Three-dimensional virtual lung reconstruction in robotic segmentectomy: A safety and feasibility trial

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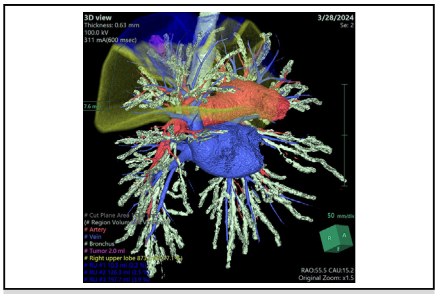
ABSTRACT

Objective: Robotic pulmonary segmental resection is a technically challenging procedure. Near-infrared fluorescence mapping with intravascular indocyanine green dye is a valuable adjunct; however, conversion to lobectomy still occurs in up to 40% of cases. We hypothesized that the incorporation of 3-dimensional virtual lung reconstruction would result in low rates of conversion from segmentectomy to lobectomy and increased confidence in the surgical plan.

Methods: A prospective single-center cohort trial was conducted to determine the safety and feasibility of this approach. Patients undergoing robotic segmentectomy for clinical stage I non–small cell lung cancer less than 3 cm were enrolled, and 3-dimensional reconstruction was performed with confidence scores assigned before and after 3-dimensional reconstruction. Adverse events, rates of conversion to lobectomy, and changes in confidence scores were recorded and analyzed.

Results: A total of 79 patients were enrolled from December 2022 to April 2024, and 76 patients (96.20%) underwent surgery. Three-dimensional reconstruction was successfully performed in 88.16% (67/76) of cases, and indocyanine green dye was used in 68.66% (46/67) with no adverse events related to its use. The 30-day mortality was 1.49% (1/59). The majority of patients (80.60%; 54/67) underwent a successful segmentectomy, whereas 8.96% (6/67) of cases were converted to lobectomy after segmentectomy was started. The planned operation was modified after 3-dimensional reconstruction in 36.07% (22/61) of cases leading to a significant increase in confidence scores ($P < .001$).

Conclusions: Three-dimensional lung reconstruction in targeted robotic segmental resection is associated with low rates of conversion to lobectomy and increased surgeon confidence. Further studies are warranted to establish the effectiveness of this technique. (JTCVS Techniques 2025;29:150-60)



3D virtual lung model for planning of right S1 resection generated by Synapse 3D.

CENTRAL MESSAGE

3D virtual lung reconstruction in robotic segmentectomy is associated with a low rate of conversion to lobectomy and improved surgeon confidence.

PERSPECTIVE

This study demonstrates that in patients undergoing robotic segmentectomy, 3D virtual lung reconstruction for preoperative planning is associated with low rates of conversion to lobectomy, a change in the target segment in more than one-third of cases, and increased confidence in the preoperative plan. Adoption of this approach may be beneficial.

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Abbreviations and Acronyms

CR	= confidence rating
CT	= computed tomography
ICG	= indocyanine green
IQR	= interquartile range
NIF	= near-infrared fluorescence
3D	= 3-dimensional
VATS	= video-assisted thoracoscopic surgery

▶ Video clip is available online.

To view the AATS Annual Meeting Webcast, see the URL next to the webcast thumbnail.

Lung cancer screening has led to an increase in the number of cases diagnosed at an earlier stage.[1-3] As emphasized by Vanstraelen and colleagues,[3] the current trend toward minimally invasive resection with preservation of healthy lung tissue has led to an increased need for detailed preoperative planning and accurate tumor localization.[3] Contemporary studies provide evidence of a range of improved outcomes in patients undergoing robotic segmentectomy compared with open or video-assisted thoracoscopic surgery (VATS) anatomic sublobar resection.[4] Nevertheless, robotic segmentectomy remains a technically challenging operation, and basal segmental resections are rarely completed without the help of imaging adjuncts.[5] Near-infrared fluorescence (NIF) mapping using intravascular indocyanine green (ICG) dye has been shown to improve the identification of the intersegmental plane and improve oncological margins.[6,7] However, with or without the use of ICG, the rate of conversion from planned segmentectomy to lobectomy ranges from 7% to 40%.[7,8] This is primarily due to the difficulty in accurately identifying the segmental bronchovascular anatomy of the lesion of interest.[7]

Three-dimensional (3D) lung reconstruction with virtual modeling provides an opportunity to visualize the tumor within the target segment and confirm bronchovascular anatomy,[3,9,10] thereby allowing for optimal surgical planning. Although there are published data evaluating the feasibility of 3D reconstruction in VATS segmental resection,[10,11] there is little prospective evidence assessing the utility of 3D reconstruction as a preoperative tool that could enhance the completion rate of robotic segmentectomy.

The aim of this study is to determine the rate of conversion from robotic segmentectomy to lobectomy when preoperative planning is performed with 3D reconstruction.

