Surgical Technique

# IQQA-3D imaging interpretation and analysis system-guided single-port video-assisted thoracic surgery for anatomical sub-segmentectomy ($LS^{1+2}$a+b)

**Guobing Xu, Chun Chen, Wei Zheng, Yong Zhu, Bin Zheng, Hao Chen**

Department of Thoracic Surgery, Fujian Medical University Union Hospital, Fuzhou 350001, China

*Correspondence to:* Chun Chen. Department of Thoracic Surgery, Fujian Medical University Fujian Union Hospital, 29 Xinquan Road, Fuzhou 350000, China. Email: chenchun0209@163.com.

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## Introduction

Gradual improvements in health awareness and expanded physical examinations have resulted in more frequent discovery of pulmonary nodules, especially those of ground-glass opacity. In turn, diagnosis of early lung cancer is increasingly common. Surgeons have found that these early lung cancers may be safely removed via segmentectomy or sub-segmentectomy instead of lobectomy. However, the hilum structure of lung segments is complicated, and the many variations increase the challenge of performing segmental or subsegmental resection.

To minimize this problem, several three-dimensional (3D) reconstruction imaging software products have been developed. Surgeons have successfully applied these programs to segmentectomy (1-3). The present video presents one case in which the IQQA-3D Image Interpretation and Analysis System (developed by IQQA-Chest; EDDA Technology, Princeton Junction, NJ, USA) was used to guide surgeons through a single-port, video-assisted, anatomical sub-segmentectomy ($LS^{1+2}$a+b). The patient was a 50-year-old woman whose examination 6 months earlier had revealed a nodule in the upper left lung. Chest computed tomography (CT) showed a 0.6-cm diameter lesion with ground-glass opacity and a mean CT value of −500 Hu. The nodule had shown no significant change and was thought to be early lung cancer. The patient had good lung function, with the following relevant indicators: forced expiratory volume-one second (FEV1), 2.77 L; actual/predicted value, 97.7%; maximum voluntary ventilation (MVV), 92.3 L; actual/predicted value, 87.5%. Therefore, surgery was performed. IQQA has already been applied for precise segmental hepatectomy (4-6). We used this software to accomplish 3D reconstruction of the bronchi and vessels and then successfully planned and performed a left $S^{1+2}$a+b sub-segmentectomy following the specific operative strategy planned preoperatively. There has been no previous report of the use of IQQA for planning segmentectomy or sub-segmentectomy. We learned that IQQA could play an important guiding role in simplifying and individualizing the operation.

## Operative technique

After admission, the patient underwent thin-section (0.625 mm), enhanced CT scanning of the lung (GE Revolution CT, USA). After scanning, the data were imported into the IQQA-3D Image Interpretation and Analysis System for identification of the nodule location and 3D quantitative reconstruction of pulmonary structures, including bronchi, arteries, and veins. In addition, the targeted area of the lung with removal of the involved segmental bronchi, arteries, and veins was simulated, and the intersegmental veins that needed to be reserved were identified.

We can use the simulated resection range determine whether there is sufficient distance between the nodule and the tissue margin. On the basis of the anatomical characteristics, the operation procedure is strategized to determine the sequence in which the bronchi, arteries, and veins will be removed. In this case, the CT scan showed that the nodule was in the upper left lung (*Figure 1*). IQQA,

