Three-dimensional printing technology for localised thoracoscopic segmental resection for lung cancer

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3D printing technique, Position, Ground glass nodule, Thoracoscopic segmentectomy
Abstract

Background
Three-dimensional (3D) CT reconstruction technology has gained increasing attention owing to its potential in locating ground glass nodules in the lung. The 3D printing technology additionally allows visualising the surrounding anatomical structure and variations. However, the clinical utility of these techniques is not known. We aimed to establish a lung tumour and an anatomical lung model using three-dimensional (3D) printing and 3D chest computed tomography (CT) reconstruction and to evaluate the clinical potential of 3D printing technology in uniportal video-assisted thoracoscopic segmentectomy.

Methods
Eighty-nine patients with ground glass nodules who underwent uniportal video-assisted thoracoscopic segmentectomy were divided into the following groups: Group A, lung models for pre-positioning and simulated surgery that were made with 3D chest CT reconstruction and 3D printing; Group B, patients who underwent chest CT scans with image enhancement for 3D reconstruction. The differences in the surgery approach transfer rate, surgical method conversion rate, operative time, intraoperative blood loss, and postoperative complication rate were compared between the groups.

Results
The surgery approach transfer rate was 0% and 10.5% for Groups A and B, respectively, showing a significant difference (p = 0.030). The operative time was 2.07 ± 0.24 hours and 2.55 ± 0.41 hours, respectively, showing a significant difference (p < 0.001). Intraoperative blood loss volume was 43.25 ± 13.63 and 96.68 ± 32.82 ml, respectively, showing a significant difference (p < 0.001). The postoperative complication rate was 3.9% and 13.2%, respectively, showing a non-significant difference (P = 0.132). The rate of surgical method conversion to lobectomy in Group A was 0%, which was significantly lower than that of 10.5% in group B (p < 0.030).

Conclusions
3D printing technology helps surgeons to locate the nodules more accurately, as it is based on 2D and 3D imaging findings, thereby improving the accuracy and safety of surgery. This technique is worth for application in clinical practice.

Trial registration:
Retrospectively registered.

Background
According to the China National Health and Wellness Committee's third survey, cancer has become the leading cause of death among urban residents in China, with lung cancer ranking first[1]. With widespread use of low-dose computed tomography (CT) scans, many lung ground glass nodules (GGNs) have been discovered at an early stage and are monitored for their potential malignant transformation[2, 3]. Currently, surgery remains the main treatment method for GGN. Thoracoscopic surgery is the standard treatment for early-stage lung tumours. It has the advantages of causing minimal trauma and having a rapid postoperative recovery rate; it is widely recognised and applied by thoracic surgeons [3, 4]. Anatomical segmentectomy has been proven to be an effective surgical treatment, while retaining as much of the lung tissue as possible and to have an oncological effect comparable to that of lobectomy[5]. In addition to the location of the target lesion, the definition of intersegmental segmentation is critical for anatomical segmentectomy. Recently, three-dimensional (3D) CT reconstruction technology has received more attention to help locate the position of lung GGNs [4]. With the development of 3D printing technology and its introduction in the field of surgery, the relationship between lung anatomy and lung tumour can be visualised preoperatively, which can help the surgeon determine the specific location of the lesion and the surrounding anatomical structure and variations, simulate surgical procedures, and explore the optimal surgical path to reduce the rate of surgery, operative time, and intraoperative blood loss. This study aimed to analyse the potential of 3D chest CT reconstruction combined with 3D printing technology in uniportal video-assisted thoracoscopic segmentectomy.

Methods

Ethics statement and patients
All procedures were carried out in accordance with the principles of the Declaration of Helsinki. The study was approved by the Clinical Research Ethics Committee at the Fujian Provincial Hospital, Fujian Province, China (K2015-022-01, September 30, 2015). Informed consent was obtained from the patients included in the study.
**Inclusion and exclusion criteria**

Patients whose chest CT scans showed pulmonary GGNs and who underwent segmentectomy at Fujian Provincial Hospital between March 2016 and September 2018 were enrolled. The inclusion criteria were as follows: a single lesion located in the lateral one-third of the lung parenchyma with a diameter of ≤2 cm, and according to the indications for segmental resection in the National Comprehensive Cancer Network (NCCN) guidelines, a uniportal video-assisted thoracoscopic segmentectomy was indicated for the patients. The exclusion criteria were as follows: central lesions with a tumour-to-intersegmental fissure distance of <2 cm; patients who do not meet the indications for segmental resection stipulated in the NCCN guidelines; and general conditions that do not allow surgery or preoperative examinations that suggest distant metastasis. See study flow diagram.