MATERIAL AND METHODS

Study Design and Patients

This is a single-center, prospective cohort trial involving patients undergoing robotic segmental lung resection at a high-volume tertiary center in which the primary surgeon performs more than 25 pulmonary resections annually[12] (St Joseph's Healthcare Hamilton, Hamilton, Ontario, Canada) and was granted ethics approval on September 12, 2019, by the Hamilton Integrated Research Ethics Board (Project #6006). Eligible patients were 18 years of age or older with suspected or confirmed clinical stage I non–small cell lung cancer with tumors less than 3 cm in diameter and a preoperative computed tomography (CT) of the thorax confirming that the tumor was confined to 1 bronchopulmonary segment, thereby rendering the patient a candidate for segmental resection. Patients who had a history of hypersensitivity or allergy to contrast dye were excluded along with women who were pregnant, breastfeeding, or of childbearing potential and not on adequate contraceptives.

Patients were prospectively enrolled at the time of consent for surgery and were followed for 30 days postoperatively. Baseline data were collected including demographic characteristics, medical history, smoking history, social history, current diagnosis, previous cancer diagnoses, preoperative test results including pulmonary function tests, and preoperative staging.

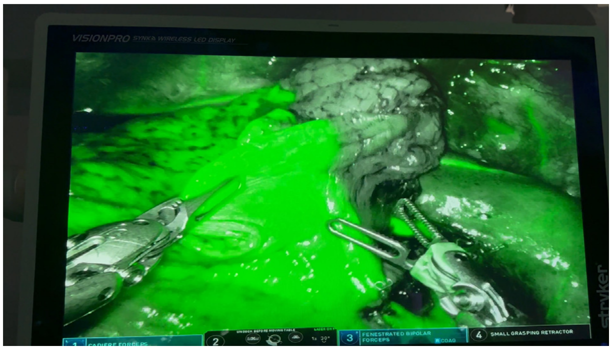
Generation of 3D Model

All patients underwent a high-resolution CT scan of the chest with 0.625-mm slices with contrast in the pulmonary artery phase before the operation. These images were used for 3D modeling using Synapse 3D (Fujifilm). The 3D model was used for operative planning; identifying the corresponding segmental bronchus, pulmonary arteries, and veins; simulating the segmental resection based on arterial division; and measuring margins between the tumor and the planned intersegmental plane (Video 1). Perioperative complications, chest tube duration, length of hospital stay, and 30-day morbidity and mortality rates were recorded.

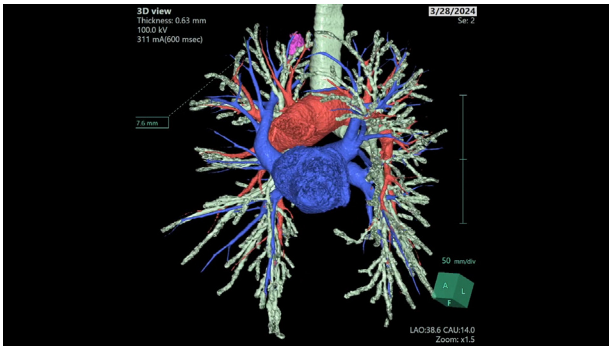
The trial was granted a no objection letter from Health Canada authorizing the off-label use of ICG (Control #227838) and was conducted in full compliance with the Canadian Tri-Council Policy Statement on Ethical Conduct for Research Involving Human Subjects. All participants provided full informed consent for the operative procedure as well as the use of ICG and Synapse 3D in the context of a clinical trial.

Objectives

The primary objective of this study is to determine the rate of conversion from segmentectomy to lobectomy when preoperative planning is performed



VIDEO 1. The 3D model was used for operative planning, identifying the corresponding segmental bronchus, pulmonary artery(s) and vein(s), simulating the segmental resection based on arterial division, and measuring margins between the tumor and the planned intersegmental plane. Video available at: https://www.jtcvs.org/article/S2666-2507(24)00499-1/fulltext.



VIDEO 2. Following ligation of the corresponding segmental artery(s), vein(s) and bronchus, ICG was administered to allow for identification of the intersegmental plane.. Video available at: https://www.jtcvs.org/article/S2666-2507(24)00499-1/fulltext

with 3D reconstruction. The safety of the operation was also evaluated based on rates of postoperative complications within 30 days of surgery, as defined by the Ottawa Thoracic Morbidity and Mortality classification system.[13] Other secondary objectives and outcomes include the overall success rate of the operation, surgeon confidence, rate of conversion to thoracotomy, duration of chest tubes in situ, length of stay in hospital, length of time of procedure, number of lymph node stations sampled, number of lymph nodes sampled, intraoperative blood transfusion rate, and estimated blood loss.

Preoperative and Intraoperative Outcome Measures

The ability of the operating surgeon to identify the appropriate bronchopulmonary segment, along with its corresponding pulmonary arteries and veins based on the preoperative CT scan, was captured using a binary response questionnaire (Figure 1). The level of confidence of the surgeon in the preoperative plan was assessed by a 5-item Likert scale that was developed based on input by experienced thoracic surgeons and consensus by the research team (Figure 1). This scale measures the confidence rating (CR) of the operating surgeon in the ability to identify the segmental anatomy and execute the operative plan in vivo. The CR was measured 3 times: first, preoperatively, based on the preoperative CT scan before generation of the 3D model (CR_{CT}; Figure 1, *A*); a second time, preoperatively, based on the 3D model (CR_{3D}; Figure 1, *B*); and a third time postoperatively, based on palpation of the resection specimen. Changes in both the CR of the surgical plan before and after 3D reconstruction were captured using binary-response questions (Figure 1, *B*).

