy.

Intraoperative management of intersegmental planes (statements 15–18)

Delineation and division of the ISP is one of the most critical and sometimes difficult steps during segmentectomy.

This step ensures that an oncologically safe distance of tumour from resection margins is achieved without unnecessary resection of adjacent lung tissue pertinent to other segments. The panel reached consensus in all statements about intraoperative management of ISP.

An important aspect of this topic is the recommendation to use one of the available methods to define the ISP always guided by the anatomy of the segment and the location of the tumour.

Several methods have been proposed in the literature to define the ISP. Certainly, one of the most used is the inflation–deflation technique (re-ventilation of the lung after clamping of the target bronchus). Although conceptually acceptable this method is often made imprecise by the presence of collateral ventilation.

The selective inflation is a similar technique in which the target segment is maintained inflated while the rest of the lung is deflated. This is achieved by clamping the target segmental bronchus after inflation of the whole lung and then excluding the lung after clamping. This allows the rest of the lung to deflate while the target segment remains inflated.

The preferable method according to this panel is the use of near IRI with ICG injection after the division of the segmental vessels and bronchi. This causes all parenchyma to become fluorescent with the exception of the segment to be resected [56, 57]. A success rate above 90–95% has been reported [58, 59].

Similar to other methods, ISP definition by ICG may be inaccurate in case of severe COPD due to the reduction of the vascular bed in the parenchyma of these patients [60].

The panel agreed on the recommendation to divide the ISP by using staplers over the more conventional method of using electrocautery or other sealing devices.

Staplers have the advantage to reduce the risk of bleeding and air leak [61]

Some authors have however criticized the use of staplers to divide the ISP as it could impair lung re-expansion and compromise the intersegmental vein, which, could in turn impair gas exchanges in the preserved segment [62].

A recent prospective randomized study comparing stapling versus electrocautery to dissect ISPs in segmentectomy patients was stopped early due to a significantly increased rate of pulmonary air leak after electrocautery dissection (34.4% vs 6.1%, $P = 0.004$) [63].

Regarding the safe minimum distance of the tumour from the resection margins a recent systematic review has shown that the deflection point for increased local recurrence is a distance of shorter than 1 cm or a margin distance-to-tumour diameter ratio of smaller than 1 [64].

Consensus-based recommendations:

- The ISPs should be defined based on the anatomy of the segment and identified using preferably near IRI with ICG systemic injection.
- The location of the tumour should determine the extent of resection (single segment, multiple segments, extended segmentectomy or lobectomy) to ensure safe oncological margins (1 cm distance or margin/tumour ratio >1).
- In case of positive margins at intraoperative pathologic examination, the resection should be extended to the adjacent parenchyma (up to a completion lobectomy).
- The division of the ISP should be performed preferably by staplers.

Management of positive resection margins (statement 19)

The major concern when implementing segmentectomy on a large scale for early-stage lung cancer is the increased risk of local recurrence. Despite the favourable overall survival for segmentectomy in the JCOG0802 trial, the incidence of local recurrence was 10.5% in the segmentectomy arm vs 5.4% in the lobectomy arm ($P = 0.0018$). The disease-free survival was equal between the 2 groups [1]. In this trial, frozen section or cytological examination on the resection margins was performed intraoperatively if the resection margin was less than the tumour/margin ratio or <2.0 cm. In case of a positive margin or suspicion of a positive margin, additional resection was mandatory. Only 4 of the 550 patients in the segmentectomy arm underwent conversion to

lobectomy intraoperatively and 3 patients underwent completion lobectomy after the final pathology. When sending margins for frozen section intraoperatively it is important to mark the resection margins to guide the pathologists. However, positive margins discovered at final pathology, usually 2 weeks after primary surgery can be a challenge. Depending on the patient's comorbidity, physical function and lung function, a completion segmentectomy or more often a completion lobectomy may be considered. The decision should be taken by a Multidisciplinary Tumour Board and presented to the patient as a shared decision. Completion lobectomies are often more difficult due to adhesions and fibrosis around the vessels in the hilum, however feasible with an acceptable complication rate [65]. A majority of 96% of the panellists found that in case of positive or uncertain margin (tumour seen at the margin when the stapled line is removed by the pathologist) detected only on the final pathological report, the case should be discussed at the Tumour Board and reoperation for completion lobectomy may be considered whenever possible and if reasonable.

Management of unsuspected positive lymph nodes (statements 20–20b)

The incidence of nodal upstaging on final pathology in the JCOG 0802 trial was 3.1% for pN1 and 3.1% for pN2, despite the recommendation of an intraoperative frozen section on lymph nodes and conversion from segmentectomy to lobectomy in case of positive frozen section. In the segmentectomy arm, 16 patients (2.9%) were switched to lobectomy due to positive hilar or mediastinal lymph nodes detected at frozen section [1]. It is controversial whether a completion lobectomy should be performed before sending the patient to adjuvant chemotherapy. A recent study analysed 4556 node-positive patients with stage Ia NSCLC from the National Cancer Database and compared 115 segmentectomies with 4441 lobectomies. Adjuvant chemotherapy was administered to 71% in the segmentectomy group and 77% in the lobectomy group. On the multivariate Cox regression analysis, there was no difference in overall survival between the segmentectomy group and the lobectomy group. Based on these results the authors suggested that it may not be compulsory to perform completion lobectomy in well-selected patients for segmentectomy [66]. In addition, Rezi and coll. recently analysed clinical stage I patients from the National Cancer Database with unsuspected positive N1 or N2 nodes found after surgery. They found that the extent of resection (segmentectomy or lobectomy) was not associated with different overall survival (OS). The only factor associated with OS after multivariable regression was receiving adjuvant chemotherapy [67].