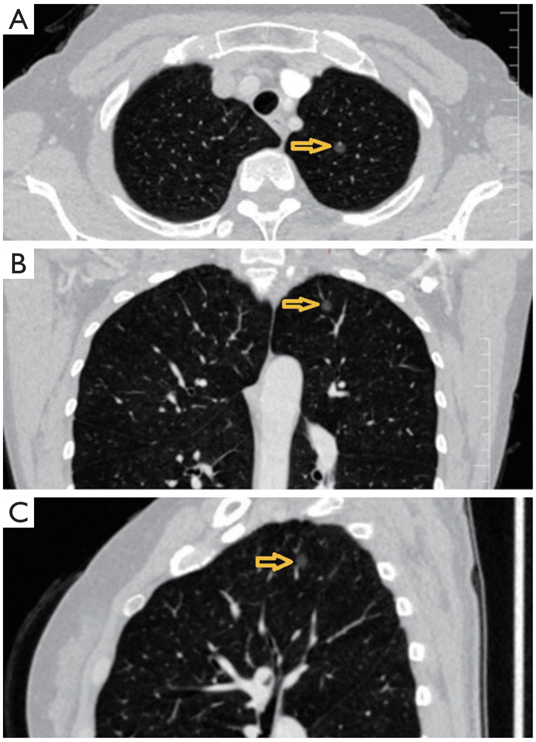


**Figure 1** CT scan shows the nodule, which measures about 0.6 cm in diameter, in the upper left lung. (A) Axial view; (B) coronal view; (C) sagittal view. CT, computed tomography.

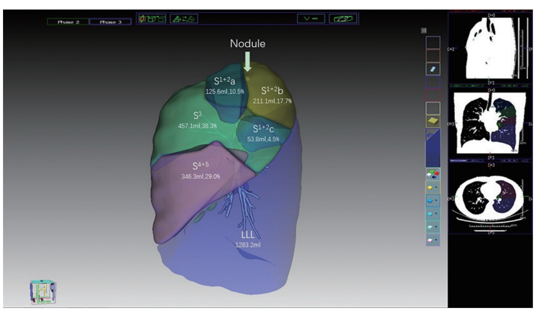


**Figure 2** IQQA software indicates that the nodule locates between $S^{1+2}$a and $S^{1+2}$b. $LS^{1+2}$a+b resection is needed to obtain a sufficient margin. The volumes and percentages of left upper lung tissue were quantified as follows. $S^{1+2}$a: 125.6 mL (10.5%); $S^{1+2}$b: 211.1 mL (17.7%); $S^{1+2}$c: 53.8 mL (4.5%); $S^{3}$: 457.1 mL (38.3%); $S^{4+5}$: 346.3 mL (29.0%). LLL, left lower lobe; LUL, left upper lobe.

which was used to improve the preoperative planning, indicated that the nodule was located between segments (S) $S^{1+2}$a and $S^{1+2}$b. Thus, to obtain a sufficient margin, left segment (LS) $LS^{1+2}$a+b resection was needed (*Figure 2*). The targeted segmental bronchus (B), artery (A), and vein (V) that needed to be dissected were $B^{1+2}$a+b, $A^{1+2}$a, $A^{1+2}$b, and $V^{1+2}$b. The intersegmental veins that needed to be reserved were $V^{1+2}$a (between $S^{1+2}$a and $S^{3}$) and $V^{1+2}$c (between $S^{1+2}$b and $S^{1+2}$c) (*Figure 3*). On the basis of the 3D anatomical relations, a surgical plan was made to approach the segmental hilum in the following order: $A^{1+2}$a+b to $B^{1+2}$a+b to $V^{1+2}$b (*Figure 4*). The procedure was as follows.

First, a portion of the hilum of the left upper lobe was exposed from the ventral to the dorsal side to reveal the pulmonary vein ($V^{1+2}$) and pulmonary arteries. $A^{3}$ and $A^{1+2}$ were identified from the results of the IQQA-3D image interpretation and analysis system. The branch near $A^{3}$ was $A^{1+2}$a (*Figure 5A*); $A^{1+2}$b was combined with $A^{1+2}$c. We then dissected $A^{1+2}$b+c toward the peripheral lung. $A^{1+2}$b (*Figure 5B*) could be identified when $A^{1+2}$b+c was separated to the bifurcation. When $A^{1+2}$a and $A^{1+2}$b were clearly defined, they were ligated with #4 common silk suture and transected with an ultrasonic knife (*Figure 6*). Lymph nodes #12 and #13 were removed and sent for frozen biopsy (*Figure 7*). $B^{1+2}$a was combined with $B^{1+2}$b. The distal stumps of $A^{1+2}$a, $A^{1+2}$b, and $B^{1+2}$a+b was easily confirmed, as the 3D reconstruction had shown (*Figure 8*). $B^{1+2}$a+b was divided with a linear cutting stapler.