Operative Technique

All robotic pulmonary segmental resections were conducted by a single surgeon on the DaVinci Xi (Intuitive Surgical) robotic platform, using the RPS-4 approach[7,14] and Firefly Fluorescence Imaging camera (Intuitive Surgical) as a NIF light source. Conversion to lobectomy was performed when N1 disease was suspected intraoperatively or confirmed on frozen section, when positive margins were suspected, or when the tumor was not found in the resection specimen. Conversion to thoracotomy occurred due to intraoperative complications or failure to progress robotically.

After ligation of the corresponding segmental arteries, veins, and bronchus, ICG was administered to allow for identification of the intersegmental plane (Video 2). ICG was reconstituted using distilled water to produce a 2.5 mg/mL solution, and a volume of 8 mL was injected intravenously via a peripheral venous catheter, followed by a 10-mL flush of sterile normal saline.[6,15] After injection of ICG, the parenchyma was visualized using the integrated fluorescence imaging feature of the Firefly camera, with the intersegmental plane being demarcated by the lack of green color to the target segment. This plane was then definitively demarcated using cautery to allow for accurate stapling of the lung parenchyma. In select cases in which the tumor was easily visible on the parenchymal surface, ICG administration was not performed, because the surgeon could visually maximize margin distance between the visible tumor and the staple line. After retrieval of the surgical specimen, anatomic accuracy was evaluated by the operating surgeon based on ex vivo localization of the lesion and ex vivo confirmation of tumor-free margins around the lesion.

Statistical Analysis

Statistical analyses were performed using the statistical software SPSS [IBM 2023, Version: 29.0.2.0(20)]. Descriptive statistics were used to summarize patient demographics, staging information, surgical data, and each of the proposed outcome variables. Mean [SD] and median [interquartile range (IQR)] values were calculated for continuous variables. Frequencies and percentages were computed for categorical variables where feasible. Differences in CRs before and after 3D reconstruction were analyzed using the related samples Wilcoxon signed-rank test. Backward stepwise logistic regression was performed using pathologic T stage, pathologic N stage, use of ICG, successful 3D reconstruction, lobar location of the lesion, and change in the target segment after 3D reconstruction. Missing data were accounted for by stepwise deletion for regression analysis or listwise deletion for all other analyses where applicable.

RESULTS

Of the 96 patients screened, 79 (82.29%) were eligible and enrolled in the trial between December 2022 and April 2024, with 67 (84.81%) undergoing surgery with 3D modeling (Figure 2). Patient characteristics are presented in Table 1. Seven participants (7/79; 8.86%) were withdrawn because the models were not successfully generated based on the high-resolution CT scans. 3D reconstruction was successful in 67 of 76 patients (88.16%), and ICG was used in 68.66% (46/67) with no adverse events related to its use. Of the 67 planned and attempted segmentectomy cases with 3D modeling, the majority (54/67; 80.60%) received a successful segmental resection. In 10.45% (7/67) of cases, the planned segmental resection was never started because the 3D model predicted that a lobectomy should be done (7.46%; 5/67) or because of conversion to thoracotomy before docking the robot due to dense adhesions (2.99%; 2/67) (Figure 2). In 8.96% (6/67), the planned segmentectomy was started, but could not be completed, and was converted to lobectomy. Five (5/6; 83.33%) of those conversions were to robotic lobectomy for the following reasons: [n = 1 for suspicion of positive margins, n = 1 for inability to perform the segmentectomy that the Synapse 3D virtual model proposed, n = 1 for failure to ventilate remaining segments, n = 2 for oncological purposes (frozen section on lymph node came back suspicious for malignancy; and frozen section on tumor likely related to a mucinous adenocarcinoma with intraparenchymal skip lesions)], whereas 1 (1/6; 16.67%) was to open lobectomy for bulky lymphadenopathy. Backward stepwise logistic regression revealed no predictors of successful completion of segmentectomy or conversion to lobectomy after planned segmentectomy had started.

The most common lobe involved in the planned segmental resection was the right upper lobe (21/67;

Prior to Surgery - Based on CT Scan Only	
Able to identify the segment in which the lung nodule is located based on CT Scan only?	○ Yes ○ No
Indicate Lobe	☐ RUL ☐ RML ☐ RLL ☐ LUL ☐ LLL
Indicate Segment	☐ Apical Segment (S1) ☐ Posterior Segment (S2) ☐ Anterior Segment (S3)
Inidicate Segment	☐ Lateral Segment (S4) ☐ Medial Segment (S5)
Indicate Segment	☐ Superior Segment (S6) ☐ Medial Segment (S7) ☐ Anterior Segment (S8) ☐ Lateral Segment (S9) ☐ Posterior Segment (S10)
Indicate Segment	☐ Apical Segment (S1) ☐ Posterior Segment (S2) ☐ Anterior Segment (S3) ☐ Superior Lingular Segment (S4) ☐ Inferior Lingular Segment (S5)
Indicate Segment	☐ Superior Segment (S6) ☐ Medial Segment (S7) ☐ Anterior Segment (S8) ☐ Lateral Segment (S9) ☐ Posterior Segment (S10)
Able to identify the corresponding pulmonary artery and pulmonary vein based on CT Scan only?	○ Yes ○ No
Provide Confidence Rating based on CT Scan only	○ 1 Not at all confident ○ 2 Somewhat confident ○ 3 Confident ○ 4 Very confident ○ 5 Extremely confident

A

FIGURE 1. A, Assessment tool used to assess surgeon confidence based on index CT scan. B, Assessment tool used to assess surgeon confidence based on 3D virtual model and resected specimen. *CT*, Computed tomography; *3D*, 3-dimensional.

