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TECHNICAL NOTE

3D Slicer-based preprocedural trajectory planning for transvenous mediastinal biopsy using automated segmentation: a technical note

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ABSTRACT

Histological diagnosis of mediastinal tumors can be challenging when safe puncture access is limited by adjacent airway and vascular structures. This technical note describes a 3D Slicer software-based preprocedural planning workflow for transvenous mediastinal biopsy using automated segmentation of normal anatomical structures. In a woman in her 60s with a large mediastinal tumor and superior vena cava (SVC) syndrome, a transpulmonary approach was considered undesirable because of the risk of pneumothorax and hemorrhage, and a transvenous approach was advantageous because biopsy and subsequent endovascular management of SVC syndrome could be incorporated into the same strategy. Contrast-enhanced computed tomography data were imported into 3D Slicer, and critical organs were segmented using artificial intelligence-based tools, and the tumor was manually segmented. With a fixed entry point in the SVC, six candidate puncture trajectories were generated and compared using three-dimensional distance-based metrics. A composite risk score was used to rank the trajectories as a heuristic within-case decision-support tool rather than a validated predictor. The workflow did not automatically determine the puncture direction but provided practical decision support by visualizing and avoiding high-risk trajectories. Transvenous biopsy was successfully performed under biplane fluoroscopic guidance using a transjugular liver biopsy kit without procedural complications.

KEYWORDS

3D Slicer, automated segmentation, mediastinum, superior vena cava syndrome, transvenous biopsy

Histological diagnosis of mediastinal tumors is essential for treatment planning. Computed tomography (CT)-guided percutaneous biopsy is widely used and generally provides high diagnostic yield; however, in some patients, a transpulmonary route may be required, increasing the risk of pneumothorax or pulmonary hemorrhage.[1,2] When the lesion is adjacent to the trachea or major mediastinal vessels, small differences in needle orientation may substantially alter procedural risk.

Transvenous biopsy using a transjugular liver biopsy (TJLB) device has been reported as an alternative approach in selected mediastinal lesions, particularly when a conventional percutaneous route is considered unfavorable.[3,4] In bulky mediastinal tumors with superior vena cava (SVC) syndrome, a transvenous approach may also be advantageous because tissue diagnosis and SVC stent placement can be incorporated into a single-stage strategy. Although transbronchial or endobronchial ultrasound-guided sampling may be considered in selected mediastinal lesions, the transvenous approach was preferred in this case because it avoided a transpulmonary route and could be integrated with planned endovascular treatment for SVC syndrome. Puncture direction in these procedures is usually determined by operator experience and two-dimensional image interpretation, and objective three-dimensional (3D) assessment of multiple candidate trajectories before the procedure has not been well established.

The 3D Slicer software package is widely used for medical image visualization, segmentation, and quantitative analysis,[5] and TotalSegmentator facilitates rapid extraction of nor-

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mal anatomical structures from contrast-enhanced CT.[6] The main contribution of this report is not artificial intelligence-driven path optimization itself but a practical workflow combining automated segmentation, generation of multiple candidate transvenous trajectories, and quantitative comparison under procedural constraints to support operator decision-making.

Technique

A woman in her 60s presented with dyspnea. Contrast-enhanced CT showed a large mediastinal tumor with SVC syndrome (Figure 1). Because a transpulmonary approach was considered undesirable and because biopsy and subsequent SVC stent placement could be incorporated into the same strategy, transvenous biopsy planning was performed using preprocedural CT data. Potential vascular seeding was also considered, and the sheath tip was kept closely opposed to the vessel wall during puncture to minimize tumor exposure to the venous lumen. This technical application was approved by the Institutional Review Board of Tokyo Shinagawa Hospital (approval number: 25-C53, date: March 4, 2026), which waived the requirement for informed consent, and was conducted in accordance with the principles of the Declaration of Helsinki.

