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ORIGINAL ARTICLE / ÖZGÜN MAKALE

Effect of preoperative three-dimensional modeling on uniportal video-assisted thoracoscopic bronchial sleeve resection and early postoperative outcomes

Uniportal video yardımlı torakoskopik bronşiyal sleeve rezeksiyonda ameliyat öncesi üç boyutlu modellemenin etkisi ve ameliyat sonrası erken dönem sonuçlar

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ABSTRACT

Background: The aim of this study was to evaluate the effects of preoperative three-dimensional (3D) modeling on the performance of uniportal video-assisted thoracoscopic bronchial sleeve resection and early postoperative outcomes.

Methods: A total of 10 patients (5 males, 5 females; mean age: 53.8±16.9 years; range, 18 to 75 years) who underwent uniportal video-assisted thoracoscopic bronchial sleeve resection with preoperative 3D modeling between April 2021 and November 2023 were retrospectively analyzed. Preoperative 3D modeling was prepared using computed tomography with an open-source 3D software program. Demographic, clinical, intraoperative, and postoperative data of the patients were recorded. Anatomical landmarks identified by preoperative 3D modeling were compared with intraoperative findings.

Results: The anatomical landmarks created with the 3D model were in 100% agreement with the intraoperative findings. The procedures performed were three left lower lobes, three right upper lobes, one middle lobe, one right lower lobe, and one parenchyma-sparing intermediate bronchial sleeve resection. Bronchial sleeve resection was completed using uniportal video-assisted thoracoscopic technique in 90% of patients, with only one patient requiring conversion to open thoracotomy. The mean resection time was 264.2±40.5 min, and the mean anastomosis time was 86.0±20.3 min. Anastomosis times decreased with increasing experience (p=0.008). Postoperative atelectasis was observed in two patients, and there was no mortality. The mean follow-up duration was 12.2±11.8 months.

Conclusion: Preoperative 3D modeling significantly contributed to the successful implementation of uniportal video-assisted thoracoscopic bronchial sleeve resection surgery. In the future, with advancements in simulation programs, patient-specific 3D modeling is expected to benefit the identification of anatomical landmarks for bronchial sleeve resections.

Keywords: Bronchial sleeve resection, three-dimensional modeling, uniportal, video-assisted thoracoscopic surgery.

ÖZ

Amaç: Bu çalışmada, ameliyat öncesi üç boyutlu (3D) modellemenin uniportal video yardımlı torakoskopik bronşiyal sleeve rezeksiyonun performansı ve ameliyat sonrası erken dönem sonuçları üzerindeki etkileri değerlendirildi.

Çalışma planı: Nisan 2021 ve Kasım 2023 tarihleri arasında ameliyat öncesi 3D modelleme ile uniportal video yardımlı torakoskopik bronşiyal sleeve rezeksiyon uygulanan toplam 10 hasta (5 erkek, 5 kadın; ort. yaş: 53.8±16.9 yıl; dağılım, 18-75 yıl) retrospektif olarak analiz edildi. Ameliyat öncesi 3D modelleme, açık kaynaklı bir 3D yazılım programı ile bilgisayarlı tomografi kullanılarak hazırlandı. Hastaların demografik, klinik, ameliyat sırası ve ameliyat sonrası verileri kaydedildi. Ameliyat öncesi 3D modelleme ile belirlenen anatomik işaretler ameliyat sırası bulgularla karşılaştırıldı.

Bulgular: Üç boyutlu model ile oluşturulan anatomik işaretler ameliyat sırası bulgularla %100 uyumluydu. Uygulanan işlemler üç sol alt lob, üç sağ üst lob, bir orta lob, bir sağ alt lob ve bir parankim koruyucu ara bronşiyal sleeve rezeksiyon idi. Hastaların %90'ında bronşiyal sleeve rezeksiyon uniportal video yardımlı torakoskopik teknik kullanılarak tamamlandı ve sadece bir hastada açık torakotomiye dönüşüm gerekti. Ortalama rezeksiyon süresi 264.2±40.5 dk ve ortalama anastomoz süresi 86.0±20.3 dk idi. Anastomoz süreleri deneyim arttıkça azaldı (p=0.008). İki hastada ameliyat sonrası atelektazi gözlendi ve mortalite olmadı. Ortalama takip süresi 12.2±11.8 ay idi.