31.34%) (Table 1). The most frequently planned segmental resection on the right side based on the index CT scan was resection of the apical and posterior segments (S1+S2) of the right upper lobe (5/67; 7.46%) (Table 2). The most frequently planned segmental resection on the left side based on the index CT scan was a resection of the apicoposterior segment (S1+2) (7/67; 10.45%) (Table 2). The most frequently planned segmental resections on the right side after 3D reconstruction were resection of S2 of the right upper lobe (5/59; 8.47%) and resection of S1+S2 of the right upper lobe (5/59; 8.47%). Conversely, the most frequently planned segmental resections on the left side after 3D reconstruction were resection of S1+2 of the left upper lobe (5/59; 8.47%) and resection of the apicoposterior and anterior segments (S1+2+S3) of the left upper lobe (5/59; 8.47%). Of the patients who had successful segmentectomy, the most common resection on the right side was resection of S2 of the right upper lobe (5/54; 9.26%), whereas on the left side resection of S1+2 (5/54; 9.26%) and resection of S1+2+S3 (5/54; 9.26%) of the left upper lobe were most common (Table 2).

The mean total operating time was 176.85 (SD, 33.34) minutes, median blood loss was 50 (IQR, 25-100) mL, and no blood transfusions were required intraoperatively (Table 3). The median number of lymph node stations sampled was 8 (IQR, 7-9), and the median number of lymph nodes sampled was 10 (IQR, 9-14). A primary lung malignancy was diagnosed in 84.13% (53/63) of cases, whereas 7.94% (5/63) of lesions were benign and 7.94% (5/63) represented metastatic disease from a nonlung primary. Final pathology revealed most tumors were pT1b and pT1c lesions (29/52; 55.77%), and N1 and N2 disease

Prior to Surgery - Based on Synapse 3D Virtual Model	
Provide Confidence Rating based on Synapse 3D Virtual Model	○ 1 Not at all confident ○ 2 Somewhat confident ○ 3 Confident ○ 4 Very confident ○ 5 Extremely confident
Did confidence level change based on Synapse 3D Virtual Model?	○ Yes, confidence level decreased ○ No, confidence level remained the same ○ Yes, confidence level increased
Did segment change?	○ Yes ○ No
Indicate Segment	☐ Apical Segment (S1) ☐ Posterior Segment (S2) ☐ Anterior Segment (S3) ☐ Segment(s) from Another Lobe
Indicate segment(s) from another lobe	______________________
Indicate Segment	☐ Lateral Segment (S4) ☐ Medial Segment (S5)
Indicate Segment	☐ Superior Segment (S6) ☐ Medial Segment (S7) ☐ Anterior Segment (S8) ☐ Lateral Segment (S9) ☐ Posterior Segment (S10)
Indicate Segment	☐ Apical Segment (S1) ☐ Posterior Segment (S2) ☐ Anterior Segment (S3) ☐ Superior Lingular Segment (S4) ☐ Inferior Lingular Segment (S5)
Indicate Segment	☐ Superior Segment (S6) ☐ Medial Segment (S7) ☐ Anterior Segment (S8) ☐ Lateral Segment (S9) ☐ Posterior Segment (S10)
After Surgery	
Provide Confidence Rating based on Post-Segmental Resection	○ 1 Not at all confident ○ 2 Somewhat confident ○ 3 Confident ○ 4 Very confident ○ 5 Extremely confident
Was the segment that was indicated after using the Synapse 3D Virtual Model the same as the one resected during surgery?	○ Yes ○ No

B

FIGURE 1. (*continued*).

were identified in 7.69% (4/52). M1a disease was identified postoperatively in 1.92% (1/52) of cases.

At the time of analysis, 65 patients had complete discharge data and 59 patients had complete follow-up data at 30 days. No adverse events due to ICG were documented within 30 days of surgery. The 30-day mortality rate was 1.49% (1/59), and this death was secondary to multiorgan failure in the setting of multiple postoperative thrombotic events of unclear etiology. Analysis of the adverse event data showed 32 of 59 patients (54.24%) experienced a total of 48 adverse events with 14 patients experiencing 2 concomitant adverse events and 5 experiencing a third adverse event within 30 days (Tables 4 and E1). Most adverse events were grade II or lower (44/48; 91.67%), and 8.33% (4/48) were grade IIIa or higher. The median chest tube duration was 2 (IQR, 1-5) days, and 15.38% (10/65) were discharged home with a chest tube. The median hospital length of stay was 2 (IQR, 1-5) days, with 32.31% (21/65) being discharged on postoperative day 1.

