Intraoperative Navigation, Dual Imaging, and Advanced Imaging-Guided Techniques in Thoracic Surgery

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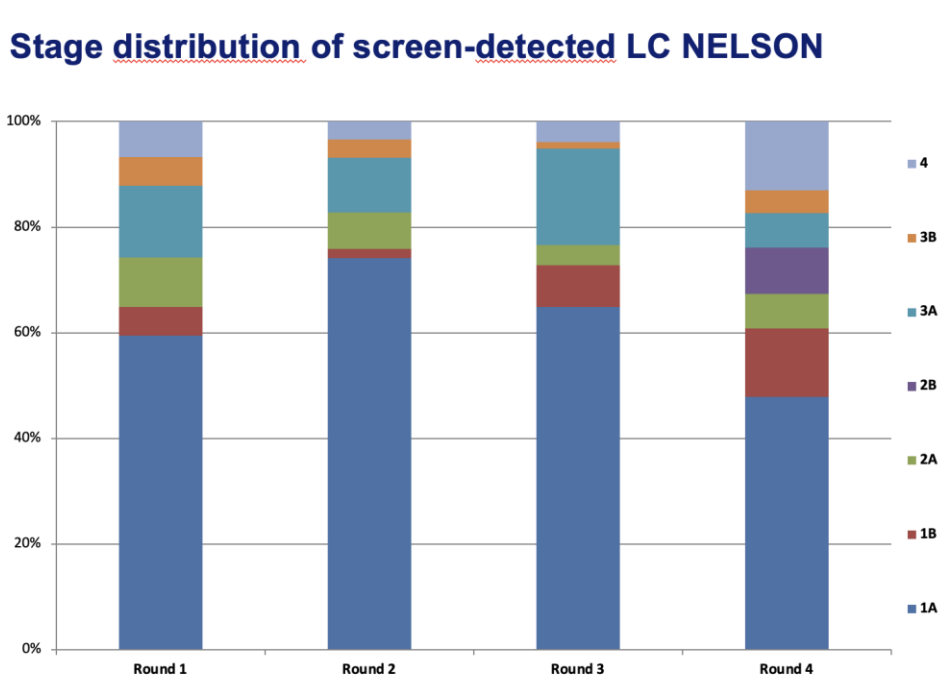
Lung cancer screening will lead to a considerable stage shift in lung cancer patients



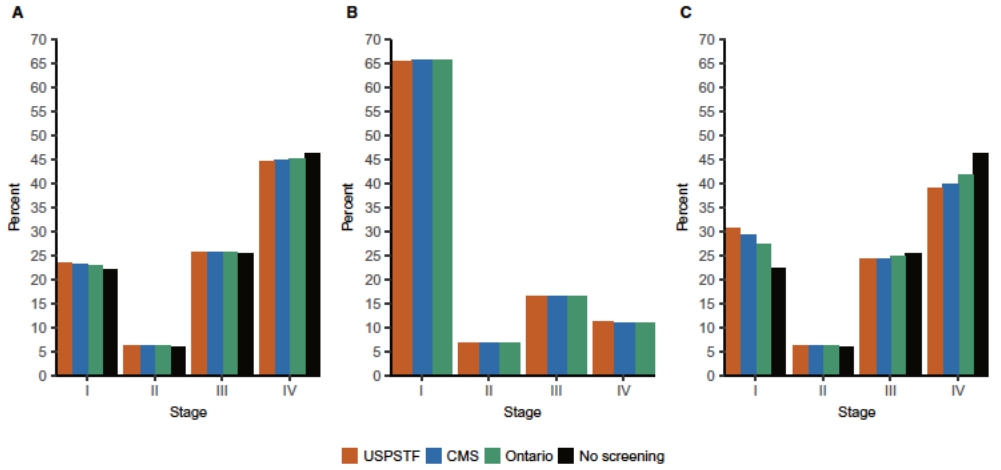
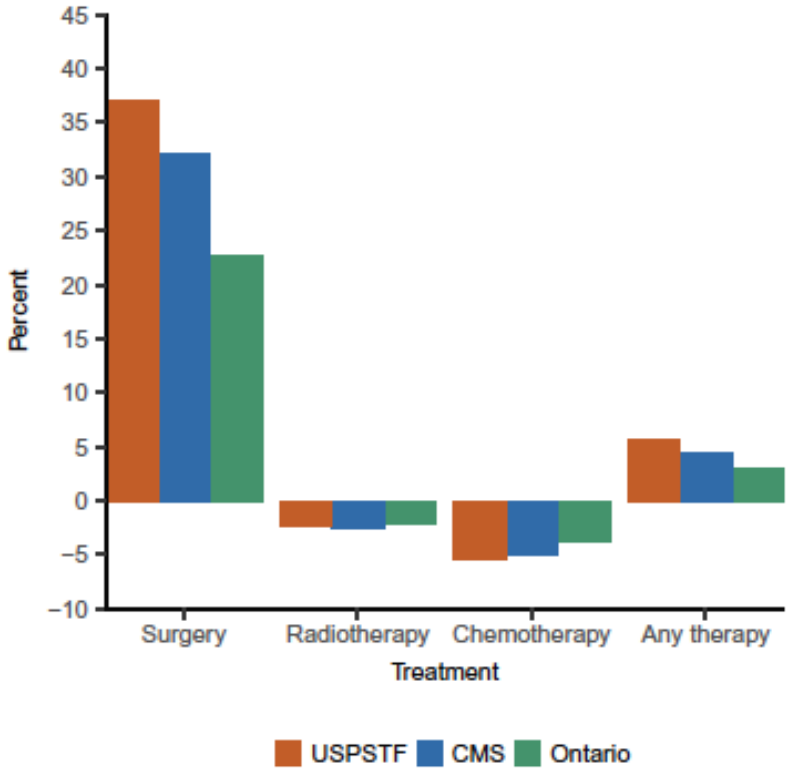
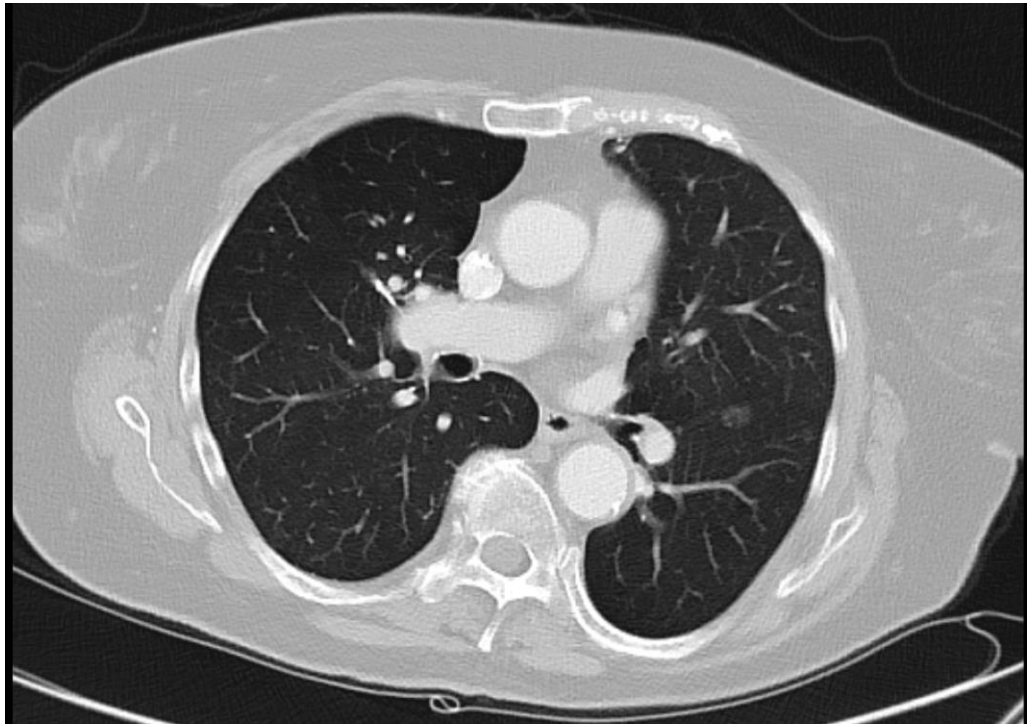


Figure 1. Distribution of stages at diagnosis for (A) clinically detected lung cancer cases, (B) screen-detected cases, and (C) all cases in the United States between 2015 and 2040 in the absence of low-dose computed tomography screening and for the 3 screening policies implemented in 2018. All policies assumed a constant 50% adherence to screening. CMS indicates Centers for Medicare and Medicaid Services recommendations (annual screening of current smokers and former smokers who quit fewer than 15 years ago, aged 55-77 years, with a smoking history of at least 30 pack-years); Ontario, most cost-effective policy from a study for Cancer Care Ontario (annual screening of current smokers and former smokers who quit fewer than 10 years ago, aged 55-75 years, with a smoking history of at least 40 pack-years); USPSTF, US Preventive Services Task Force recommendations (annual screening of current smokers and former smokers who quit fewer than 15 years ago, aged 55-80 years, with a smoking history of at least 30 pack-years).