**General information**

All patients admitted to the hospital for surgical treatment, excluding those with poor surgical tolerance, distant metastasis, stroke sequelae, severe lung ventilation dysfunction, and other conditions, routinely undergo pulmonary function tests, cardiac ultrasound, total abdominal colour Doppler ultrasound, cranial magnetic resonance imaging, and whole-body bone scanning. All patients who met the enrolment criteria were included and randomly divided into experimental group A and control group B using the coin method. For the experimental group A, 3D chest CT reconstruction combined with the 3D printing technique was used to simulate the model to analyse the anatomical relationship and variations. For control group B, only a 3D CT scan was performed. A total of 89 patients were included, with 51 in the experimental group A [21 men and 30 women, aged 43-80 years, mean age 62 years; 17 patients were smokers (all men)] and 38 cases in the control group B [14 men and 24 women, aged 40-81 years, mean age 61 years; 9 patients were smokers (all men)]. There were no significant differences in the general characteristics between the two groups (Table 1).

**3D reconstruction and 3D printing**

All patients in both groups underwent plain and enhanced chest CT scans for further diagnosis and to determine tumour location. 3D reconstruction and 3D printing were further performed for the experimental group to further locate the tumour, determine the anatomical relationship and any...
anatomical variations, and to simulate the operative process. The Siemens Sensation 64-slice CT scanner with 1.2-mm pitch and 1.0-mm scanning thickness. The contrast agent used was iofol, which was manufactured by Jiangsu Hengrui Pharmaceutical Co. Ltd. (100 ml: 74.1 g Chinese medicine quasi-word H20143027) and administered using an intravenous injection to the elbow. The arterial and venous phase images were collected 25 and 55 seconds after the injection of the contrast agent, respectively. The IQQA®-Chest system was used to preserve the pulmonary artery, pulmonary vein, bronchus, tumours, hilum, and swollen lymph nodes and to reconstruct these structures with a 1.50-mm thickness. The pulmonary artery was red, the pulmonary vein was blue, and the bronchus was white. The 3D model was printed with Objet1000 Plus (STRATASYS Company). The physical printing ratio was 1:1, and the printing material used was photosensitive resin (Figure 1).

Preoperative positioning

The “coordinate positioning method” was utilised for preoperative positioning. This method is widely used for mapping and determining object positions. Generally, to determine the position of a point, the number or angle should be identified. In the plane, two axes perpendicular to each other and having a common origin to form a plane rectangular coordinate system are identified, with the horizontal and vertical axes noted as such. This method is somewhat different when determining the location of the lesion in the experimental and control groups.

The horizontal axis data are derived from the measurement of the horizontal level of the lung lesion seen in the CT image. The ‘clock alignment method’ is adopted, assuming that the horizontal plane of the right chest is a clock and the lesion is the part indicated by the hour hand. Using the right upper lung lesion as an example (Figure 2A), the horizontal CT section where the lesion is located is selected, the right chest contour is regarded as the clock face, the midline of the clavicle is the 12 o'clock position and the right midline is intended to be the 9 o'clock position (Figure 2B). According to the ‘clock positioning method’, the lesion is at 7.5 points. In both groups, the horizontal axis clock positioning method can be established in the CT horizontal plane.

The measurement of the vertical axis adopts a ‘scale-localisation algorithm’. There was a difference in the proportional positioning method between the experimental and control groups. In the
experimental group, the upper end to the lower end of the lobe where the lesion is located on each longitudinal axis is the measurement interval. Depending on the lobes, the upper end can be the tip of the lung or the interlobular fissure, whereas the lower end can be the interlobular fissure or the base of the lung. On the 3D lung model, the distance from the lesion to the upper and lower ends was measured on the vertical axis, and the proportional position of the lesion on the vertical axis was calculated. Continuing to take the right upper lung lesion as an example, the axis on the 7.5-hour position on the 3D lung model was selected. The length of the lesion to the tip of the lung and to the interlobular fissure is recorded as ‘a’ and ‘b’, respectively. The proportional position of the lesion on the vertical axis was calculated using the formula \[\frac{a}{a+b}\] (Figure 2C).