The operating surgeon reported being able to identify the appropriate bronchopulmonary segment of the target nodule based only on the preoperative CT scan in all 67 cases;

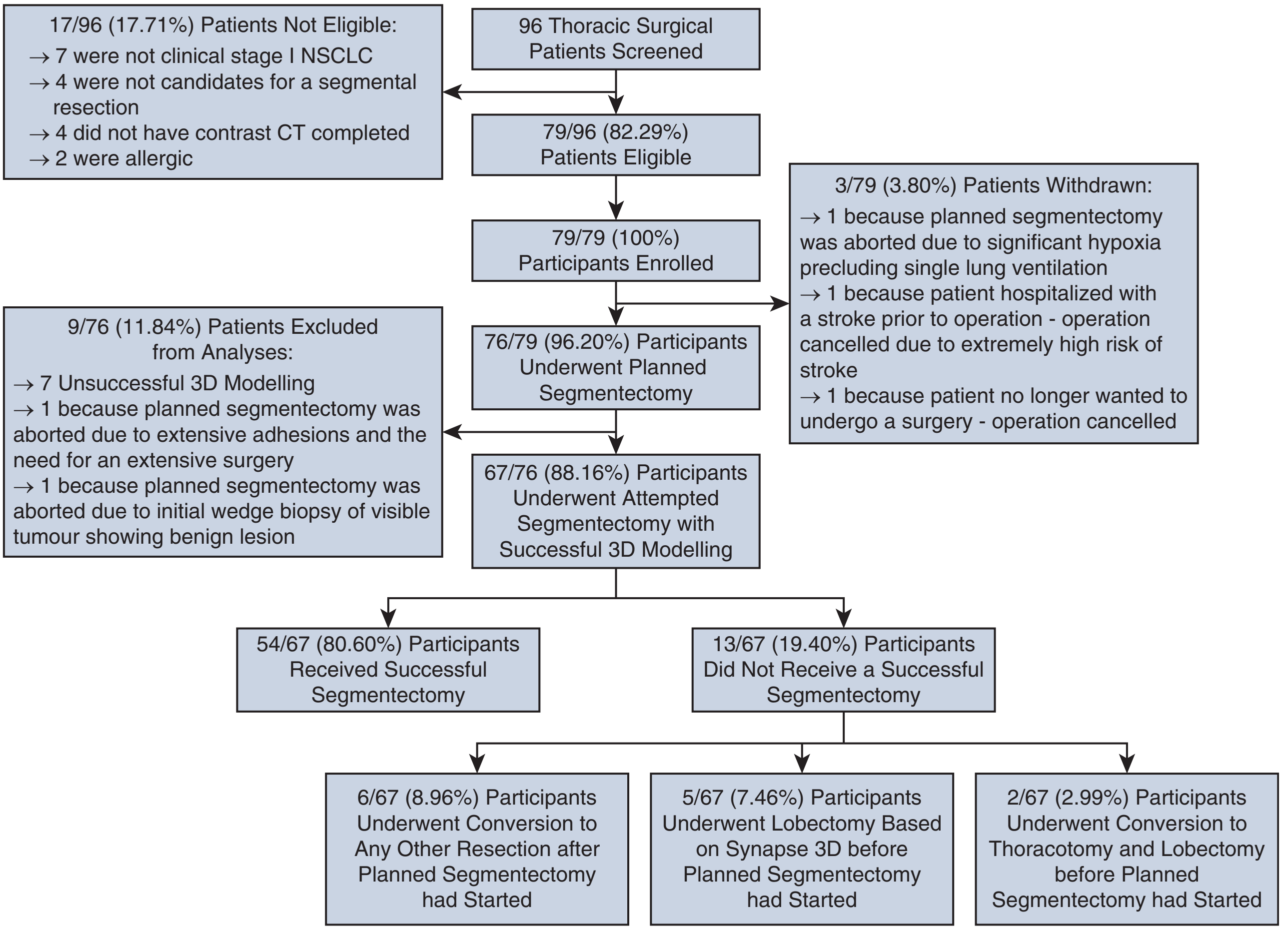


FIGURE 2. CONSORT diagram illustrating the distribution of patients in the trial. *NSCLC*, Non–small cell lung cancer; *CT*, computed tomography; *3D*, 3-dimensional.

however, the target segment was changed after 3D reconstruction in 35.59% (21/59) of cases (Table 5). Moreover, the corresponding pulmonary artery and vein were identified on CT scan in only 47.76% of cases (32/67) (Table 5). The median CR_{CT} was 2: somewhat confident (IQR, 2-3) and the median CR_{3D} was 4: very confident (IQR, 3-4), and this represented a statistically significant increase in confidence scores ($P < .001$). Surgeon confidence in the operative plan was reported to increase after 3D reconstruction in 77.97% (46/59) of cases (Table 5). The median CR_{Res} was 4: very confident (IQR, 4-5), and the segment that was identified after 3D reconstruction was the primary resected segment in 98.15% (53/54) of cases (Table 5).