We then used the "inflation-deflation" method to reveal the intersegmental plane. The procedure was as follows. The lungs were filled with 100% oxygen at 15–20 cm $H_2O$ airway pressure and double-lung ventilation until full expansion, after which we changed to single-lung ventilation. After about 11 minutes, the lung deflated except for the targeted segment, ($S^{1+2}$a+b), which remained inflated. The intersegmental plane was then clearly visible (*Figure 9*). The distal stump of $B^{1+2}$a+b was lifted peripherally and denuded. $V^{1+2}$b and $V^{1+2}$c could then be seen on the deep side of the distal $B^{1+2}$a+b stump, with $V^{1+2}$b running into $S^{1+2}$b+c (*Figure 10*). When compared with the 3D images, $V^{1+2}$b was clearly identified. The intersegmental veins $V^{1+2}$a and $V^{1+2}$c were also clearly revealed (*Figure 11*). $V^{1+2}$b was transected in the same manner as $A^{1+2}$a and $A^{1+2}$b (*Figure 12*). Finally, the lung tissue was cut along $V^{1+2}$a and $V^{1+2}$c as well as along the inflation–deflation line, thereby completing the $S^{1+2}$a+b-sub-segmentectomy (*Figure 13*). The intersegmental plane was cut with a combination of ultrasonic knife and linear cutting stapler (*Figure 14*).

The postoperative pathological diagnosis was microinvasive adenocarcinoma with a tumor diameter of 0.6 cm, mainly adherent to the wall, and a small lesion showing the growth pattern of acinar, without mediastinal lymph node