Sonuç: Ameliyat öncesi 3D modelleme, uniportal video yardımlı torakoskopik bronşiyal sleeve rezeksiyon cerrahisinin başarılı bir şekilde uygulanmasına önemli ölçüde katkıda bulundu. Gelecekte, simülasyon programlarındaki ilerlemelerle birlikte, hastaya özgü 3D modellemenin bronşiyal sleeve rezeksiyonlar için anatomik işaretlerin belirlenmesinde fayda sağlaması beklenmektedir.

Anahtar sözcükler: Bronşiyal sleeve rezeksiyon, üç boyutlu modelleme, uniportal, video yardımlı torakoskopik cerrahi.

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Bronchial sleeve resection (BSR) is a safe technique widely used in the surgical treatment of lung cancer. The main aim is to maximally preserve respiratory function using a parenchyma-sparing surgical approach with negative surgical margins.[1] Video-assisted thoracoscopic surgery (VATS) BSR was first reported in the literature in 2002.[2] With the recent developments in VATS, the risks of morbidity and mortality have been shown to be significantly lower in VATS BSR than in conventional thoracotomy.[3-5] However, Gonzales-Rivas et al.[3] reported VATS BSR through a single incision, taking the minimally invasive method further using the uniportal technique.[3,6,7]

Uniportal VATS (uVATS) BSR is not widely preferred owing to its complicated technique.[8] In recent years, preoperative three-dimensional (3D) modeling has been widely used to identify anatomical landmarks to overcome difficulties in lung surgery. Three-dimensional modeling of the lung can significantly improve preoperative surgical planning as it provides more detailed visual data than a normal computed tomography (CT) image for assessing bronchovascular anatomy and can simplify the complex procedure by making it easier to assess the patient's specific anatomy. As there are many variations in pulmonary arteries and veins, a detailed preoperative understanding of the patient's specific anatomy can contribute to the safe performance of lung surgery and prevent complications.[9] In centrally located tumors, it can contribute to the intraoperative analysis of complex anatomy by determining anatomical landmarks. Therefore, in our study, we aimed to evaluate the effects of preoperative 3D modeling on the performance of uVATS BSR, a complex procedure, and to present early postoperative results.

PATIENTS AND METHODS

A total of 86 patients who underwent preoperative planning with 3D modeling at the Ondokuz Mayıs University Health Practice and Research Hospital between April 2021 and November 2023 were retrospectively analyzed. Ten patients (5 males, 5 females; 53.8±16.9 years; range, 18 to 75 years) who underwent uVATS BSR were included in this study. Baseline data, including 3D modeling and intraoperative video recordings, were also evaluated. Demographic, pathological, and pre- and postoperative data were obtained from the digital database of our hospital. All the patients were discussed by a multidisciplinary lung oncology council. Positron emission tomography, brain magnetic resonance imaging, complete blood count, coagulation profile, and biochemical parameters were also evaluated. Preoperative endobronchial examination with flexible bronchoscopy and mediastinal invasive staging were performed before resection.

Bronchial sleeve lobectomy criteria were as follows: *(i)* centrally located tumors extending to the main bronchus or invading the intermediate bronchus, *(ii)* adequate respiratory capacity for lobectomy, *(iii)* age >18 years, *(iv)* body mass index <40, *(v)* no mediastinal lymph node involvement, and *(vi)* not receiving neoadjuvant/definitive chemoradiotherapy. Patients with peripheral tumors suitable for lobectomy and segmentectomy, distant metastasis, and hilar/peribronchial calcific lymph nodes were excluded.