N Engl J Med. 2020 Feb 6;382(6):503-513, Cancer. 2019 Jun 15;125(12):2039-2048

Lung cancer screening will lead to a considerable stage shift in lung cancer patients





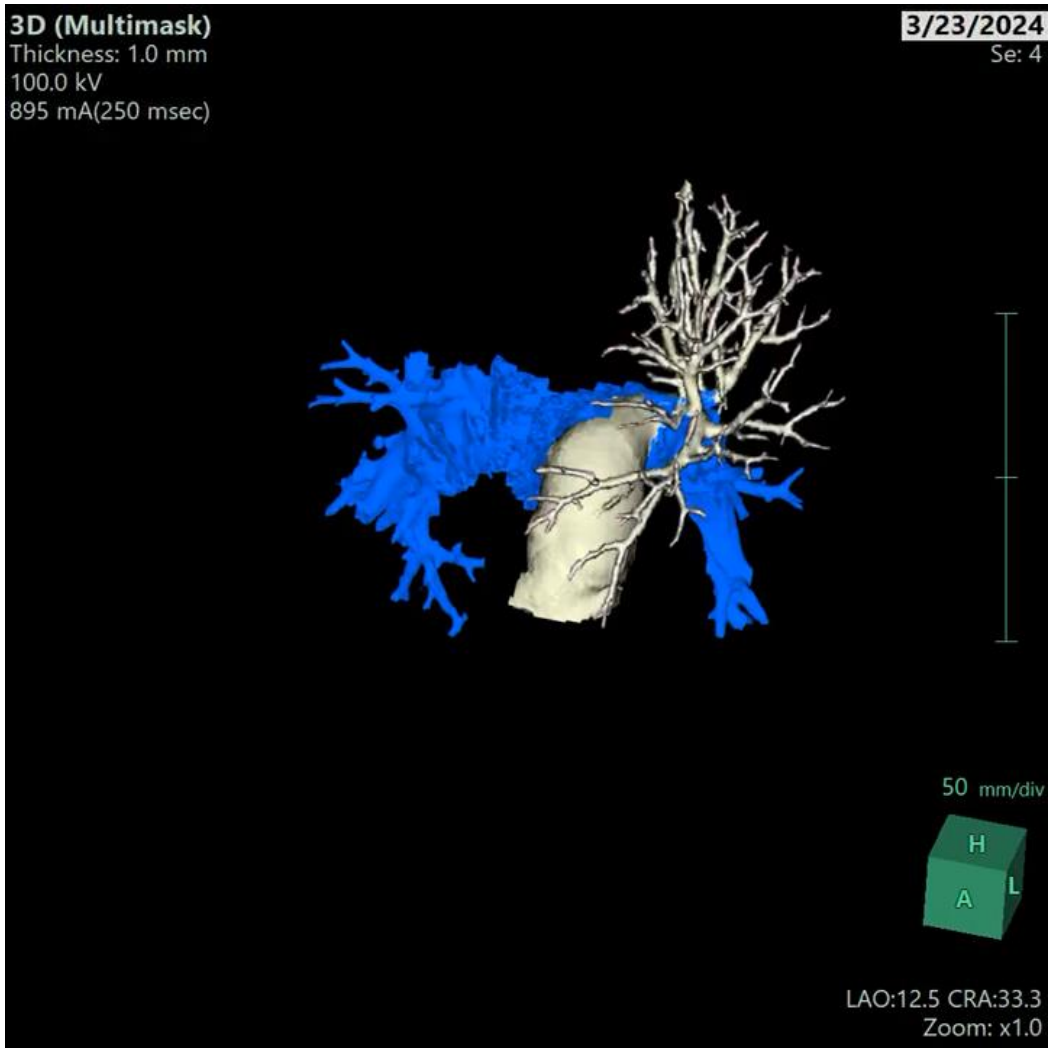
Cancer. 2019 Jun 15;125(12):2039-2048

Advanced Imaging-Guided Techniques in Thoracic Surgery

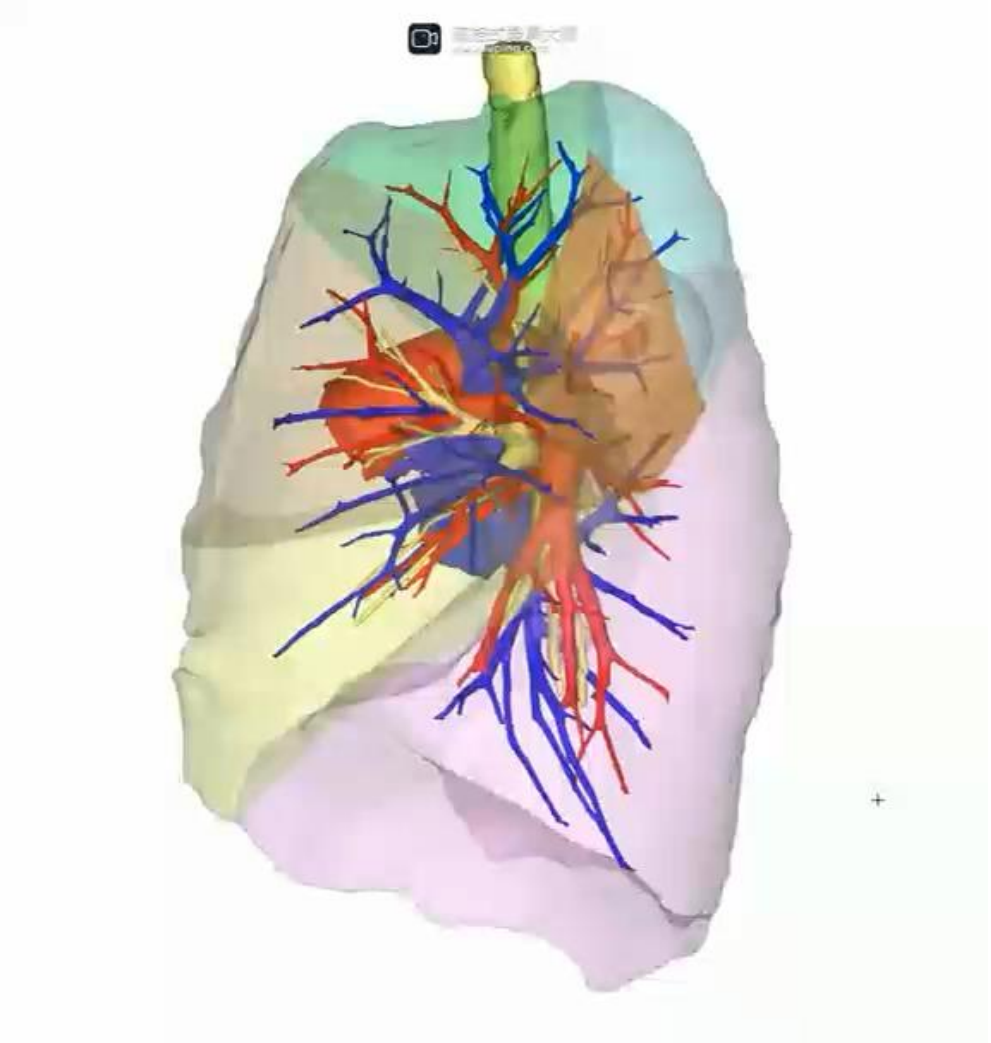
1. **Preoperative 3D reconstruction**
2. Electromagnetic Navigation Bronchoscopy (ENB) guided marking
3. Dual image hybrid operation
4. Infrared thoracoscopy with intravenous injection of indocyanine green (IRT-ICG) method

Cancer. 2019 Jun 15;125(12):2039-2048

3D reconstruction for preoperative planning



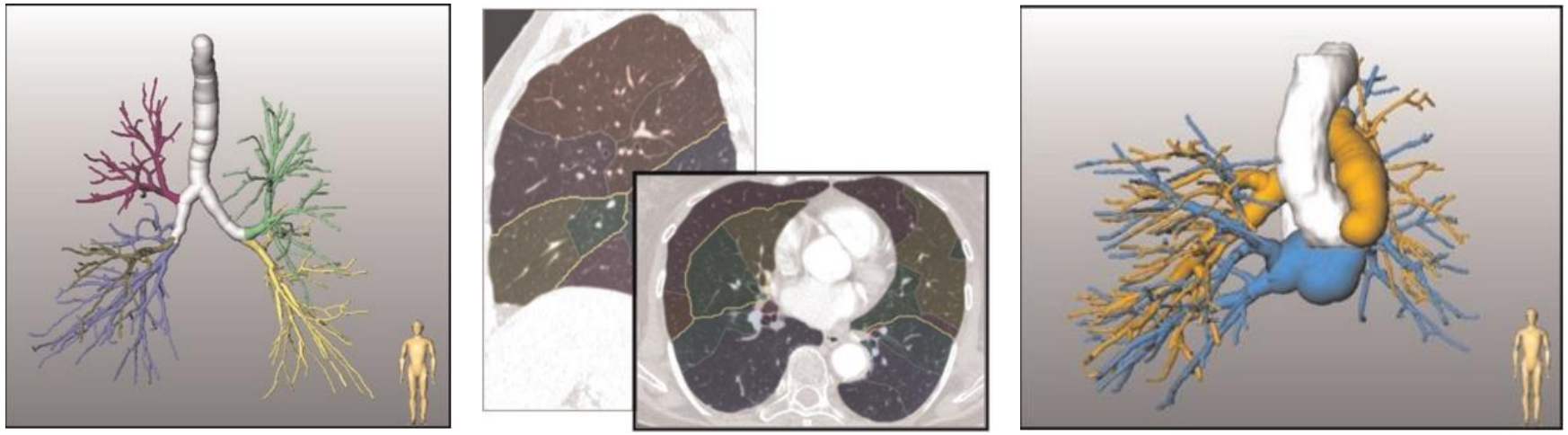
Andres Obesoa, Numan Balci b, Yusuf Bayraka, Usman Ahmada (2024) . Innovative Use of 3D Reconstruction Models of the Pulmonary Artery for Preoperative Planning,