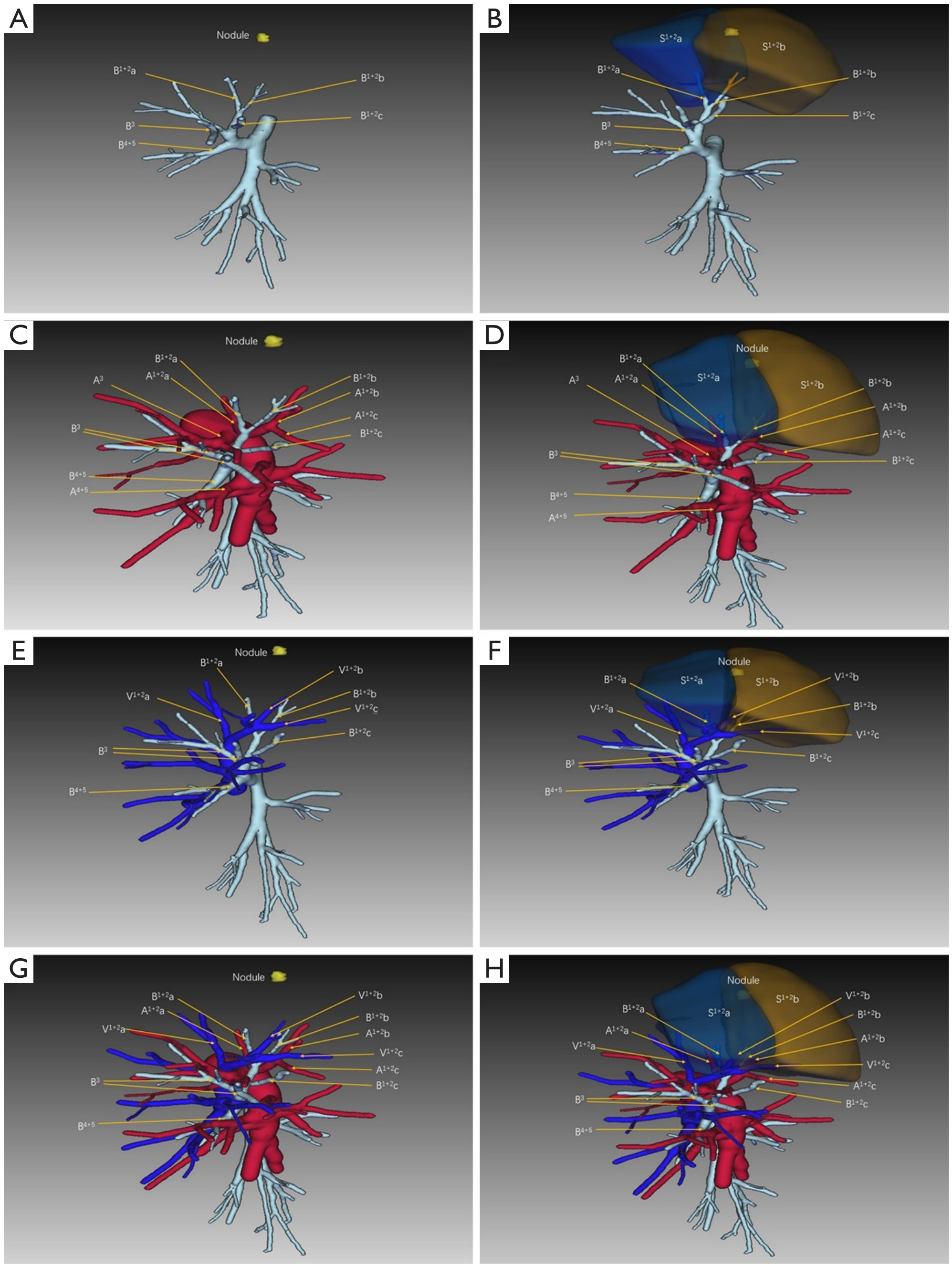


**Figure 3** Three-dimensional reconstruction of pulmonary structures. (A,B) The 3D reconstruction of bronchi with the IQQA-3D image interpretation analysis system (called IQQA hereafter) showing that $B^{1+2}a$ is combined with $B^{1+2}b$; (C,D) 3D reconstruction of the pulmonary artery with IQQA. $A^{1+2}a$ is adjacent to $A^{3}$, without mediastinal type $A^{4+5}$. $A^{1+2}b$ is combined with $A^{1+2}c$; (E,F) 3D reconstruction of pulmonary vein with IQQA. The intersegmental vein, which needs to be preserved, included $V^{1+2}a$ (between $S^{1+2}a$ and $S^{3}$) and $V^{1+2}c$ (between $S^{1+2}b$ and $S^{1+2}c$). Transection of segmental vein $V^{1+2}b$ is planned; (G,H) the targeted segmental bronchus, artery, and vein that require dissection are $B^{1+2}a$+b, $A^{1+2}a$, $A^{1+2}b$, and $V^{1+2}b$. The intersegmental veins that require preservation are $V^{1+2}a$ (between $S^{1+2}a$ and $S^{3}$) and $V^{1+2}c$ (between $S^{1+2}b$ and $S^{1+2}c$). 3D, three-dimensional.

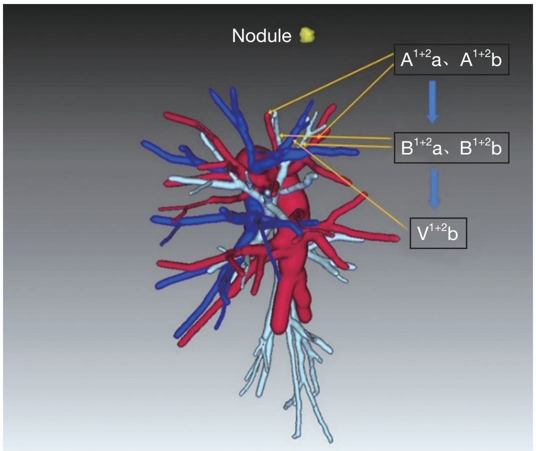


**Figure 4** On basis of the 3D anatomical relations, a surgical plan was created to deal with the segmental hilum in following order: $A^{1+2}$a to $A^{1+2}$a+b to $B^{1+2}$a+b to $V^{1+2}$b. 3D, three-dimensional.

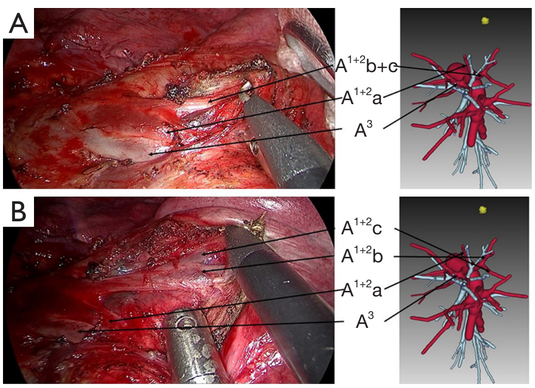


**Figure 5** (A) On the basis of the results of IQQA, $A^3$ and $A^{1+2}$ were identified; the branch near $A^3$ was $A^{1+2}$a; (B) $A^{1+2}$b was combined with $A^{1+2}$c, $A^{1+2}$b+c was dissected toward the periphery, and $A^{1+2}$b was confirmed when $A^{1+2}$b+c was separated to the bifurcation.