Three-dimensional reconstruction and planning

All patients underwent preoperative CT imaging using a 64-detector multidetector CT scanner (GE Healthcare Discovery CT750 HD scanner; GE Healthcare, Milwaukee, WI, USA), and iohexol (Opaxol) as a contrast agent [70 mL of nonionic contrast agent (350 mg I/Ml)] was injected into the antecubital vein at 2 mL/sec via a power injector. The DICOM (Digital Imaging and Communications in Medicine) data were transferred to a dedicated workstation. Based on the contrast-enhanced CT images, 3D modeling was performed with a software-based evaluation using the software tools “Segment Editor” and “Segmentation” of the open-source 3D Slicer software version 5.1.1 (https://www.slicer.org). For optimal results, contrast-enhanced CT images with a slice thickness of 1.25 mm or less were used for 3D modeling. Lung reconstruction was performed by identifying and segmenting the pulmonary bronchovascular structures and by placing the tumor. The use of contrast medium combined with accurate contrast timing allows the system to automatically perform 3D modeling of pulmonary arteries and veins (Figure 1). In addition, tumor extraction was performed by virtual simulation to visualize the resection site and extent of the surgical margin. The 3D reconstruction and virtual simulation of the resection for each patient were recorded in an interactive video file, in which all pulmonary structures could be individually selected. The files were then transferred to a mobile device. All reconstructions were performed by the operating surgeon. The patients were evaluated and approved by two independent radiologists.

Surgical technique

The patient was placed in the lateral decubitus position, with the side of the procedure pointing upward.