Preprocedural contrast-enhanced CT images were imported into 3D Slicer (version 5.10.0) in Digital Imaging and Communications in Medicine format. Structures considered relevant to puncture safety included the trachea, aorta, pulmonary artery, and pulmonary veins. In the actual implementation, the pulmonary artery and pulmonary veins were handled together as a single heart-labeled segment for distance calculation. Automatically generated segmentations were reviewed and manually corrected when necessary. The mediastinal tumor was manually segmented. Artificial intelligence was used only to assist organ segmentation and distance computation; final selection of puncture direction remained at the operator's discretion. Final confirmation and minor manual adjustments were performed by the operator together with an assisting physician. The puncture entry point was fixed at the upper SVC near the confluence of the bilateral brachiocephalic veins; only the puncture direction was varied. Two vertical levels were defined, with three directions at each level: midline, 30° right, and 30° left, yielding six candidate trajectories (L1–L6) (Figure 2a). This configuration represented a simplified and clinically realistic range of sheath orientations. Because final sheath-tip orientation could not be predicted precisely, the six candidate trajectories were selected on practical procedural grounds to allow rough comparison of acceptable and unfavorable directions. The biopsy needle length was 2 cm, and all candidate trajectories were defined with the same length. Each trajectory was created as a 3D straight line using the Markups (Line) module and visualized on volume-rendered CT in relation to the tumor and surrounding organs (Figure 2b). For each candidate trajectory, the entire puncture path was evaluated quantitatively. Distance maps were generated from each segmented organ, and the trajectory line was sampled at regular intervals. Minimum 3D distances from the trajectory to the trachea, aorta, pulmonary artery, and pulmonary veins were calculated. Airway-related parameters included trajectory length within 5 mm of the trachea and tracheal contact or penetration. A composite risk score was defined to enable relative comparison among the six candidate trajectories. The score was implemented as an empirically weighted heuristic for within-case trajectory comparison rather than a validated predictive model. In this case, tracheal contact or penetration was treated as a catastrophic event, and proximity to the pulmonary artery/pulmonary venous surrogate region and the aorta was incorporated together with airway proximity based on minimum tracheal distance and near-contact segment length. The weighting coefficients were selected empirically to prioritize avoidance of airway injury over vascular proximity. Because relative weighting may vary according to anatomical context and operator judgment, the framework may be adaptable to other procedural settings, although such modification would require separate validation. The scoring framework and coefficient settings are summarized in the Supplementary Material. Quantitative analysis identified L2 as the lowest-risk trajectory, whereas leftward trajectories—particularly L3 and L6—were considered relatively high risk (Table 1). In the actual procedure, however, the theoretically optimal trajectory could not be reproduced exactly because of TJLB sheath-orientation constraints. Therefore, a trajectory approximating L4 was selected under biplane fluoroscopic guidance. Based on the preprocedural quantitative evaluation, higher-risk directions were consciously avoided, and attention was paid to preventing excessive leftward deviation. This should be interpreted as

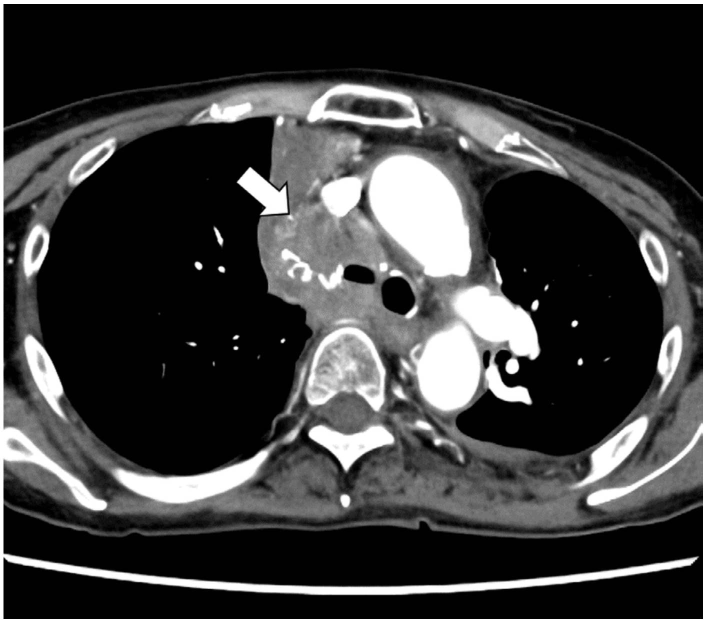

Figure 1. Contrast-enhanced axial computed tomography image demonstrating a mediastinal tumor associated with superior vena cava syndrome in a woman in her 60s. The mediastinal tumor is indicated by an arrow.

Main points

- Automated segmentation and 3D Slicer software enabled quantitative comparison of multiple candidate puncture trajectories before transvenous mediastinal biopsy.
- The workflow functioned as practical decision support for avoiding high-risk directions rather than as an automated navigation system.
- This approach enabled structured comparison of candidate trajectories using routine preprocedural contrast-enhanced computed tomography data and did not require dedicated navigation equipment.

practical decision support under real device constraints rather than automatic reproduction of a mathematically optimal trajectory. Transvenous biopsy was performed via the right internal jugular vein using a TJLB kit under biplane fluoroscopic guidance without CT guidance. Frontal and lateral projections were used to monitor needle advancement and orientation, enabling depth control and confirmation of the planned trajectory in 3D space (Figure 3a-c). After biopsy, a right femoral-right internal jugular pull-through tract was established, followed by same-session SVC stent placement. Two biopsy passes yielded adenocarcinoma without complications. The overall planning workflow required approximately 20 minutes, including 5 minutes for automated segmentation, 5 minutes for manual tumor segmentation and adjustment, and 10 minutes for candidate trajectory placement and computation.