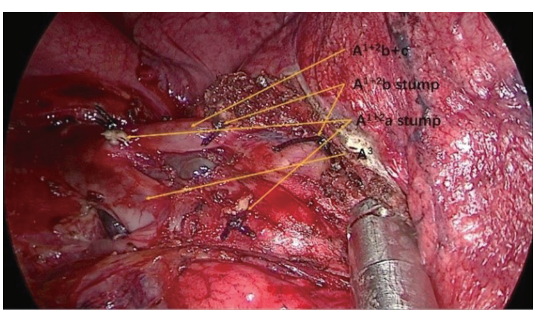


**Figure 6** Surgical wound after transection of $A^{1+2}$a and $A^{1+2}$b.

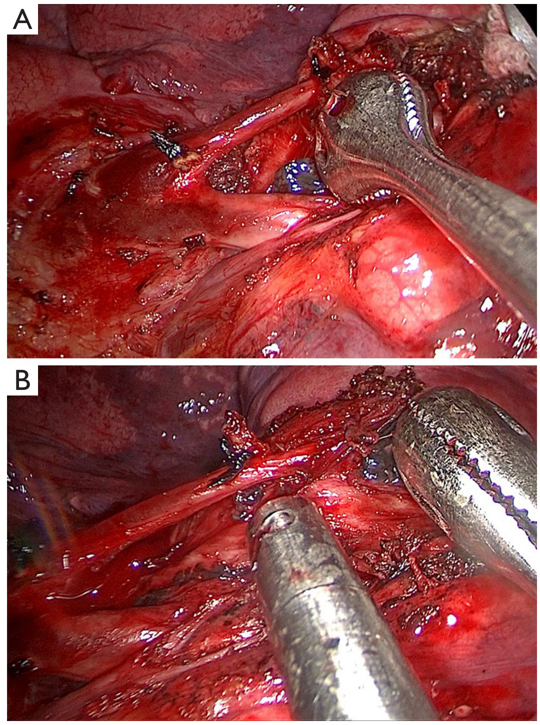


**Figure 7** Lymph nodes #12 and #13 were removed and sent for frozen biopsy.

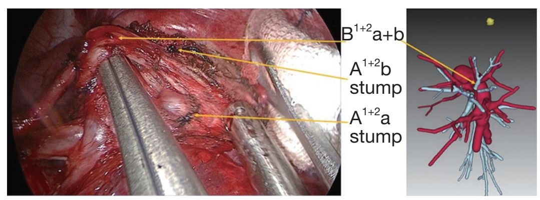


**Figure 8** $B^{1+2}$a was combined with $B^{1+2}$b. The distal stumps of $A^{1+2}$a, $A^{1+2}$b, and $B^{1+2}$a+b was easily revealed, as shown in the 3D reconstruction (at right). 3D, three-dimensional.

metastasis. The patient was discharged 3 days after surgery, with chest radiography suggesting a satisfactory recovery.

## Comments

For early lung cancer, pulmonary segmental resection not only meets the requirements of tumor resection, it also causes less loss of lung function. However, it is difficult to perform these resections because of the complicated and variable hilum structure of lung segments. Hence, 3D imaging reconstruction software has been developed to obtain stereoscopic images, allowing assessment of the

