Appendix 1

AI-assisted or conventional surgical simulation

In our AI-assisted surgical simulation system for pulmonary nodule surgery, we employed the EfficientDet method for lung nodule detection. The model utilizes a multi-layer backbone module to extract features at various scales. These features are then bidirectionally fused through multiple weighted Bidirectional Feature Pyramid Networks (BiFPN) from the 3rd to 7th layers of the backbone. Finally, two convolutional layers predict the probability and bounding box range for each nodule.

The core of our 3D reconstruction is an image segmentation algorithm based on Mamba-Unet and SegRefiner. This algorithm segments complex medical images, including lung parenchyma, lung segments, blood vessels, bronchi, and nodules (*Figure 2*). Initially, Mamba-Unet (15) performs coarse segmentation, which SegRefiner (16) then iteratively optimizes to correct errors and achieve a refined mask. The marching cube algorithm (17) is subsequently used to generate a mesh representation. During training, we optimize the model using four types of loss functions: focal loss, dice loss, cross-entropy loss, and distance loss.

For conventional surgical simulation, we used a CT post-processing workstation (AW). Here, the Lung VCAR software is used to manually locate suspicious nodules. The software then automatically analyzes the nodule's characteristics such as morphology, volume, size, and CT value. Specific structures like pulmonary vessels, bronchi, and nodules are semi-automatically reconstructed and assigned unique colors. These structures are then fused to create a comprehensive 3D image of the lung, with optimization through adjustments in window width, window level, and structure transparency. Advanced imaging techniques such as multi-planar reconstruction (MRP), maximal intensity projection (MIP), and minimum intensity projection (MinIP) are utilized to analyze the spatial relationships between pulmonary nodules, vessels, and bronchi. These techniques also aid in measuring nodule size and evaluating morphology. Additionally, lung segments are reviewed using Thoracic VCAR and Lobe Segmentation software packages, enhancing the precision and effectiveness of the simula

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