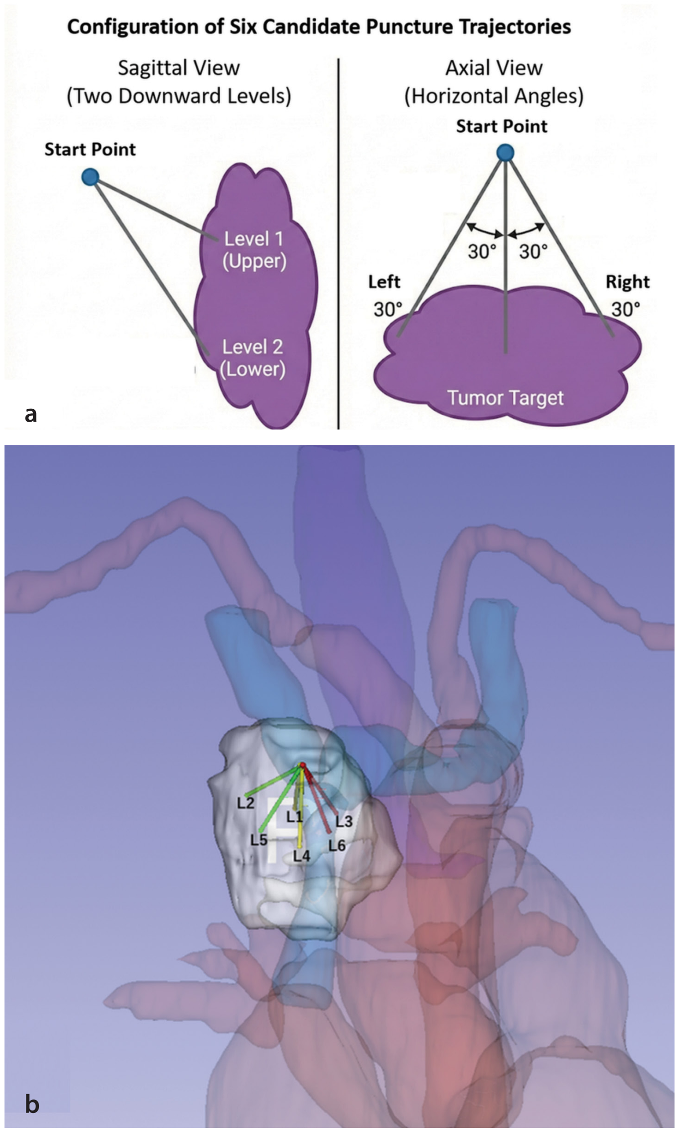

Figure 2. Candidate puncture trajectories generated from a fixed entry point in the superior vena cava. **(a)** Configuration of six candidate puncture trajectories (L1–L6) defined by two vertical levels and three horizontal angulations. **(b)** Three-dimensional volume-rendered image demonstrating the six candidate trajectories from the fixed entry point toward the mediastinal tumor.

Discussion

This technical note demonstrates the practical use of quantitative trajectory evaluation with 3D Slicer for preprocedural planning of transvenous mediastinal biopsy. In this case, the workflow enabled comparison of six candidate trajectories and helped identify high-risk directions before the procedure. The value of this approach lies not in automated trajectory selection but in providing human-in-the-loop decision support in an anatomically complex setting. We do not propose this workflow as a substitute for cone-beam CT-assisted guidance; rather, its value lies in structured preprocedural comparison of candidate directions using routine CT data, and real-time puncture adjustment in this case was achieved with biplane fluoroscopy. Although L2 was ranked as the lowest-risk trajectory, the final puncture direction had to be modified because of sheath orientation constraints of the TJLB device. This highlights an important mismatch between the virtual model and actual procedural feasibility. Thus, the workflow should not be interpreted as a navigation system that enforces the mathematically optimal path but rather as a practical preprocedural tool to identify directions to avoid and to support safer trajectory selection within real device limitations. In this case, the preprocedural evaluation helped the operator avoid excessive leftward deviation during the actual procedure. Although not demonstrated in the present single-case technical

Table 1. Composite risk scores and relative ranking of the six candidate trajectories (L1–L6)

Trajectory	Catastrophic risk (tracheal contact)	Vascular proximity risk	Airway proximity risk	Composite risk score[a]	Relative risk ranking[b]
L1	No	Mild	Moderate	0.538	5
L2	No	Minimal	Minimal	0.197	6 (lowest)
L3	Yes	—	—	101.474	1 (highest)
L4	No	Moderate	Mild	2.211	3
L5	No	Mild	Minimal	1.301	4
L6	No	Marked	Mild	4.318	2

[a]Composite risk score was calculated using a predefined weighted model. Details are provided in the Supplementary Material.
[b]Relative risk ranking is shown in descending order of composite risk score (1 = highest risk; 6 = lowest risk).