There was consensus among the panellists in this study to the statement: in case of unexpected positive station lymph nodes stations 10 or mediastinal lymph nodes node found only on the final pathological report, the patient should be referred to adjuvant chemotherapy and NOT for completion lobectomy with 79% and 89% agreement. However, in case of positive nodes found at stations 11 and 12, consensus was not obtained (68%). This seems an apparent discrepancy with the majority of surgeons agreeing to extend the segmentectomy to a lobectomy in case positive segmental or hilar nodes are detected intraoperatively at frozen section examination (see statement 14). It is clear that bringing back a patient to surgery 2–3 weeks after the original operation to perform a completion lobectomy is perceived as a greater trauma than proceeding to a lobectomy in the same setting. Potential delay in adjuvant systemic treatment in case of a second operation should also be accounted for as a factor against completion lobectomy after definitive pathology.

Management of spread through air space (statement 20c)

The concept of STAS was introduced in the World Health Organization classification in 2015 and defined as 'spread of micropapillary clusters, solid nests, and/or single cancer cells into airspaces in the lung parenchyma beyond the edge of the main tumour' and is considered a pattern of invasion [68].

In a propensity score-matched study of 1497 T1N0M0 patients with adenocarcinoma, the incidence of recurrence was significantly increased in sublobar resections compared to lobectomy (high resolution (HR) 2.84; $P < 0.001$) in patients with STAS. This difference was independent of the tumour/margin ratio, supporting completion lobectomy for patients with the presence of STAS after sublobar resection [69]. Likewise, another recent study from Japan analysed 555 patients with stage Ia NSCLC and showed that STAS was correlated with worse recurrence-free survival and OS. However, in this case, there was no difference between lobectomies and segmentectomies. Nevertheless, wedge resections had a significantly higher local recurrence rate [70]. Consensus was not obtained by the panel (68%) on the statement to refer the patient to completion lobectomy in case of STAS detected at definitive pathology.

Consensus-based recommendations:

- In case of positive or uncertain margin (tumour seen at the margin when the stapled line is removed by the pathologist) detected only on the final pathological report, the case should be discussed at the Tumour Board and reoperation for completion lobectomy may be considered whenever possible and if reasonable.
- In case of unexpected positive station 10 lymph node found only on the final pathological report, the patient should be referred to adjuvant chemotherapy and NOT for completion lobectomy.
- In case of unexpected positive mediastinal (pN2) station lymph node found on the final pathological report, the patient should be referred to adjuvant chemotherapy and NOT for completion lobectomy.

Knowledge gaps:

The role of completion lobectomy for STAS or positive hilar lymph nodes detected at final pathology is uncertain and needs further study in prospective trials.

Limitations

- Delphi studies are driven by expert opinions and may be subject to biases. We tried to minimize biases by including a sizeable group of experts representing diverse European healthcare systems and clinical practices.

- The determination of the group of experts participating in this survey was based on pre-defined criteria (such as ESTS membership, contribution to the ESTS database of a certain volume of segmentectomies, and affiliation to ESTS working groups dealing with minimally invasive surgery) to minimize subjectivity in the selection process. However, the panel recognizes that by using these criteria some surgeons with a relevant experience in the topic may have been missed and not invited to vote.
- Assembling a group of experts with the same interests and opinions may lead to a specific selection bias. This needs to be taken into consideration when interpreting the results.
- In particular, the conclusions from this survey may not reflect the opinion of a wider thoracic surgery community with variable levels of surgical experience in performing segmentectomies.
- As with all surveys, the wording of the statements may have influenced the responses. However, the statements were initially agreed by the steering group and were further modified if necessary, taking into account the input from the wider panel after the first round.
- Although the results of this survey represent expert opinions and cannot be properly defined as evidence based, they may be used as a practical guide for surgeons in the absence of a higher level of evidence specific to the technique of segmentectomy. In addition, consensus methods such as Delphi process have been shown to have acceptable construct validity [71] and reliability [72]. They can be used to develop an evidence base that can guide decisions, overcoming the obvious limitations of relying on individual experience.

Delphi process embodies the concept of practice-based evidence, which is readily implementable within the healthcare system by capitalizing on accumulated practical experience [73].

CONCLUSIONS

The panel was able to generate a series of consensus-based recommendations on the technical aspects of segmentectomy for early-stage NSCLC. These recommendations represent useful guidance to safely implement this procedure on a wider scale in the thoracic community by preserving the oncological principles of lung cancer surgery. In addition, a number of knowledge gaps were also identified which can be used to design future studies to expand the knowledge on this subject and improve quality of care.