Xinyu Zhang, Di Yang, Linqian Li, Jianing Wang, Si Liang, Peng Li, Zhe Han, Xiaodong Wang and Ke Zhang. pplication of threedimensional technology in video-assisted thoracoscopic surgery sublobectomy

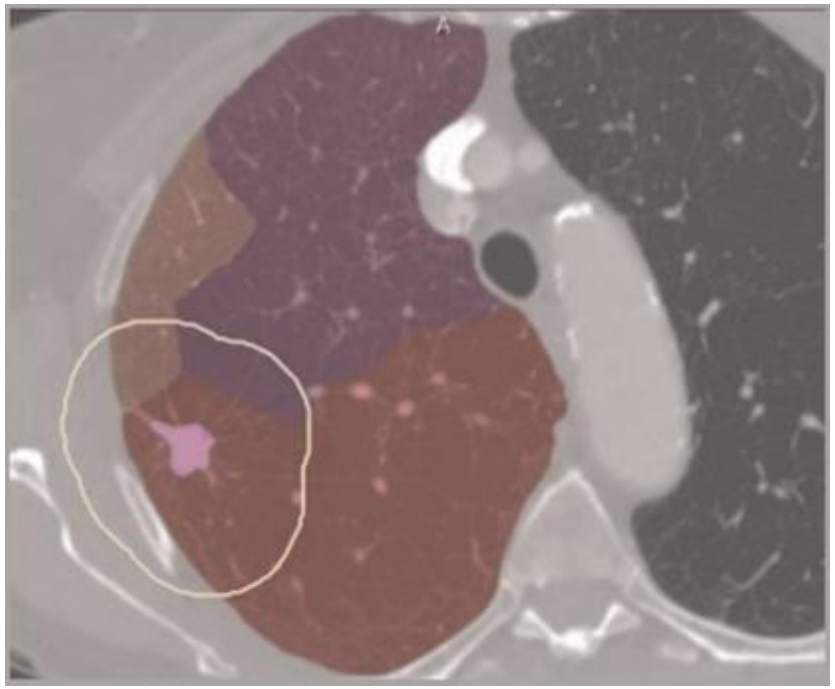
3D reconstruction for preoperative planning

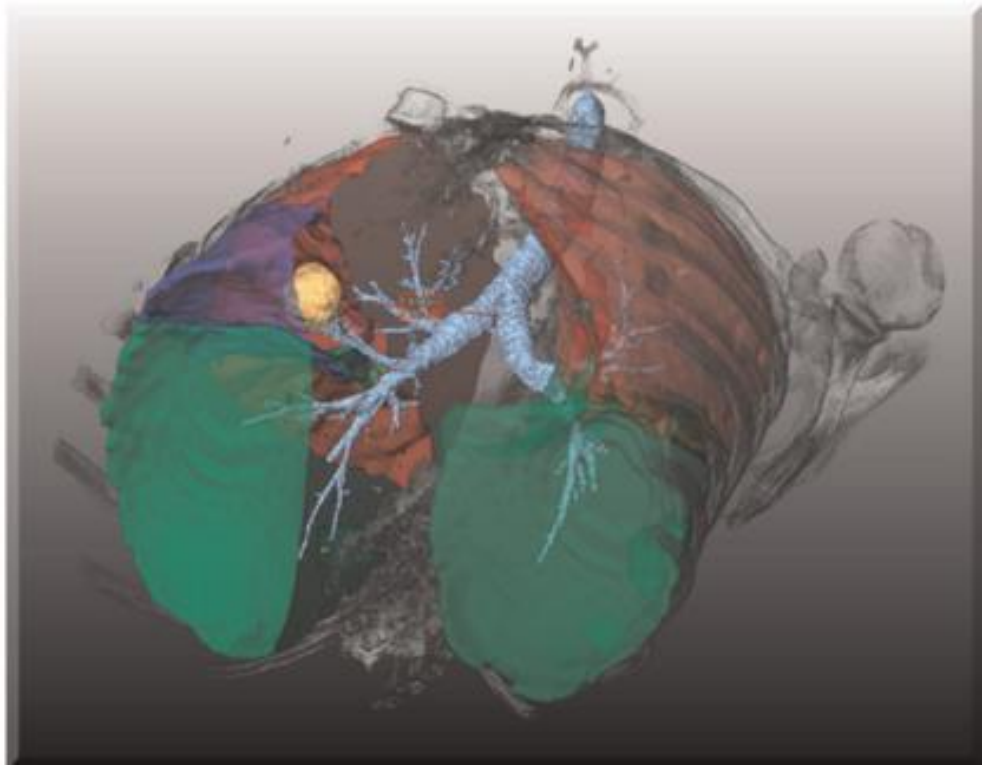
(a) Three-dimensional (3D) lung reconstruction. (b) Visualization of the arterial vessels. (c) Visualization of venous system



Krass, S., Lassen-Schmidt, B., & Schenk, A. (2022). Computer-assisted image-based risk analysis and planning in lung surgery— A review. Frontiers in Surgery, 9, 920457

3D reconstruction for preoperative planning





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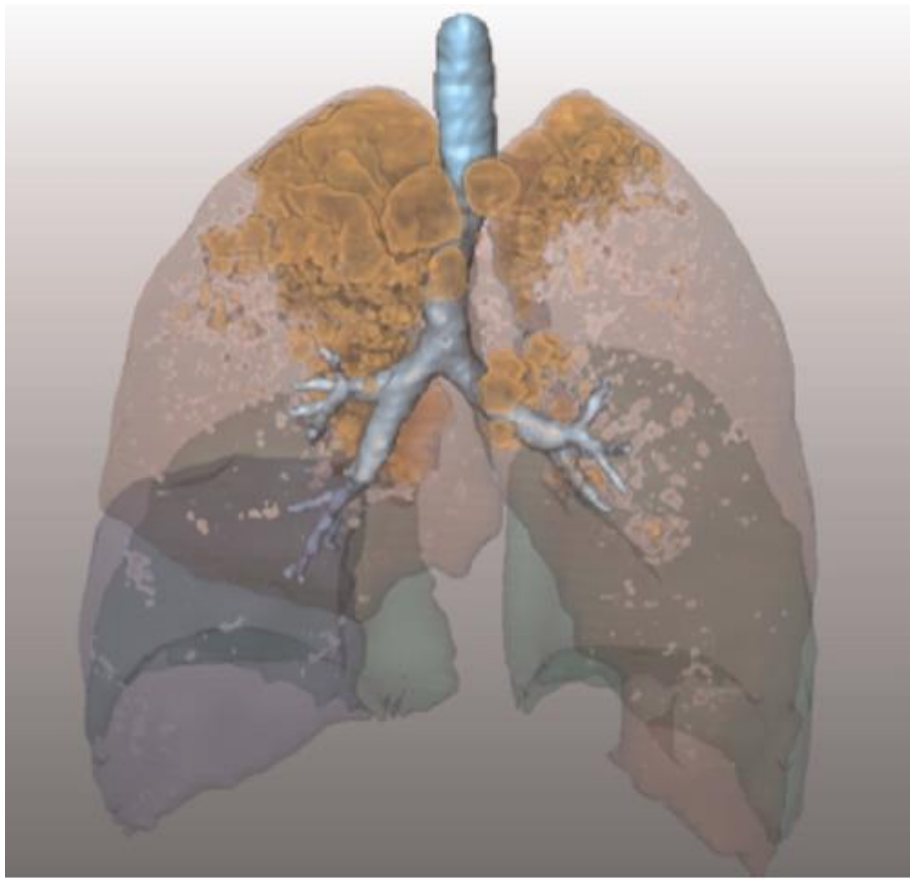
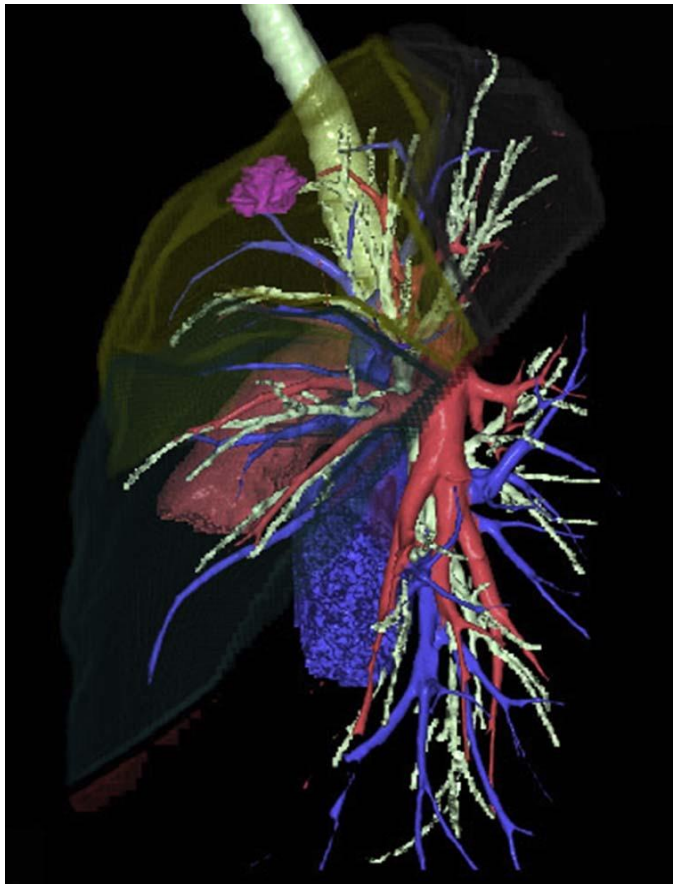