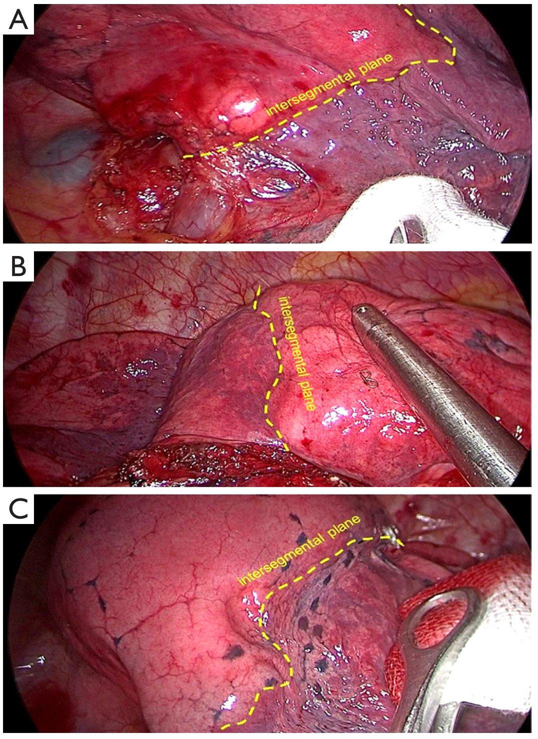


**Figure 9** The intersegmental plane is revealed with the "inflation-deflation" method. (A) Intersegmental plane between $S^{1+2}$a+b and $S^3$; (B) intersegmental plane between $S^{1+2}$a+b and $S^{1+2}$c; (C) intersegmental plane between $S^{1+2}$a+b and $S^{1+2}$c + $S^3$.

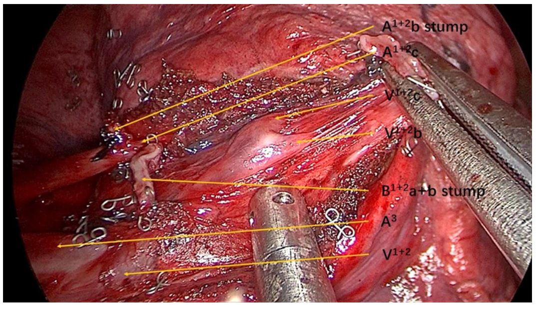


**Figure 10** Surgical wound after $B^{1+2}$a+b transection. $V^{1+2}$b and $V^{1+2}$c are seen on the deep side of the distal $B^{1+2}$a+b stump. $V^{1+2}$b runs into $S^{1+2}$b+c.

structural variations, and providing an important basis for preoperative surgical planning.

In the described case, the use of the IQQA-3D image interpretation analysis system for preoperative planning clearly showed the 3D relationships among the segmental bronchi, arteries, and veins. The targeted segment was

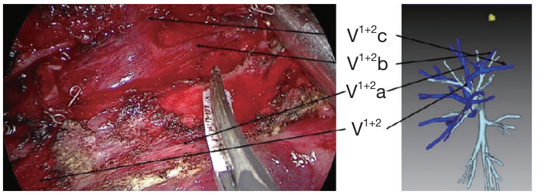


**Figure 11** $V^{1+2}$ has been denuded toward the periphery. $V^{1+2}$b and $V^{1+2}$c are seen on the deep side of the distal $B^{1+2}$a+b stump. $V^{1+2}$b runs into $S^{1+2}$b+c. Compared with 3D images, $V^{1+2}$b is clearly identified. The intersegmental veins $V^{1+2}$a and $V^{1+2}$c are also clearly seen. 3D, three-dimensional.

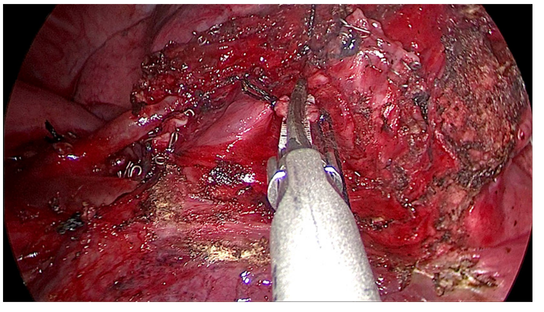

**Figure 12** An ultrasonic knife is used to cut $V^{1+2}$b following ligation with #4 common silk suture.

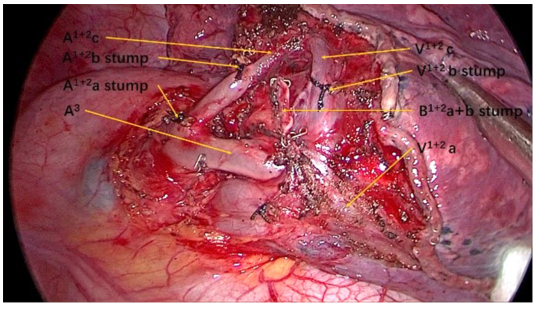


**Figure 13** Surgical wound after $LS^{1+2}$a+b sub-segmentectomy.

determined based on the simulated resection. A surgical plan was devised to deal with the segmental hilum from shallow to deep—from the pulmonary artery ($A^{1+2}$a+b) to the bronchi ($B^{1+2}$a+b) to the pulmonary veins ($V^{1+2}$b), in that order, on the basis of the 3D anatomical relationships.