In experimental group A, the vertical position was located using the proportional segmentation method with the scale positioning technique, which was performed on the 3D lung model. The steps are as follows: (a) locate the lobe where the nodule is located on the 3D model; (b) measure the distance between the nodule and the upper boundary of the lobe (a) and the length of the upper and lower boundaries of the lobe (a+b); (c) the ratio of the distance from the upper boundary (a) to the length (a+b) of the upper and lower boundaries of the lung lobe \[\frac{a}{a+b}\] is the position of the nodule in the longitudinal axis of the lobe.

In control group B, preoperative vertical positional localisation was performed according to the sagittal and coronal planes of the CT image, using the following steps: (a) identify the lobe where the nodule is located on the CT image; (b) count the number of CT slices of the nodule from the border of the lung (n) and the total number of CT layers (N) of the upper and lower boundaries of the lobe; (c) calculate the ratio of the number of CT layers (n) of the nodule to the upper boundary of the lobe to the total number of CT layers (N) of the upper and lower boundaries of the lobe, thereby positioning the nodule longitudinally in the lobe.

In addition to the coordinate localisation method, we also selected anatomical landmarks such as the apex of the lung, bottom of the lung, front edge of the lung rib, midline of the lung rib surface, posterior edge line of the lung rib surface, and the interlobular fissure as references. Maneuverer, the lung segment area, tracheal block expansion, and finger touch detection methods, among others,
were performed to position the lesion accurately.

**Surgical methods**

All patients underwent uniportal video-assisted thoracoscopic segmentectomy and systemic lymphadenectomy. The operation was performed by the treatment team led by the chief physician of the Department of Thoracic Surgery, Fujian Provincial Hospital. The assistant adopted a “same side, high position, single hand, sideways” posture mirror [6] and the operator performed the procedure using a thoracoscopic instrument. The location of the intraoperative nodules was determined using data from the preoperative positioning methods described previously. A wedge-shaped resection was initially performed and followed by an intraoperative rapid frozen pathological examination. According to the rapid freezing pathological examination, the segmental vein, artery, and bronchus were separated at the anatomical level and the linear cutting suture device was broken or disconnected. To determine the inter-segment plane, the ‘Lung Expansion-Falling Method’ [7] was utilised for the last segment of the lung fissure. The two groups were separated from the inter-segment plane to the rib surface, and a straight-section cutting stapler was used to process the inter-segment plane. During the operation, the frozen tumour and margin tissues were sent for pathological examinations and the combined lung segment or lobectomy was determined according to the distance between the tumour and the margin (2 cm). Then, a conventional systemic lymph node dissection was performed. One chest tube was placed in the posterior margin of the incision, and one micro-thoracic tube was placed in the lower thoracic cavity (Figure 3).

**Observation indicators**

The surgical method conversion rate, operative time, intraoperative blood loss, postoperative complication rate, and segmental conversion rate of the lobectomy were measured and the differences between these variables were compared between the two groups. Surgical transfer rate is difficult to complete owing to pleural adhesion. Similarly, microscopic resection and laparoscopic mass resection are difficult to complete and the number of cases that undergo a successful transthoracic surgery is limited due to intraoperative bleeding. The surgical method conversion rate is the proportion of cases in which the segmental resection was converted to a lobectomy due to various
factors during the operation. The operative time was defined as the time from the start of the skin incision to suturing completion (h). Intraoperative blood loss is defined as the amount of blood absorbed by the gauze and the intraoperative suction (ml). And it is determined using the weighing method to calculate the attracting liquid hemoglobin content.

**Statistical analysis**

All data were analysed using SPSS21.0 statistical software. Measurement data were expressed as mean ± standard deviation and the two-sample t-test was used for comparison between groups. The number of count data was used (n) and the ratio of count data (%) was calculated by the X² test or Fisher’s exact probability method. P<0.05 indicated a statistically significant difference.

**Results**

**Surgical approach transfer rate**

The surgery approach transfer rate was 0% and 10.5% for Groups A and B, respectively (p<0.05). Among the 51 patients in Group A, none were transferred to thoracotomy. In this group, we identified and avoided vascular variation by performing the 3D CT reconstruction combined with 3D printing technology. On the contrary, among the 38 patients in the control group, four patients underwent conversion to thoracotomy owing to vascular variation of A1+2L, V8+9R, V4+5L and A8+9R.