DISCUSSION

The role of minimally invasive pulmonary segmental resection is rapidly increasing.[3,5,7,10] Proponents of this technique cite the ability to preserve healthy lung tissue in patients with compromised lung function or multiple evolving nodules as a major benefit of this approach.[7,10,16] Minimally invasive segmentectomy is technically challenging and requires more extensive intraparenchymal dissection and accurate identification of segmental bronchovascular anatomy when compared with lobectomy.[5,7,10] Additionally, the difficulty encountered in identifying the appropriate intersegmental parenchymal plane also adds a level of complexity to this procedure.[7,10] Although advancements in robotic surgical technology have allowed for increased adoption of targeted pulmonary segmental resection, intricate segmental bronchovascular anatomy and poorly defined intersegmental planes continually prove challenging to overcome. Recent developments in 3D reconstruction and NIF technology have emerged as useful adjuncts to overcome these limitations.[5-7,10,11,17-19] Although the evidence for these technologies has been promising, there is a paucity of data evaluating outcomes associated with the combination of 3D reconstruction and NIF mapping in robotic segmentectomy. Our study aimed to assess the safety and feasibility of combining 3D lung reconstruction with NIF mapping in robotic segmentectomy, and to determine whether 3D lung reconstruction may allow for low rates of conversion to lobectomy.

TABLE 1. Patient and tumor characteristics

Characteristic	Total (N = 67)
Age at surgery, y, median (IQR)	70 (65-74)
BMI, kg/m^2, median (IQR)	28.06 (24.58-30.39)
FEV1, % predicted, median (IQR)	92 (81-107)
DLCO, % predicted, median (IQR)	81 (70-100)
ASA, median (IQR)	III (III-IV)
Female, n (%)	39 (58.21)
Smoking status	
Current smoker, n (%)	22 (32.84)
Former smoker, n (%)	34 (50.75)
Never smoker, n (%)	11 (16.42)
Previous cancer, n (%)	24 (35.82)
Tumor size, cm, median (IQR)	1.9 (1.5-3.0)
Tumor location (lobe), n (%)	
Right upper lobe	21 (31.34)
Right middle lobe	-
Right lower lobe	14 (20.90)
Left upper lobe	19 (28.36)
Left lower lobe	13 (19.40)

IQR, Interquartile range; *BMI*, body mass index; *FEV1*, forced expiratory volume in 1 second; *DLCO*, diffusing capacity of the lung for carbon monoxide; *ASA*, American Society of Anesthesiologists Physical Status.

The primary outcome of conversion from segmentectomy to lobectomy was chosen because we thought it would be a useful and informative end point for North American surgeons. It is true that the rate of conversion to lobectomy reported in the JCOG0802 study was very low (4%).[16] However, the CALGB140503 trial demonstrated a much lower segmentectomy rate in the sublobar group (37.9%) with 59.1% of patients in this group undergoing wedge resections.[20] In our own previous experience, before the introduction of 3D reconstruction, we have demonstrated that ICG, when used as an adjunct to segmental resection, is positively correlated with the length of oncological margins.[7] However, we also showed a high rate of conversion from segmentectomy to lobectomy, even with the use of ICG.[7] In the article by Mehta and colleagues,[7] of 53 cases of planned segmentectomy, only 31 cases (58.49%) were completed, despite careful planning and use of ICG.[7] Our data from this article suggest that the introduction of 3D reconstruction has improved this rate of completion.

It is possible that our team's experience in segmentectomy may have improved over time, thus partially accounting for the improved rate of conversion. However, we believe that the difference in confidence scores before and after 3D reconstruction and the fact that more than one-third of the target segments were changed after 3D reconstruction are solely due to the introduction of this technology. In addition, the similarity in the confidence scores after 3D reconstruction compared with the confidence scores for the postresection specimen underscores the value of preoperative 3D reconstruction in increasing the likelihood of successful segmentectomy. An interesting finding in our study was that approximately 7% of patients who were scheduled for segmentectomy were converted to lobectomy before the start of the operation based on the results of 3D reconstruction. The fact that virtual lung modeling allowed for increased confidence with the plan of proceeding to lobectomy also emphasizes the value of this technology.

Other perioperative metrics assessed in our study provided evidence of comparable surgical outcomes relative to other published cohorts.[4,7] Notably, the 30-day mortality rate and 30-day adverse event rate were in keeping with previously published data.[4,7] Additionally, operating time, intraoperative blood loss and transfusion rates, number of lymph node stations sampled, and total number of lymph nodes sampled/harvested were all within the expected range for this procedure.[4,7]

This study builds on previous work by Bakhuis and colleagues[10] that demonstrated the value of 3D virtual reality lung reconstruction in patients undergoing VATS segmentectomy. Furthermore, our group has previously published on the increase in margin distance derived from the addition of NIF mapping in patients undergoing robotic segmentectomy.[7] To our knowledge, this study is the first prospective trial to combine preoperative planning using 3D reconstruction with NIF mapping in patients undergoing robotic segmentectomy, with a focus on both rates of conversion to lobectomy and confidence scores. Our data not only confirm the safety and feasibility of this approach but also provide evidence of improved accuracy of segmental anatomy identification and the potential for reducing the rate of conversion to lobectomy.