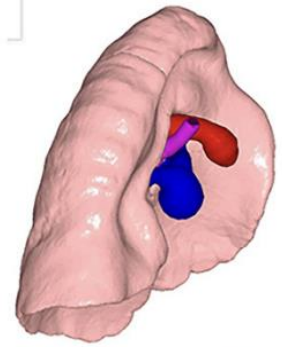
Krass, S., Lassen-Schmidt, B., & Schenk, A. (2022). Computer-assisted image-based risk analysis and planning in lung surgery— A review. Frontiers in Surgery, 9, 920457

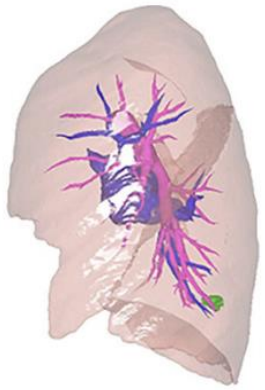
Sung Soo Chang, MD, Taku Okamoto, MD, Yoshimasa Tokunaga, MD, and Takayuki Nakano, MD. Intraoperative Computed Tomography Navigation During Thoracoscopic Segmentectomy for Small-sized Lung Tumors

3D reconstruction for preoperative planning

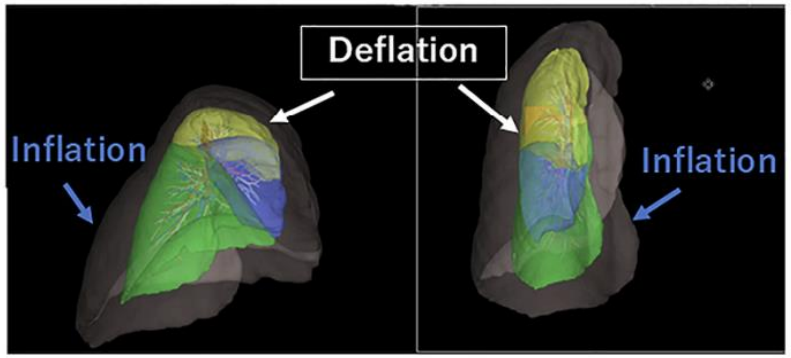
Preoperative simulation

Resection Process Map (RPM)
(Dynamic Virtual 3D-CT image)

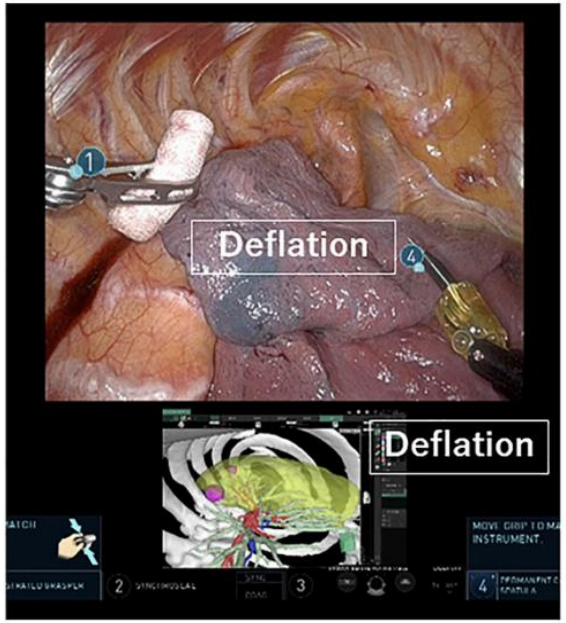




RPM
(Dynamic Virtual 3D-CT image)



Intraoperative view



Toyofumi Fengshi Chen-Yoshikawa (2024). Current Status and Future Perspectives of Preoperative and Intraoperative Marking in Thoracic Surgery

3D reconstruction for preoperative planning

Advantages

- Enhanced anatomical understanding
- Accurate surgical planning and assessment of R0 resection
- Shorter operating time
- Less intraoperative complications
- Improves surgical training and education

Limitations

- Resource intensive
- Depending on CT imaging quality -> HR + 1mm CT scan!
- Calculation of deflation during surgery (lung inflated in CT – Impact on Resection margin)
- Preparation of 3D model

Advanced Imaging-Guided Techniques in Thoracic Surgery

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2. **Electromagnetic Navigation Bronchoscopy (ENB) guided marking**
3. Dual image hybrid operation
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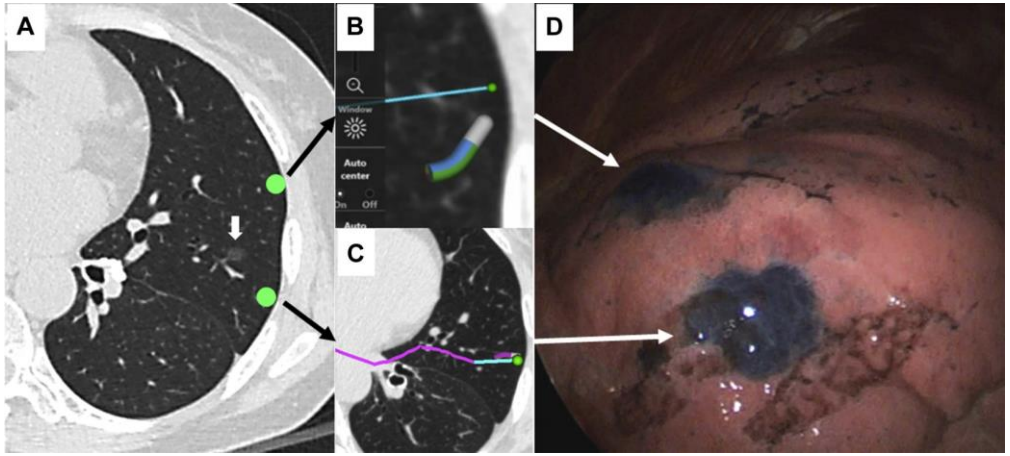
Cancer. 2019 Jun 15;125(12):2039-2048

ENB guided marking and resection

1. Dye marking with Methylen blue
   -> visible for more than 3 days after marking

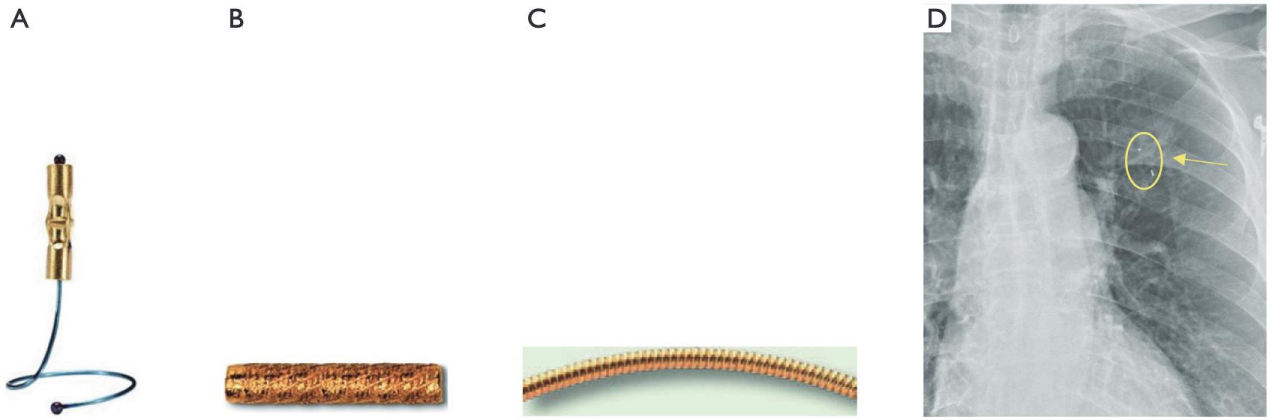
Limitations:
- Absence of blue print on pleural surface
- Dye leckage into adjacent segments
- Could interfere with histological analysis