**Surgical method conversion rate**

The surgical method conversion rate was 0% and 10.5% for Groups A and B, respectively (p<0.05). In the experimental group, none were converted to a lobectomy and we identified and avoided vascular variation through 3D CT reconstruction combined with 3D printing technology. On the contrary, in the control group, four patients were converted to lobectomy due to vascular variation of A4+5L, A1+2L, B6R and lack of incision margin (2 cm).

**Operative time**

The operative time was 2.07±0.24 and 2.55±0.41 hours for Groups A and B, respectively, showing a significant difference (p< 0.05). The difference in the operation time between the two groups was mainly due to intraoperative localisation and complications during the separation of various structures. The intraoperative localisation time is the time at which the lung nodules are located. Two
patients in the control group received a wedge-shaped resection to obtain the lesion. Compared to the control group B, the time spent for intraoperative positioning in the experimental group A was shortened by approximately 5-13 min, although this was not significant. The problems encountered during the separation of anatomical structures included tumour identification difficulties, bleeding, and anatomical variations.

**Intraoperative blood loss**
The intraoperative blood loss volume was 43.25±13.63 and 96.68±32.82 ml for Groups A and B, respectively, showing a significant difference (p<0.05). In the experimental group, we identified and avoided vascular variation through 3D CT reconstruction combined with 3D printing technology, and therefore, bleeding was reduced.

**Postoperative complications**
The postoperative complication rate was 3.9% and 13.2% for Groups A and B, respectively (p>0.05). In Group A, one patient developed cerebral infarction and another patient developed pulmonary infection. In Group B, one patient experienced persistent lung leakage, two experienced pulmonary infections, one had a cerebral infarction, and one developed arrhythmia (Tables 2 and 3).

**Discussion**
With the widespread use of low-dose CT scans and the increasing number of physical examinations, the number of GGNs detected early in the course of lung cancer has been increasing[8]. In recent years, with the advancement of thoracic surgical techniques, segmentectomy has replaced classic lobectomy as the treatment of small lung malignancies. Anatomical segmentectomy has gradually proven to be effective. Surgical treatment that promotes optimal lung tissue retention has an oncological effect comparable to that of lobectomy[9]. In the past, standard lobectomy was performed more often, resulting in unnecessarily extensive surgeries to remove GGNs. With the advancement of thoracic surgery in recent years, the rate of sublobar resection, especially the resection of a lung segment, has increased significantly.

This study was established based on the common problems encountered in segmental resection. The patients’ preoperative CT imaging data were used to establish the 3D imaging data of the affected
lung using the 3D imaging software program and then 3D printing technology was used to create pulmonary blood vessels. The 3D anatomical model of the lungs with important structures such as the bronchus and lesions was established. We collected several important indicators that are closely related to the quality of surgery to investigate the value of the 3D printed model of the lung in the segmentectomy, such as surgical time, intraoperative blood loss, surgical transfer rate, surgical method conversion rate, and postoperative complication rate.

The lung GGNs are usually non-solid lesions, and they are difficult to locate using the finger touch method. In clinical practice, we have also used CT-mediated injection of Meilan and the placement of coils around the lesion to locate small lesions that are difficult to detect. Meilan can be absorbed by the lung tissue and stays on the surface of the lungs for a short period. However, Meilan stains often disappear during surgery, and the coils placed in the lung tissue are often difficult to handle owing to their small size and softness. Therefore, these methods are often ineffective for locating the lesion.

The 3D print of the lung model helps the surgeon locate the lesion during surgery. The advantages of 3D reconstruction combined with 3D printing technology compared to traditional 2D and 3D positioning in CT images are obvious. With the aid of the 3D lung-printing model, it is easy to visually determine the area where the lesion is located, apply the coordinate positioning method, select important anatomical landmarks such as lung boundary, lung tip, lung base, and leaf fissure, as reference points, and measure the lesion and each anatomy from multiple angles. The corresponding distance of the marker can accurately determine the location of the lesion. In the 3D printing model, the surgeon can intuitively calculate the distance between the nodule and the upper boundary of the lung and the length of the upper and lower boundaries of the lung, reducing unnecessary errors. In 2D and 3D CT images, the distance between the nodule and the upper boundary of the lung lobe and the length of the upper and lower boundaries of the lung lobe are calculated by the number of CT layers.