Conflict of interest: Alessandro Brunelli: Advisory Board role and speaker honoraria with Astra Zeneca, MSD, BMS and Ethicon. Dominique Gossot: Consulting fees with Delacroix-Chevalier. Speaker fee from Medtronic, Johnson & Johnson, Olympus. Rene H Petersen: Advisory Board: AstraZeneca, Roche, MSD, BMS. Speaker fee: Medtronic, AMBU, Medela, AstraZenecaHenrik Hansen: Speaker fees from Medtronic and BD. Pierre Benoit Pages: consulting fee from Intuitive Surgical. Isabelle Opitz: Advisory Board with Astra Zeneca, MSD and BMS. Speaker fees from Astra Zeneca and Roche. Consulting fees with Intuitive Surgical. Institutional grant: Roche and Medtronic. Giulia Veronesi: Consulting fees from Ab Medica SpA, Astra ZENECA, ROCHE, Intuitive Surgical.

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DATA AVAILABILITY

The data underlying this article are available in the article and in its online supplementary material.

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Appendix

Table A1: Results of the first round of Delphi process

Statements	Strongly agree	Agree	Disagree	Strongly disagree
Statement 1: A segmentectomy should be defined as an anatomic lung resection lesser than a lobectomy and including the dissection and division of the corresponding segmental artery/arteries, bronchi and veins. Certain segments may not require the individual division of the segmental vein as venous tributaries are divided along the intersegmental plane	21	5	2	0
Statement 2: This panel discourages the classification of simple versus complex segmentectomy which appears arbitrary	6	12	9	1
Statement 3: Segmentectomies should be classified based on the number of anatomic segments removed into single or multiple segmentectomies (>1 segment removed)	14	11	3	0
Statement 4: The functional benefit of segmentectomies involving >2 segments (i.e. left upper division, basilar segmentectomy) is uncertain and requires further research	13	13	2	0
Statement 5: Preoperative 3D reconstruction is highly recommendable in all cases to better define the location of the tumour, possible anatomic vascular variants and to ensure that adequate resection margins would be achieved with that specific segmentectomy	17	9	2	0
Statement 6: Segmentectomies should be preferably performed by minimally invasive techniques (VATS or robotic) to maximize their functional benefit over larger resections	21	3	4	0
Statement 7: Strategy of the procedure is partly based on the anatomical landmarks as seen in the preoperative 3D reconstruction	14	13	1	0
Statement 8: The availability of a 3D model does not prevent from a precise and extended dissection of the broncho-vascular elements. This is best achieved by a 'fissure-based technique'	14	9	3	2
Statement 9: Control of arteries and bronchus follows the anatomical landmarks.	23	5	0	0
Statement 10: Except simple and clear anatomy, the control of the vein is best done within the parenchyma and not at the hilum level as a segmental vein can drain >1 segment.	10	14	4	0
Statement 11: All lymph node stations draining the target segment(s) should be removed. Lymphadenectomy at this level facilitates exposure of the segmental hilar structures.	21	7	0	0
Statement 12: A systematic or lobe-specific lymph node dissection should be performed in all segmentectomies according to the ESTS guidelines for intraoperative lymph node staging. A removal of stations 7, 9, 10 and 11 for segmentectomies of the lower lobes; R4, 7, 10 and 11 in case of right upper lobe segments; 5, 6, 7, 10 and 11 in case of segments of the left upper lobe are recommended as the minimum acceptable extent of nodal dissection	15	10	3	0
Statement 13: Frozen section of the nodes at the foot of the corresponding segmental bronchus should be performed to exclude N1 disease, with these exceptions: pure GGO or subsolid lesions with C/*T* ratio <0.5, compromised segmentectomies (due to poor cardiopulmonary capacity or comorbidities) where a completion lobectomy would not be tolerated	7	15	5	1
Statement 14: In case any lymph node station is found positive for cancer at frozen section examination, a lobectomy should be performed instead of segmentectomy to reduce the risk of local recurrence	15	9	4	0
Statement 15: Intersegmental planes should be identified and defined based on the anatomy of the segment and the location of the tumour. The recommended distance between the tumour and the intersegmental plane is at least 1 cm or an *M*/*T* ratio of at least 1	11	9	8	0
Statement 16: The identification of the intersegmental plane can be performed preferably by vascular (ICG) delineation. If not available bronchial (inflation/deflation technique) may be used	13	15	0	0
Statement 17: The division of the intersegmental plane should be performed by using staplers to decrease bleeding and postoperative air leak	16	11	1	0
Statement 18: In case of positive or doubtful margin at intraoperative examination the segmentectomy should be extended to the adjacent segment or the lobe	22	5	1	0
Statement 19: In case of positive or doubtful margin detected only on the final pathological report: a reoperation for completion lobectomy should be offered whenever possible and if reasonable	18	10	0	0
Statement 20: In case of unexpected positive lymph node found only on the final pathological report the patient should be referred to adjuvant chemotherapy and NOT for completion lobectomy	7	13	8	0

GGO: ground-glass opacity; ICG: indocyanine green; VATS: video-assisted thoracic surgery.