It is important to note that the recent seminal trials of JCOG 0802[16] and CALGB 140503[20] had not been published at the time of finalizing the protocol for this prospective study. Earlier retrospective studies demonstrated equivalent survival in patients with lesions as large as 3 cm undergoing sublobar resection.[21] In addition, a recent Japanese study reported excellent outcomes in patients with GGO dominant lesions up to 3 cm in size undergoing segmentectomy.[22] As such, and after careful consideration, we elected to include patients with lesions up to 3 cm who had predominantly GGO lesions or poor pulmonary function that was not permissive to lobectomy.

Limitations

This study has several limitations. First, the single surgeon trial design limits the external validity of these results. Because confidence is a largely subjective metric, influenced by surgeon and team experience, this metric may vary from one surgeon to another and from one center

TABLE 2. Distribution of planned and performed segmental resection

Segment	Planned for resection based on CT (n = 67)	Planned for resection based on Synapse 3D (n = 59)	Resected (n = 54)
Right upper lobe, n (%)			
Apical (S1)	4 (5.97)	2 (3.39)	1 (1.85)
Posterior (S2)	4 (5.97)	5 (8.47)	5 (9.26)
Anterior (S3)	4 (5.97)	2 (3.39)	2 (3.70)
Right middle lobe, n (%)			
Lateral (S4)	-	-	-
Medial (S5)	-	-	-
Right lower lobe, n (%)			
Superior (S6)	4 (5.97)	4 (6.78)	4 (7.41)
Medial (S7)	-	-	-
Anterior (S8)	1 (1.49)	-	-
Lateral (S9)	1 (1.49)	2 (3.39)	2 (3.70)
Posterior (S10)	-	-	-
Multi-segment, n (%)			
(S1+2)	5 (7.46)	5 (8.47)	4 (7.41)
(S1+2+7)	-	1 (1.69)	1 (1.85)
(S1+3)	1 (1.49)	-	-
(S1+3+7)	1 (1.49)	-	-
(S3+4)	2 (2.99)	2 (3.39)	1 (1.85)
(S3+4+5)	-	1 (1.69)	2 (3.70)
(S6+9)	3 (4.48)	1 (1.69)	1 (1.85)
(S6+9+10)	-	1 (1.69)	1 (1.85)
(S7+8)	-	1 (1.69)	-
(S7+8+9+10)	1 (1.49)	-	-
(S8+9+10)	1 (1.49)	1 (1.69)	1 (1.85)
(S9+10)	3 (4.48)	1 (1.69)	-
Left upper lobe, n (%)			
Apicoposterior (S1+2)	7 (10.45)	5 (8.47)	5 (9.26)
Anterior (S3)	1 (1.49)	1 (1.69)	1 (1.85)
Superior lingular (S4)	-	-	-
Inferior lingular (S5)	-	-	-
Left lower lobe, n (%)			
Superior (S6)	5 (7.46)	4 (6.78)	4 (7.41)
Medial (S7)	-	-	-
Anterior (S8)	2 (2.99)	2 (3.39)	2 (3.70)
Lateral (S9)	-	-	-
Posterior (S10)	-	-	-
Multi-segment, n (%)			
(S1+2+3)	4 (5.97)	5 (8.47)	5 (9.26)
(S1+4)	1 (1.49)	-	-
(S3+4+5)	4 (5.97)	4 (6.78)	4 (7.41)
(S4+5)	2 (2.99)	3 (5.08)	3 (5.56)
(S6+9)	1 (1.49)	-	-
(S6+9+10)	-	1 (1.69)	1 (1.85)
(S7+8)	1 (1.49)	2 (3.39)	2 (3.70)
(S8+9+10)	-	1 (1.69)	1 (1.85)
(S9+10)	4 (5.97)	2 (3.39)	1 (1.85)

3D, 3-Dimensional.

TABLE 3. Outcomes associated with robotic segmental resection using 3-dimensional reconstruction

Outcome	Total (N = 67)
Operative time (min), mean (SD)	176.85 (33.34)
Type of disease, n (%)*	
Benign	5 (7.94)
Malignant	53 (84.13)
Metastatic	5 (7.94)
Pathologic T stage, n (%)†	
T1mi	2 (3.85)
T1a	4 (7.69)
T1b	20 (38.46)
T1c	9 (17.31)
T2a	7 (13.46)
T2b	3 (5.77)
T3	5 (9.62)
Pathologic N stage, n (%)†	
N0	48 (92.31)
N1	1 (1.92)
N2	3 (5.77)
Pathologic M stage, n (%)†	
M0	51 (98.08)
M1a	1 (1.92)
No. of lymph node stations sampled, median (IQR)*	8 (7-9)
No. of lymph nodes sampled, median (IQR)*	10 (9-14)
No. of lymph nodes examined, median (IQR)*	10 (8-13)
Converted to thoracotomy, n (%)	3 (4.5)
Converted to robotic lobectomy, n (%)	5 (7.46)
30-d mortality, n (%)‡	1 (1.49)
Incidence of intraoperative complications, n (%)	2 (2.99)
Incidence of adverse events during admission, n (%)§	28 (43.08)
Incidence of postdischarge adverse events, n (%)‡	4 (6.78)
Discharged with chest tube, n (%)§	10 (15.38)
Chest tube duration, d, median (IQR)‡	2 (1-5)
Hospital length of stay, d, median (IQR)§	2 (1-5)