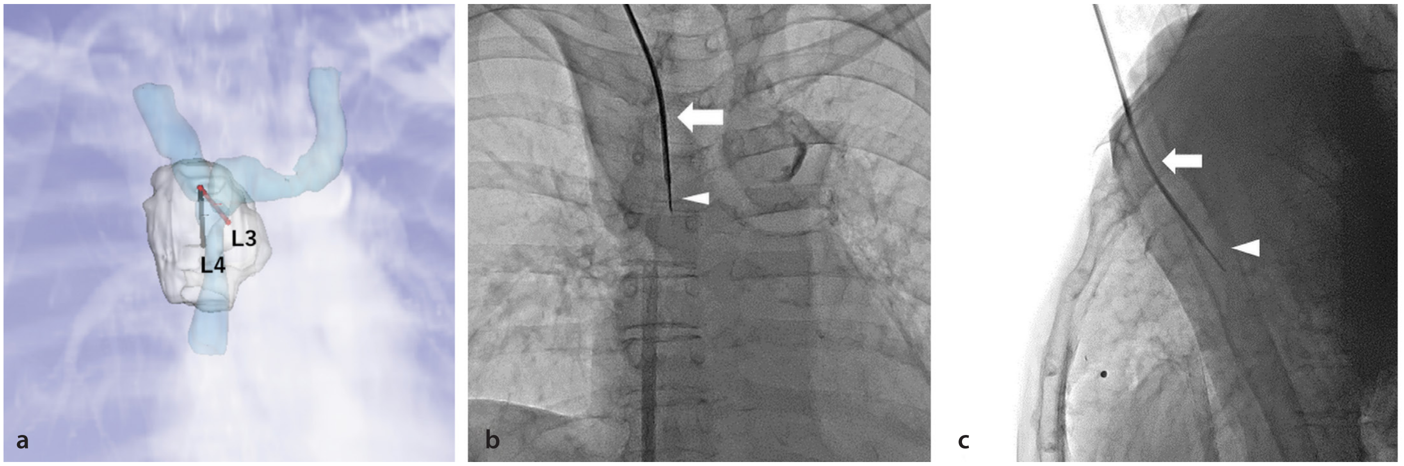

Figure 3. Simulated and intra-procedural fluoroscopic views of the selected puncture trajectory. **(a)** Simulated fluoroscopic image generated in 3D Slicer demonstrating the clinically selected trajectory approximating L4 and a representative high-risk trajectory corresponding to L3. **(b)** Frontal intra-procedural fluoroscopic image obtained during transvenous biopsy. The sheath is indicated by an arrow and the biopsy needle by an arrowhead. **(c)** Lateral intra-procedural fluoroscopic image obtained during transvenous biopsy. The sheath is indicated by an arrow and the biopsy needle by an arrowhead.

note, more oblique trajectories could theoretically be handled by defining additional candidate lines in 3D Slicer and applying the same sampling and scoring procedure. The framework may be adapted to different tumor locations, venous access routes, and devices by modifying the candidate trajectory set. In bulky mediastinal tumors with SVC syndrome, the transvenous route may also allow tissue diagnosis and SVC stent placement within the same treatment strategy. However, the transvenous route is not proposed as a standard approach for mediastinal tumors in general but as a case-specific option selected cautiously according to the anatomical and clinical context. Accordingly, same-session biopsy and SVC stenting should also be regarded as a case-specific strategy based on the patient's clinical condition, procedural complexity, and institutional workflow, rather than as a general indication for the transvenous approach. This report has several limitations. It describes a single technical application and does not establish superiority over standard practice, generalizability, inter-case variability, or reproducibility. In addition, the composite risk score was an empirically weighted heuristic for within-case comparison, was not clinically validated, and was based on static preprocedural CT, without accounting for tissue properties, vascular pulsation, or respiratory motion. Tract or vascular seeding should be recognized as theoretical concerns when considering a transvenous route, particularly in potentially lower-stage lesions or when other diagnostic approaches are feasible. Accordingly, whether this workflow improves procedural safety remains uncertain, and broader evaluation in more diverse anatomical and procedural settings is warranted.

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Footnotes

Conflict of interest disclosure

The authors declared no conflicts of interest.

Supplementary Material: https://d2v96fxpocvxx.cloudfront.net/df902063-0ec2-4245-8d72-4b997c70c061/content-images/67fc6d65-1823-41cb-bc75-fb934313636b.pdf

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