Jae Won Song MD et al (2022). Electromagnetic Navigation Bronchoscopy-Guided Dye Marking for Localization of Pulmonary Nodules

2. Fiducial markers

Limitations:
- Marker migration
- Risk of pneumothorax or hemoptysis
- Not suitable for COPD patients
- Technical challenge; operator dependent

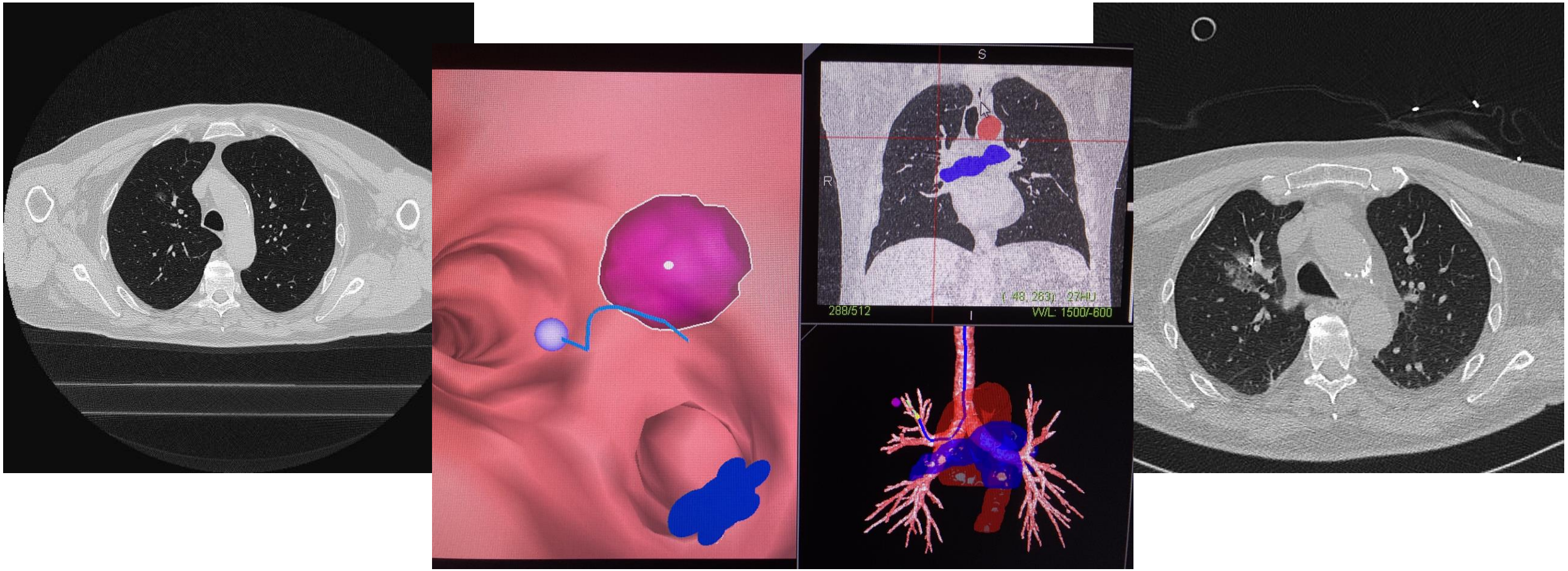


A) SuperLock™, B) CyberMark™, C) VISICOIL™

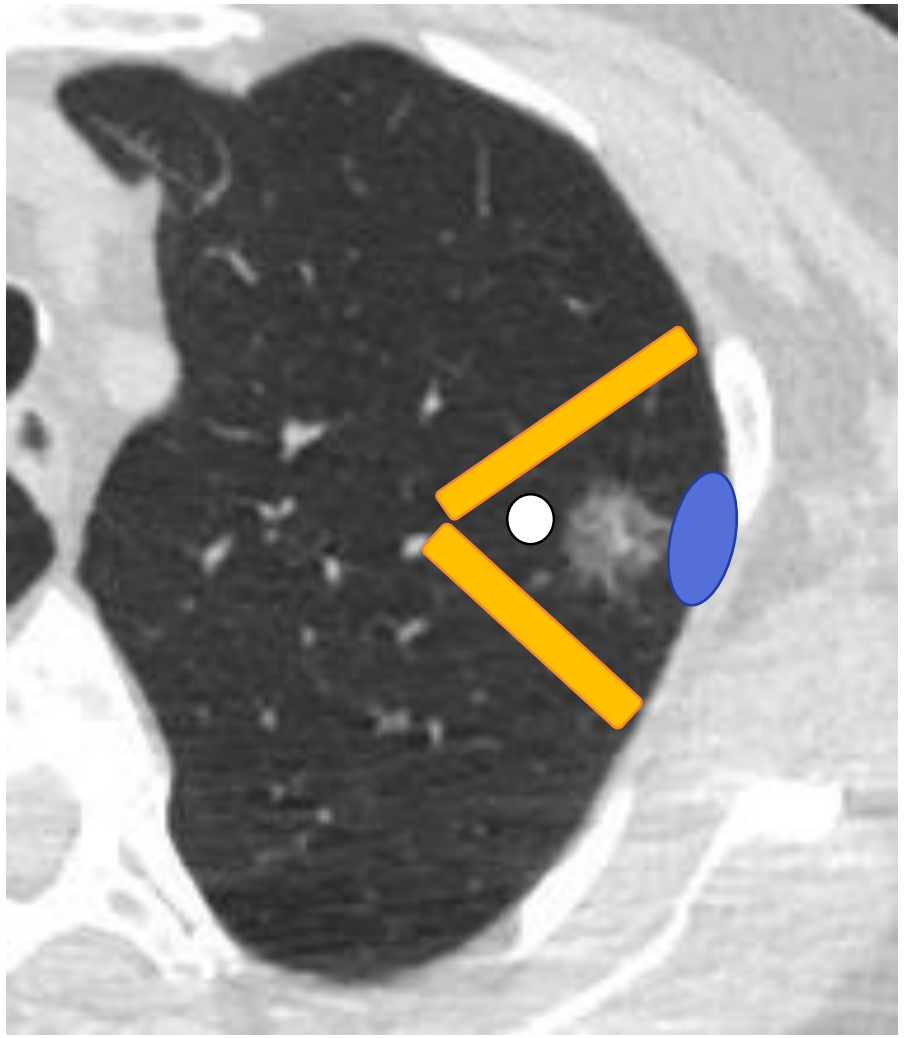
Edward M. Pickering et a. (2018). Electromagnetic navigation bronchoscopy: a comprehensive review