IQR, Interquartile range. *Number of patients with confirmed pathology at the time of analysis is 63. †Number of patients with available pathology report at the time of analysis is 52. ‡Number of patients with completed 30-day follow-up at the time of analysis is 59. §Number of patients with completed discharge data at the time of analysis is 65.

to another. As such, this finding will need further investigation for validity and generalizability. Likewise, the single surgeon design also limits the external validity of the objective metrics of planning that we measured, including the ability to identify segmental anatomy, target segments, and execution of the operative plan. Last, the learning curve related to robotic pulmonary segmentectomy was not assessed in our study. All procedures were performed by a single surgeon with extensive segmentectomy experience

TABLE 4. Adverse events experienced within 30 days of surgery

Grade of adverse events	During admission (n = 43)	Within 30-d follow-up (n = 5)
I, n (%)	19 (44.19)	-
II, n (%)	21 (48.84)	2 (40.00)
IIIa, n (%)	2 (4.65)	2 (40.00)
IIIb, n (%)	-	1 (20.00)
Iva, n (%)	-	-
Ivb, n (%)	-	-
V, n (%)	1 (2.33)	-

Percentages calculated based on total number of adverse events (48).

(>250 cases), and although published data support the notion that reductions in robotic segmentectomy procedure time and complication rates are seen with increasing case volume, this was not evaluated in our study.[23] Consequently, it is possible that the lobectomy conversion rate seen in our study may be explained at least in part by surgeon experience; however, further studies would be required to elucidate this. Our research team is currently undertaking a comparative analysis study comparing segmentectomies attempted with standard imaging for planning with those attempted using 3D planning to answer these clinical questions (HiREB #16947).

TABLE 5. Outcomes associated with surgeon confidence in preoperative plan

Surgeon confidence outcomes	Total (N = 67)
Identification of appropriate segment based on CT only, n (%)	67 (100)
Identification of vascular anatomy based on CT only, n (%)	32 (47.76)
CR_{CT}, median (IQR)*	2 (2-3)
CR_{3D}, median (IQR)†	4 (3-4)
Change in confidence score after 3D reconstruction†	
Confidence level increased, n (%)	46 (77.97)
Confidence level decreased, n (%)	1 (1.69)
Confidence level remained unchanged, n (%)	12 (20.34)
Change in target segment after 3D reconstruction, n (%)†	21 (35.59)
CRRes, median (IQR)‡	4 (4-5)
was the target segment after 3D reconstruction resected?‡	
Yes, n (%)	53 (98.15)
No, n (%)	1 (1.85)

CT, Computed tomography; *CR*, confidence rating; *IQR*, interquartile range; *3D*, 3-dimensional. *Number of patients with relevant data is 61. †Number of patients with relevant data is 59. ‡Number of patients with relevant data is 54.

CONCLUSIONS

This trial demonstrates that 3D lung reconstruction combined with NIF mapping using ICG for targeted robotic pulmonary segmental resection is feasible with an acceptable safety profile. Additionally, the 3D lung reconstruction approach is associated with a low rate of conversion to lobectomy and increased confidence in the surgical plan. Further large-scale studies are warranted to establish the effectiveness of this approach.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/3d-lung-reconstruction-with-in-7255.

Conflict of Interest Statement

W.C.H.: Hamilton Academic Health Sciences Organization AFP Innovation Grant, Advisory Board and Speakers Bureau for Astra Zeneca, Medtronic, BMS, Data Safety Monitoring Committee for Roche/Genentech, Proctoring for Intuitive Surgical, Grant Funding from Intuitive Surgical Foundation. All other authors reported no conflicts of interest.

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Key Words: fluorescence mapping, intravascular indocyanine green, segmentectomy, targeted robotic pulmonary segmental resection, 3D virtual lung reconstruction

TABLE E1. List of adverse events within 30 days of surgery

Adverse event	Within 30 days of surgery (n = 48)	Grade
Postoperative hemorrhage, n (%)	1 (2.08)	II
Prolonged air leak requiring chemical pleurodesis, n (%)	3 (6.25)	II
Arrhythmia, n (%)	2 (4.17)	II
Myocardial injury after noncardiac surgery, n (%)	2 (4.17)	II
Clostridium difficile infection, n (%)	1 (2.08)	II
Vertigo, n (%)	1 (2.08)	I
Postoperative hematoma (intrapleural), n (%)	1 (2.08)	I
Postoperative urinary retention, n (%)	5 (10.42)	II
Hoarse voice, n (%)	1 (2.08)	I
Postoperative dyspnea, n (%)	1 (2.09)	II
Constipation, n (%)	1 (2.08)	II
Chylothorax, n (%)	1 (2.08)	IIIb
Pneumonia, n (%)	1 (2.08)	II
Empyema, n (%)	1 (2.08)	IIIa
Postoperative hypertension, n (%)	2 (4.17)	II
Delirium, n (%)	1 (2.08)	I
ARDS/hypercoagulability, n (%)	1 (2.08)	V
Effusion, n (%)	1 (2.08)	IIIa
Persistent space after the lobectomy	1 (2.08)	II
Superficial thrombophlebitis	1 (2.08)	II

ARDS, Acute respiratory distress syndrome.