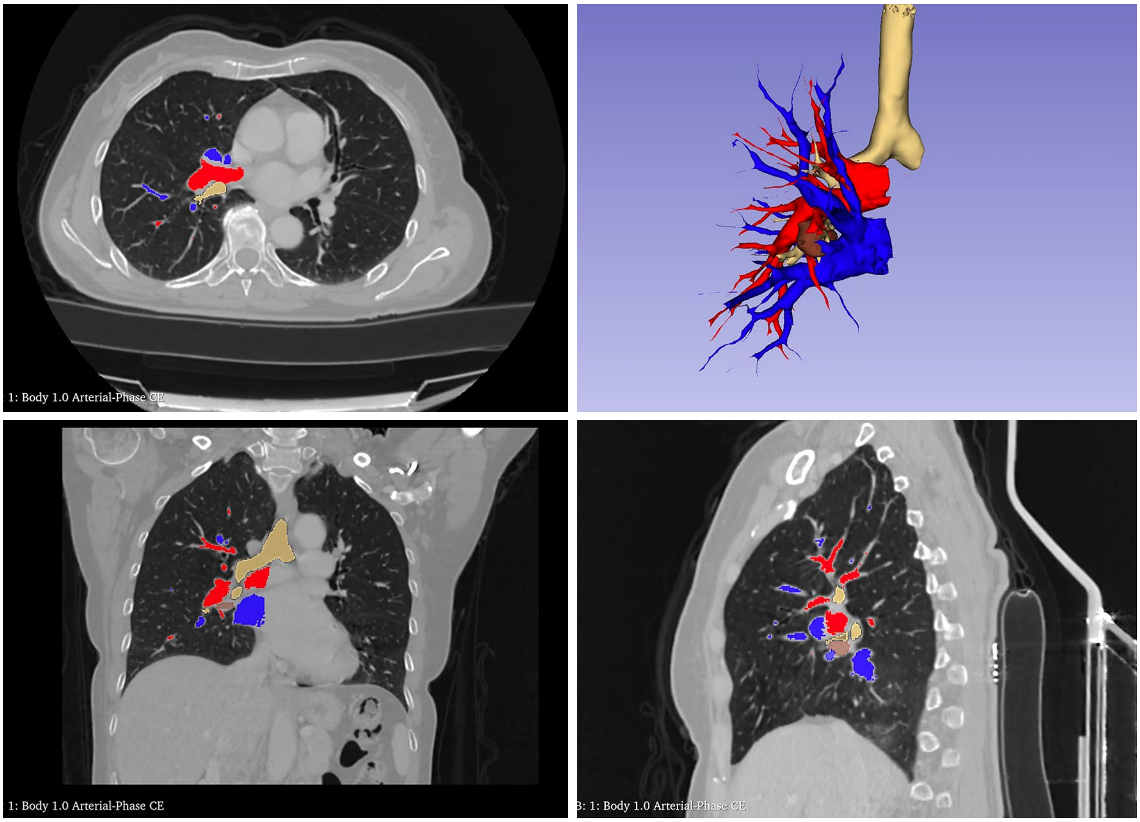

Figure 1. A 3D model was created after the automatic determination of the arteries and veins in the 3D Slicer program. Bronchovascular view of the preoperative 3D model of a patient scheduled for surgery for a carcinoid tumor at the entrance of the right middle lobe can be observed from the model, with the colors being able to be determined by the user. In this section, the pulmonary arteries are colored red, the veins blue, and the tracheobronchial system yellow.
3D: Three-dimensional.

A double-lumen intubation tube was placed, and general anesthesia with one-lung ventilation was administered. For uniportal surgery, a single 3- to 4-cm long incision was made between the anterior and midaxillary line parallel to the intercostal space at the fourth intercostal space for upper lobe resections and at the fifth or sixth intercostal space for lower lobe resections. The incision was closed by using a silicone wound protector. A 10-mm 30° thoracoscope (HOPKINS Forward-Oblique 30° Telescope; Karl Storz, Tuttlingen, Germany) was used as the camera, and an endoscopic sealer/separator (LigaSure Maryland Jaw; Medtronic, Minneapolis, MN, USA) was used as an energy device for tissue dissection. The preferred surgical instruments for vascular and bronchial dissection were the node grasper (snake), dissector clamp, endovascular clamp, right clamp, and aspirator. Hilar and systematic lymph node dissections were routinely performed in all patients to provide more space for lung manipulation. The dissected vascular structures were ligated and cut using an endostapler or polymer clips. The fissure was completed by closing the parenchyma with a stapler or energy device. The bronchial structures isolated for sleeve resection were transected with a long-handled scalpel and scissors from the locations planned in 3D modeling (Figure 2). Although secure surgical margins were achieved macroscopically, all specimens were sent for intraoperative frozen-section examination to histopathologically confirm negative resection margins. Before anastomosis, the secretions in the proximal and distal bronchial regions were washed with saline and aspirated. As shown in Figures 3 and 4, end-to-end bronchial anastomosis was performed with a continuously running suture technique using a double-needle monofilament 3-0 polypropylene single suture. An air leak test was then performed to confirm the absence of leakage under 30 cmH_2O airway pressure. The anastomotic line was supported by Tisseel tissue adhesive (Baxter Healthcare Corporation, Deerfield, IL, USA). At the end of the procedure,