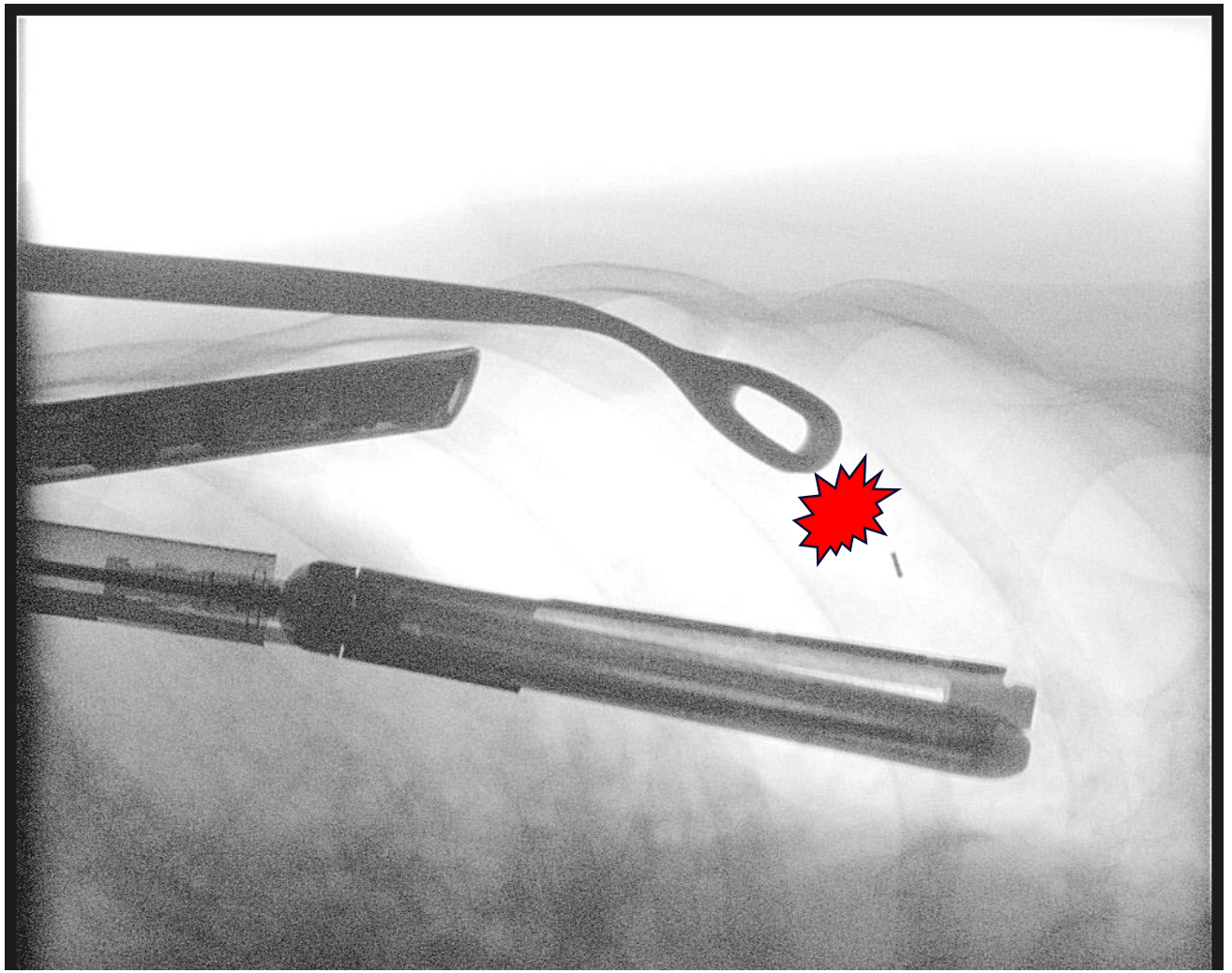
ENB guided marking and resection

- Hybrid procedures diagnosis and therapy



ENB guided marking and resection





ENB guided marking and resection

Otis B. Rickman(2014). Electromagnetic Navigation–Assisted Bronchoscopy

ENB guided marking and resection

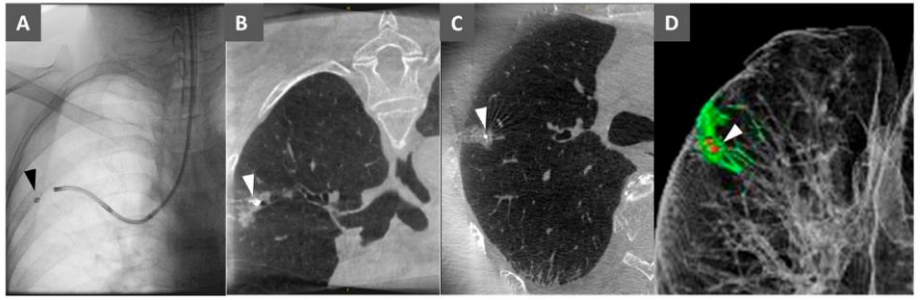
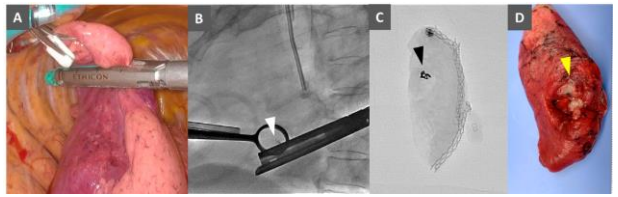


Table 1. Characteristics of patients.

No. of patients (lesions)	87 (90)
Gender	
Male	39
Female	48
Age, median (IQR)	71 (63–76)
Lesion size, median (IQR) (mm)	11 (8–15)
Distance from lesion to pleura, median (IQR) (mm)	8.7 (4–15)
Location	
RUL/RML/RLL	29/4/18
LUL/LLL	22/17
Type of lesion	
Pure GGN	19
Part-solid GGN	35
Solid	36

RUL: Right upper lobe, RML: right middle lobe, RLL: right lower lobe, LUL: left upper lobe, LLL: left lower lobe, GGN ground-glass nodule.



CBCT represents an alternative modality for identifying peripheral lung lesions due to its ability to visualize even small GGNs.

Kawakita et al, Cancers 2024, 164038

ENB guided marking and resection

Advantages

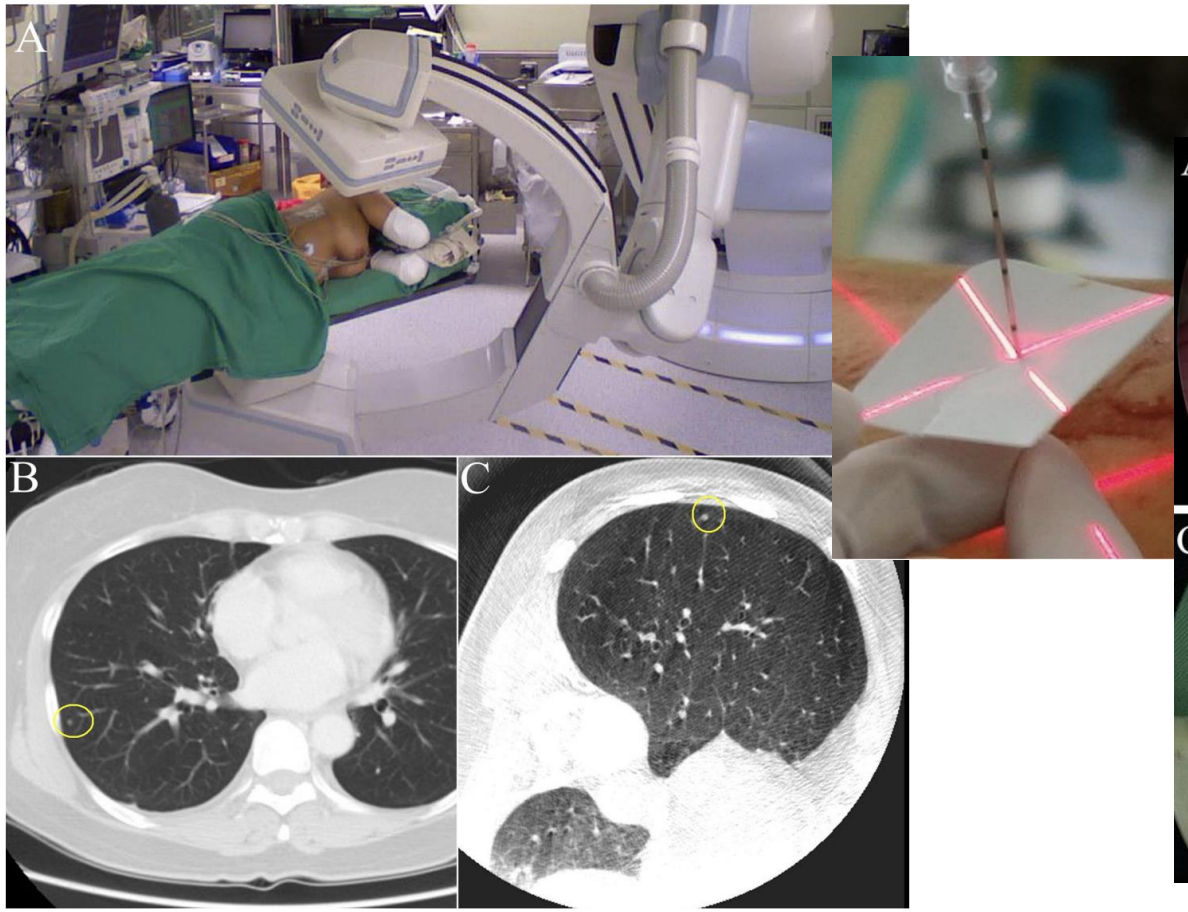
- Minimally invasive method
- Improves detection of small or deeply seated subsolid nodules
- Lower risk of penetrating the lesion, and parenchymal hematoma
- No radiation exposure
- Suitable for VATS/RATS
- Less conversions to thoracotomy