The reconstruction results reveal that this case had the following characteristics:

(I) $A^{1+2}$a was adjacent to $A^3$, without mediastinal type $A^{4+5}$. Based on this anatomical feature, the first and second branches of the left pulmonary trunk are $A^3$

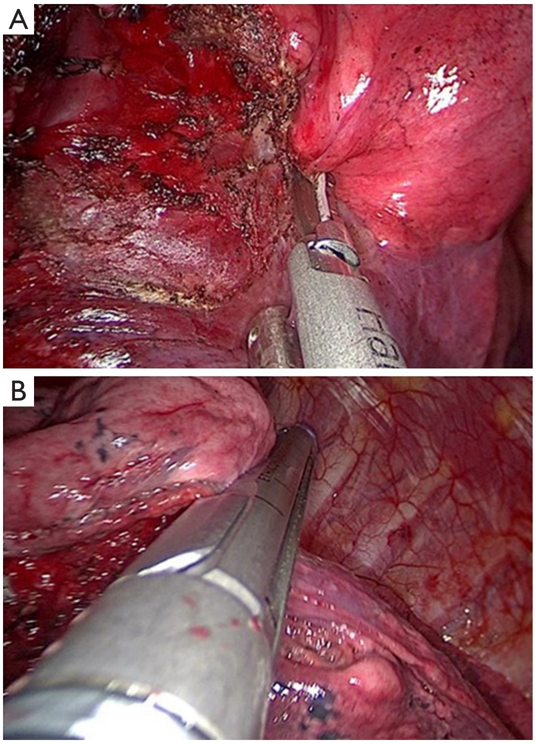


**Figure 14** The intersegmental plane was cut with a combination of ultrasonic knife and linear cutting stapler. (A) An ultrasonic knife was used to cut the intersegmental plane near the hilum; (B) the linear cutting stapler as used to cut the intersegmental plane away from the hilum.

and $A^{1+2}a$, so that $A^{1+2}a$ can be easily identified;

(II) $A^{1+2}b$ was combined with $A^{1+2}c$, which is the case, in 26% of patients (7). $A^{1+2}b+c$ must be sufficiently denuded toward the periphery to reveal $A^{1+2}b$;

(III) $B^{1+2}a$ was combined with $B^{1+2}b$. The intersegmental veins $V^{1+2}a$ and $V^{1+2}c$ needed to be preserved, and transection of segmental vein $V^{1+2}b$ was planned.

Knowing these characteristics, we easily identified each structure and successfully performed the operation under IQQA guidance.

Other authors have reported the application of various 3D reconstruction software products during segmentectomy, with various results. Most of these software programs, however, have had poor stereo effects with low resolution. With some software, it is difficult to reconstruct the trachea, or the software does not produce an ideal effect. Compared with other software systems, IQQA has the following advantages:

(I) the 3D image is clear, which makes it easier for the surgeon to correctly identify anatomical structure;

(II) it is helpful to fully understand anatomical variation before surgery to avoid damaging important structures and to provide the basis for individualized preoperative plans;

(III) this method simulates the amount of lung that needs resection, evaluates the margins, and determines an appropriate plan for segmentectomy;

(IV) this method reduces the exploration of uninvolved structures, reduces trauma, shortens surgical time, and possibly reduces complications;

(V) this method will help young doctors to familiarize themselves with anatomy and shorten their learning curves.

## Conclusions

The IQQA-3D image interpretation and analysis system can provide excellent 3D and quantitative reconstruction results, providing an important basis for individual preoperative plans. Its application to pulmonary segmental resection is safe and feasible.

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## Footnote

*Conflicts of Interest:* The authors have no conflicts of interest to declare.

*Informed Consent:* We obtained permission from the patient to use the related images and video. The patient provided written informed consent.

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