Given that an actual measurement cannot be performed, the error is inevitably increased during positioning. In this study, the intraoperative localisation time of experimental group A was shorter than that of control group B, although not significant (p > 0.05). We believe that this may be due to the small sample size; hence, we will continue to collect cases to confirm this finding in subsequent
The application of 3D printing technology based on 3D reconstruction can facilitate preoperative and intraoperative positioning. Depending on the attribution of blood vessels and bronchial tubes near the nodules, lung nodules can be located according to the corresponding pulmonary section or even subsection. Owing to the improvement in the accuracy of lesion positioning, the tissues from the lesions can be obtained with wedge excision and the in-procedure pathology examination can be carried out in time, which consequently reduces the operative time. In the present study, lesion removal was not successfully completed in two patients in the control group who received a first wedge resection and the lesion was obtained only after an additional resection, thereby increasing the wedge resection time. This was not the case in the experimental group. Therefore, 3D printing technology can improve the success rate of lesion resection during intraoperative positioning. The 3D print of the lung model helps the surgeon identify the relevant anatomy and variation during the procedure. In these procedures, various anatomical variations of the bronchi and blood vessels can cause serious consequences if handled improperly, especially during thoracoscopic surgery. A clear 3D structure is difficult to achieve only using data obtained from 2D CT imaging, which is not convenient for a multi-angle reference. However, 3D imaging overcomes this disadvantage; however, some anatomical variations are still difficult to determine. The 3D print of the lung model helps the surgeon to detect the relevant anatomical variations in advance, thereby optimising the surgical procedure due to differences in anatomical variations and avoiding accidental injury to arteries, veins, and bronchi. As such, the anatomical variation can be mastered before surgery and preventive measures can be taken not only to avoid excessive bleeding during surgery but also to avoid remediation of anatomical structure damages. The 3D print model also reduces the surgical method conversion rate. Therefore, mastery of the patient's detailed anatomy before surgery is the key to prevent surgical complications.

In this study, there was no statistically significant difference in the postoperative complication rate between the two groups, which was comparable to the results of Cheng et al. [10]. However, we believe that this may be, again, due to the insufficient sample size in this study. We will continue to
increase the sample size in the next study to obtain more comprehensive data. In theory, the incidence of postoperative complications in the experimental group should have been lower than that of the control group. Along with reduced surgical bleeding, surgical time, surgical injury, and surgical conversion rates, anaesthesia and mechanical ventilation times during surgery will also be shortened. Additionally, there will also be reduced time for lung collapse, and all of these factors will reduce the incidence of lung tissue injuries and the incidence of postoperative complications.

Conclusions
The application of 3D chest CT reconstruction combined with 3D printing technology in segmental resection can reduce the surgical conversion rate, operative time, intraoperative blood loss, and segmental lobectomy conversion rate. This technique helps to improve the accuracy and safety of surgery and is worth for application in clinical settings.

Abbreviations And Acronyms
CT=computed tomography
GGN=ground glass nodules
3D=three-dimensional
NCCN=National Comprehensive Cancer Network

Declarations

Ethics approval and consent to participate: All procedures were carried out in accordance with the principles of the Declaration of Helsinki. The study was approved by the Clinical Research Ethics Committee at the Fujian Provincial Hospital, Fujian Province, China (K2015-022-01, September 30, 2015). Informed consent was obtained from the patients included in the study.

Consent for publication: Not applicable.

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Author contribution: Yangming Chen: Data curation; Investigation; Methodology; Writing—review
and editing. **Jiguang Zhang**: Investigation; Methodology; Project administration; Resources. **Qianshun Chen**: Data curation; Formal analysis. **Tian Li**: Software; Conceptualisation; Data curation. **Xing Lin**: Formal analysis; Funding acquisition; Supervision; Validation; Visualization; Writing—original draft. **Kai Chen**: Formal analysis; Supervision; Writing—review and editing. **Qinghua Yu**: Radiographical support; Conceptualization.

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**Authors’ information**: Not applicable.