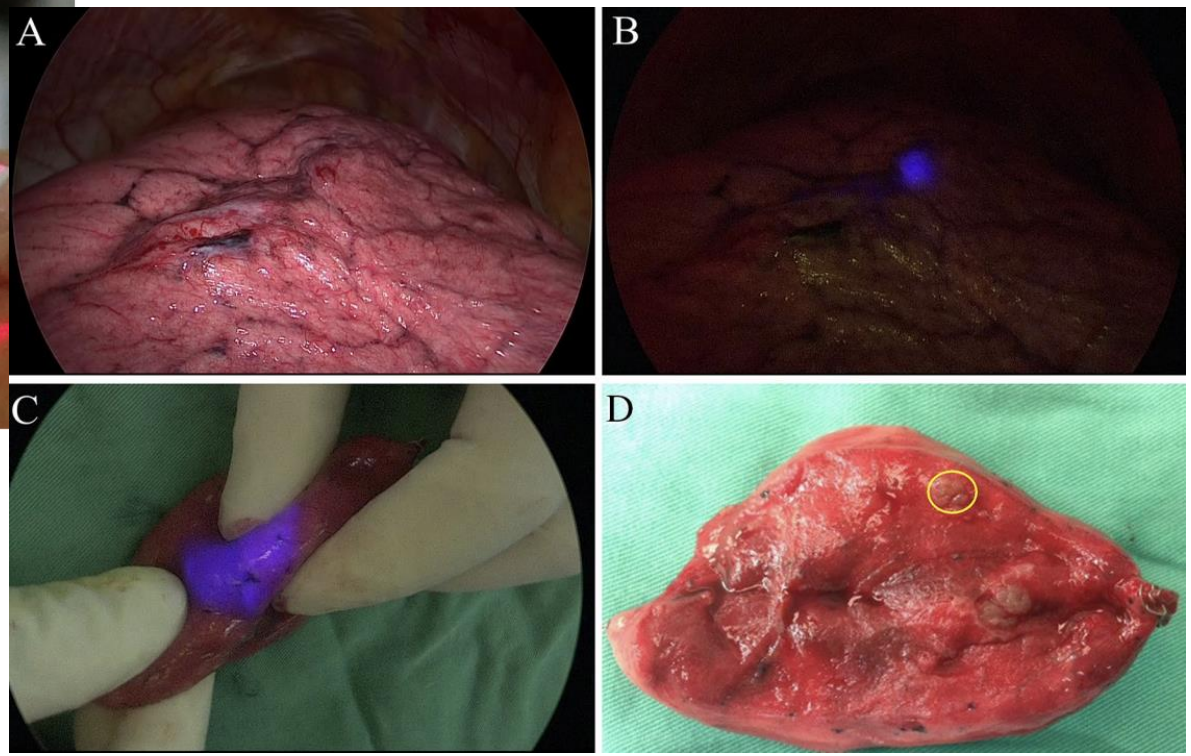
Limitations

- Technically challenging (expertise in bronchoscopy and navigation technology)
- Risk of marker migration (short time period between marking and surgery adviced)
- Challenging in patients with fibrosis and emphysema

Dual image hybrid operation – real time tracking system

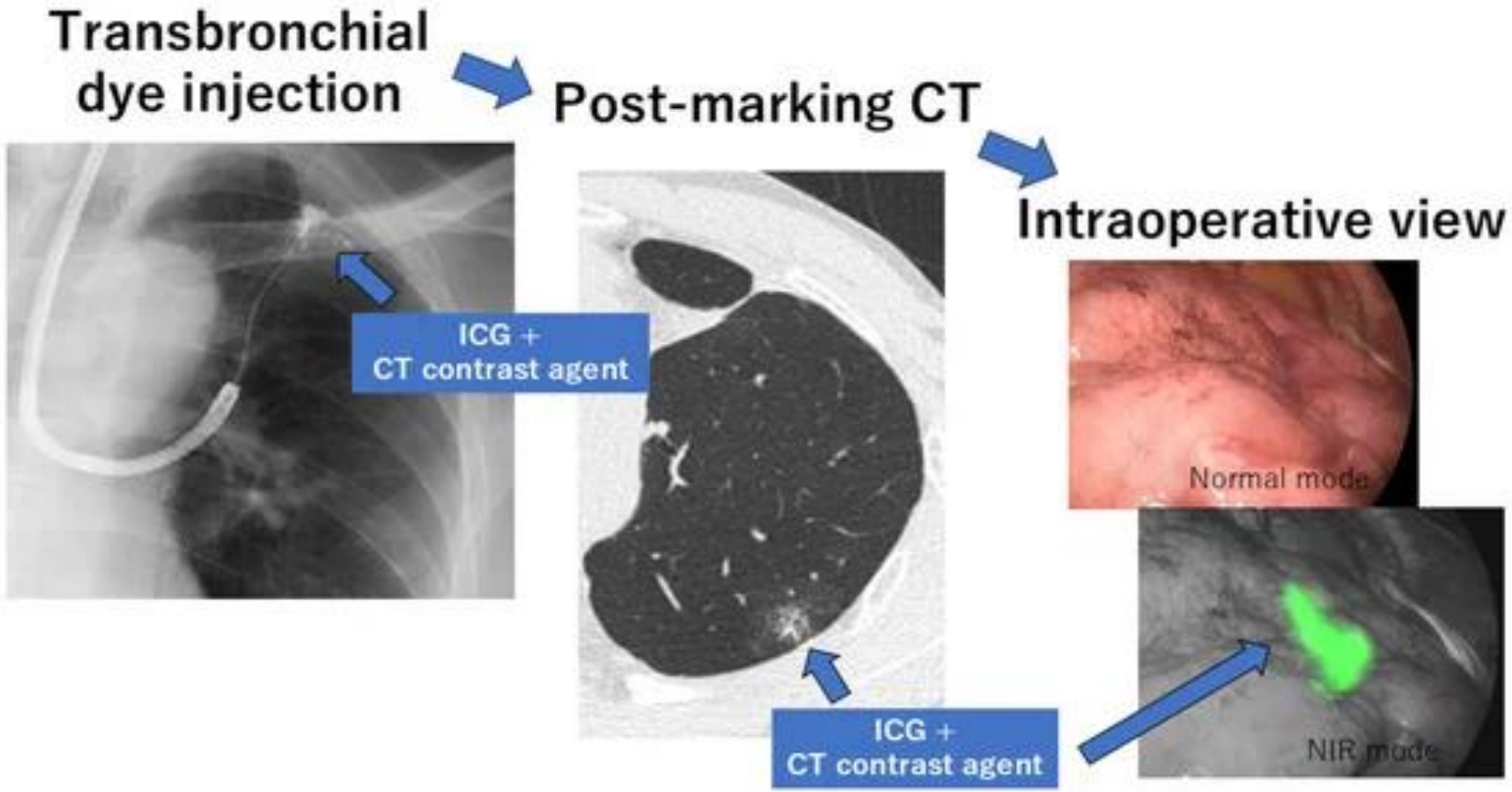
- Combining near-infrared fluorescence method and intraoperative cone-beam CT





Dual image hybrid operation – real time tracking system

- Combining virtually-assisted lung mapping with cone-beam CT and ICG-application (CAVE: patients with iodine hypersensitivity)



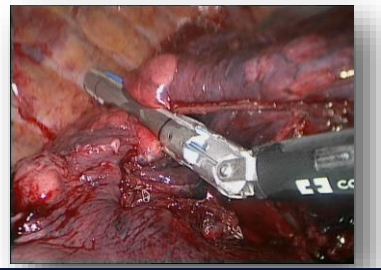
Advantages:

- Visualisation of intersegmental lines
- Precise real-time localisation of small peripheral nodules
- Minimally invasive surgery with maximized oncological results

Toyofumi Fengshi Chen-Yoshikawa (2024). Current Status and Future Perspectives of Preoperative and Intraoperative Marking in Thoracic Surgery

Standard resection

- Wedge resection
  - Safety margin ≥ tumor diameter
  - In tumors < 2 cm or reduced lung function

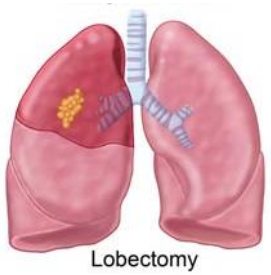


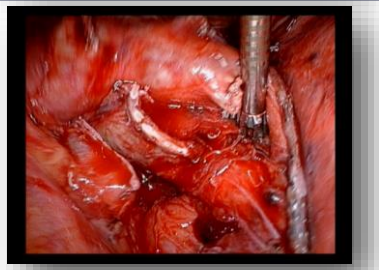
T1a+b

- Anatomical segmentectomy
  - Separate division of segmental artery, - vein and -bronchus
  - Combination of different (sub-)segments
  - In tumors ≤ 2 cm or reduced lung function

T1a+b

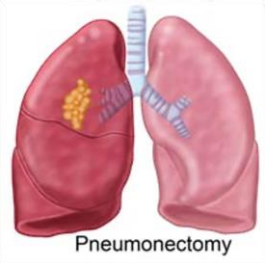
- Lobectomy, Bilobectomy, Sleeve-lobectomy
  - Anatomical standard resections





T1-T4

- Pneumonectomy, extended resections



T3/T4

Surgical margin assessment for intersegmental lesions by radiofrequency markers

- Single center prospective single arm study. Markers placed using ENB.
- ICG and wireless signal strength used to determine resection line
- 75 patients, R0 resection rate 98,7%, median margin 16 mm

The optimal segment to resect was reviewed, and virtual distance from tumor to intersegmental plane was calculated using 3D-CT.

↓

When the virtual margin distance was within 10 mm, extended segmentectomy was planned.

↓

RFID marker was placed via ENB in the vicinity o the tumor in a bronchoscopic room within 3 days of the scheduled surgery.

↓

Post RFID marking CT was reviewed to confirm the position relationship between the placed RFID marker and the tumor.

↓

Under RATS or VATS, extended segmentectomy was performed. After precise calculation of the surgical margin using wireless localization technique, adjacent subsegment was partially resected with the targeted segment beyond the ICG demarcation line.

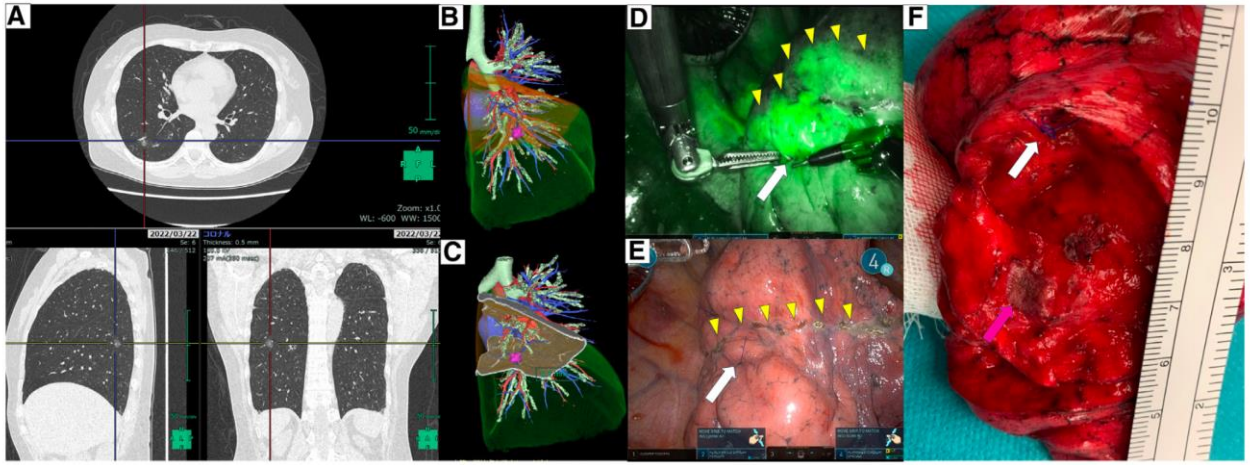
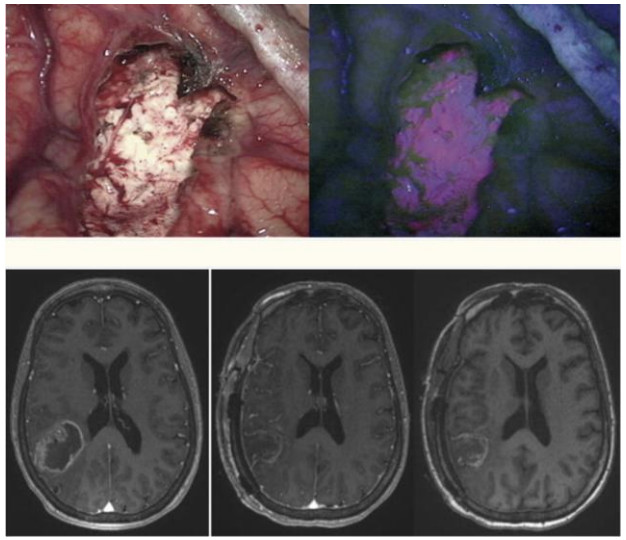


FIGURE E3. Adjustment of the resection line in right S6 segmentectomy. A, CT suggested a pure ground-glass opacity lesion (12 mm) in S6c. B and C, Preoperative 3D-CT simulation showed the virtual surgical margin from the target to the simulated intersegmental plane was 0.3 mm and an RFID marker was placed 2 mm caudal to the target (*white circle*: RFID marker, *pink mark*: target). D and E, ICG demarcation line demonstrated the RFID marker was outside the undyed area, and the marker was identified 10 mm caudal to the ICG demarcated line on the visceral pleura (*white arrow*: RFID marker, *yellow triangle*: ICG line). F, The resection line was adjusted according to the marker, and the lesion was removed with a surgical margin of 15 mm (*white arrow*: RFID marker, *pink arrow*: tumor).

Yutaka, Date et al. JTCVS Techniques 2024;28:141-50

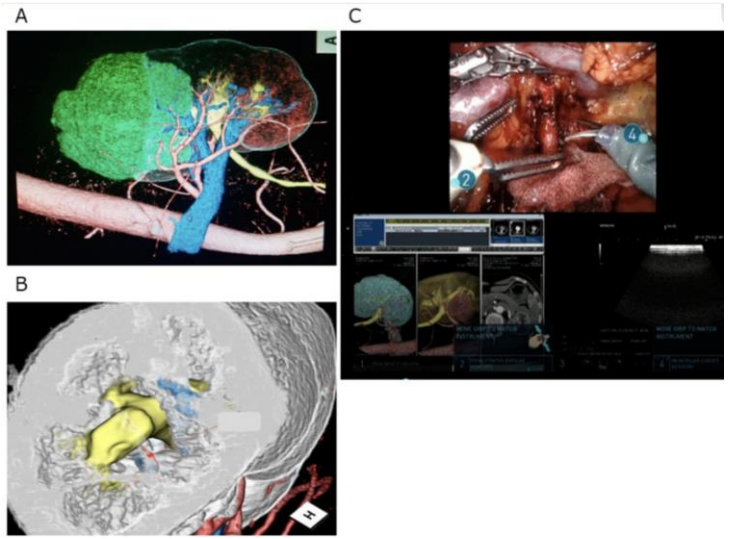
Intraoperative Navigation across other surgical specialties

Neurosurgery



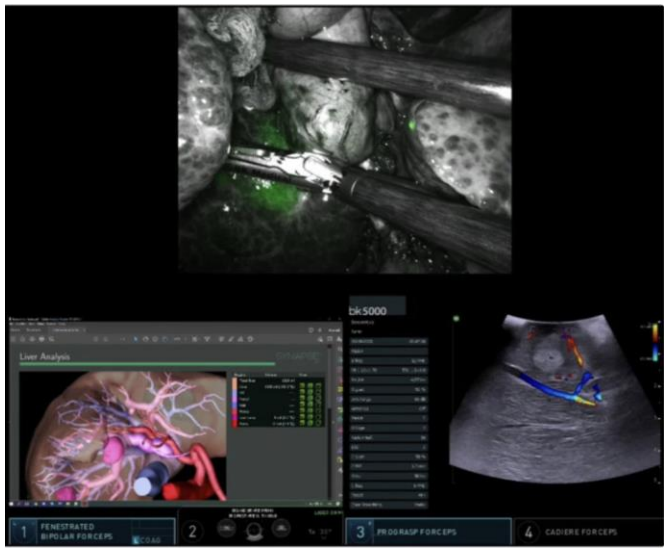
Costas Hadjipanayis et al (2015). What is the Surgical Benefit of Utilizing 5-ALA for Fluorescence-Guided Surgery of Malignant Gliomas

Urology

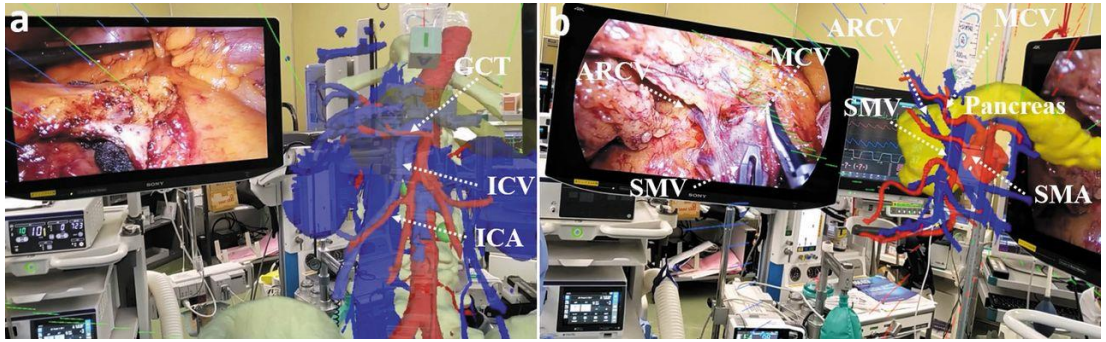


K. Takahara et al (2022). Novel Intraoperative Navigation Using Ultra-High-Resolution CT in Robot-Assisted Partial Nephrectomy

Hepatobiliary surgery



Gianluca Rompianesi et al (2023). Preoperative planning and intraoperative real-time navigation with indocyanine green fluorescence in robotic liver surgery



Colorectal surgery

Shunjin Ryu et al (2022). Intraoperative Holographic Guidance Using Virtual Reality and Mixed Reality Technology During Laparoscopic Colorectal Cancer Surgery

ESTS expert consensus recommendations on technical standards of segmentectomy for primary lung cancer

Brunelli A et al, EJCTS 2023, 63(6), ezad 224

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.

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.

Summary

- 3D preoperative reconstruction enhances anatomical understanding, improves surgical planning and increases accuracy in the assessment of R0 resection
- ENB-guided marking is a safe, minimally invasive method allowing precise resection of lung nodules
- Dual imaging alows real-time precise identification of intersegmental lines and tumor location, even in small, peripheral, non-palpable lung lesions

Thank you!

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Medical University of Vienna
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