**Tables**
|                              | Experimental group A (n = 51) | Control group B (n = 38) | Total (n = 89) | T value/x^2 | p value |
|------------------------------|------------------------------|--------------------------|----------------|--------------|---------|
| Age [year, average age (± standard deviation)] | 62±17 | 61±19 | 62±16 | 0.261 | 0.795 |
| gender | | | | | |
| Male [no. of cases (%)] | 21 | 14 | 35 | 0.171 | 0.679 |
| Female [no. of cases (%)] | 30 | 24 | 54 | | |
| Smoking | | | | | |
| Smoker [no. of cases (%)] | 17 | 11 | 28 | 0.194 | 0.659 |
| No smoking [no. of cases (%)] | 34 | 27 | 61 | | |
| Position (no. of cases, proportion %) | | | | | |
| Left lung | 18 | 13 | 31 | 0.011 | 0.915 |
| Right lung | 33 | 25 | 58 | | |
| LS1+2 | 3 | 2 | 5 | 0.829 | 1.000 |
| LS1+2+3 | 3 | 3 | 6 | | |
| LS4+5 | 3 | 2 | 5 | | |
| L3 | 2 | 1 | 3 | | |
| L6 | 2 | 2 | 4 | | |
| L basal segment | 5 | 3 | 8 | | |
| RS1 | 6 | 4 | 10 | | |
| RS1+2 | 7 | 5 | 12 | | |
| RS3 | 3 | 2 | 5 | | |
| RS6 | 5 | 3 | 8 | | |
| R basal segment | 12 | 11 | 23 | | |
### Table 2. Comparison of the observation indicators between the groups.

|                              | Surgery transfer rate (no. of cases, %) | Operative time (h, x ± SD) | Intraoperative blood loss (ml, x ± SD) | Postoperative complication rate (no. of cases, %) | Conversion rate (no. of cases, %) |
|------------------------------|-----------------------------------------|-----------------------------|----------------------------------------|---------------------------------------------------|----------------------------------|
| Experimental Group A (n=51)  | 0.0                                     | 2.07±0.24 h                 | 43.25±13.63 ml                         | 2,3.9                                             | 0.0                               |
| Control group B (n=38)       | 4,10.5                                  | 2.55±0.41 h                 | 96.68±32.82 ml                         | 5,13.2                                           | 4,10.5                            |
| t value                     | -6.366                                  | 0.001                       | 0.001                                  | 0.132                                           | 0.030                             |
| P value                      | 0.030                                   | 0.001                       | 0.001                                  | 0.132                                           | 0.030                             |

### Table 3. Comparison of the postoperative complications between the groups.

|                        | Persistent lung leak (no., %) | Atelectasis (no., %) | Pulmonary infection (no., %) | Cerebral infarction (no., %) | Arrhythmia (no., %) | Total (no., %) |
|------------------------|------------------------------|----------------------|-----------------------------|-------------------------------|---------------------|---------------|
| Group A (n=51)         | 0.0%                         | 0.0%                 | 1.2.0%                      | 1.2.0%                        | 0.0%                | 2.3.9%        |
| Group B (n=38)         | 1.2.6%                       | 0.0%                 | 2.5.3%                      | 1.2.6%                        | 1.2.6%              | 5.13.2%       |
| P value                | 0.427                        | 1.000                | 0.573                       | 1.000                         | 0.427               | 0.132         |

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Figures
CT image, 3D reconstruction image, and 3D model of the same case A. The patient’s 2D CT image showing a part-ground glass nodule (pGGN) in the left upper lung. B-E. The patient’s 3D CT reconstruction image, from which the lung veins, bronchus, and arteries can be more intuitive. F. The patient’s 3D print of the lung model not only allows visualization of the lung anatomy but also facilitates coordinate positioning, accurately locates the lesion, and helps in the precise wedge resection of the lesion during surgery.
The application process of the coordinate positioning method. A and B are the horizontal orientations. Using the right upper lung lesion as an example, the CT horizontal section where the lesion is located is selected, the right chest contour is regarded as the clock face, and the midline of the clavicle is intended to be the 12 o’clock position. The right midline is intended to be the 9 o’clock position, and the lesion in the “Clock Positioning” legend is at the 7.5 o’clock position. Image C is the vertical axis orientation. Using the right upper lung lesion as an example, the axis of the 7.5 o’clock position on the 3D lung model was selected. The length of the lesion to the tip of the lung is recorded as ‘a’, and the length of the lesion to the interlobular fissure is recorded as ‘b’. The proportional position of the lesion on this axis is calculated.
Three-dimensional reconstruction CT image of the same patient and intraoperative-related anatomy. A. Image of pulmonary artery reconstruction, with arrows pointing to A(1+2)a and A(1+2)b+c. B. The patient's pulmonary vein, pulmonary artery, bronchi, and pulmonary nodules are shown in the reconstructed image. C. The patient's intraoperative pulmonary anatomy is consistent with preoperative 3D reconstruction and 3D printing.

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