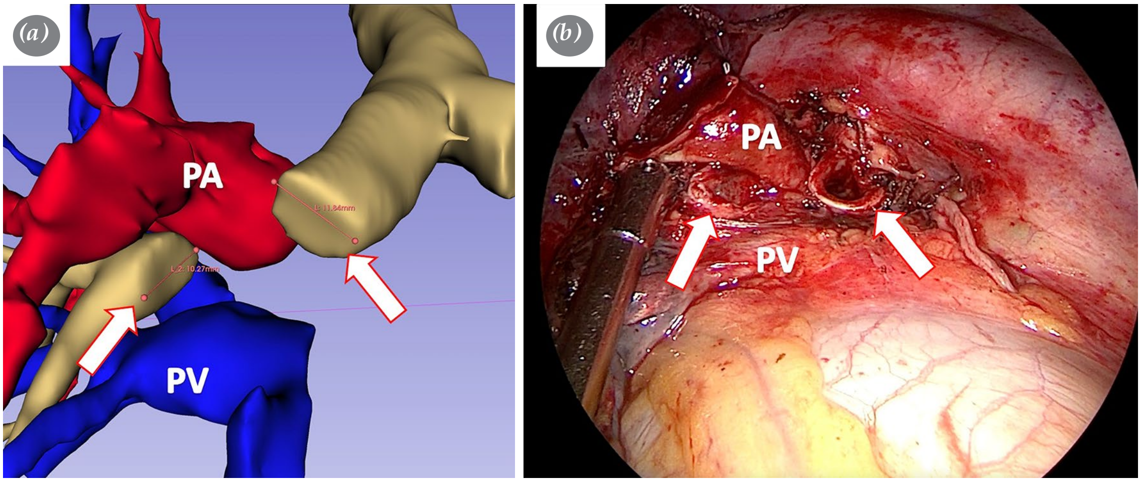

Figure 2. (a) Preoperative 3D modeling image and **(b)** intraoperative bronchial transected image of a patient who underwent left lower lobe bronchial sleeve resection showing 100% compatibility.

PA: Pulmonary artery; PV: Pulmonary vein; 3D: Three-dimensional.

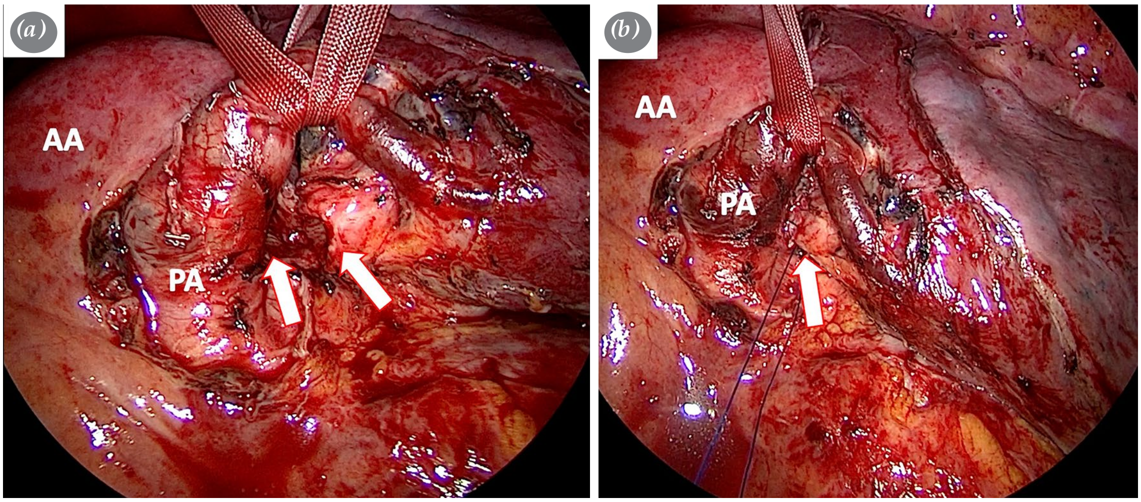

Figure 3. (a) Preanastomosis image and **(b)** end-to-end bronchial anastomosis performed with continuously running suture technique using a double-needle monofilament 3-0 polypropylene single suture.

AA: Arcus aorta; PA: Pulmonary artery.

a 28 French (Fr) chest tube was placed through the same incision, and negative pressure was provided using a closed underwater system. Postoperative anastomotic control and bronchial aspiration were performed by using a flexible bronchoscope.

Statistical analysis

Statistical analyses were performed using IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as the mean ± standard deviation (SD) or as the median [interquartile range (IQR)], while categorical data were presented as frequencies and percentages (%). The correlations between variables were assessed using the Pearson correlation test. A p-value <0.05 was regarded as statistically significant.

RESULTS

In each patient, R0 resection was performed. Histopathologically negative bronchial surgical margins were confirmed by pathologists. All operations were performed in three left lower lobes, three right upper lobes, one parenchyma-sparing intermediate

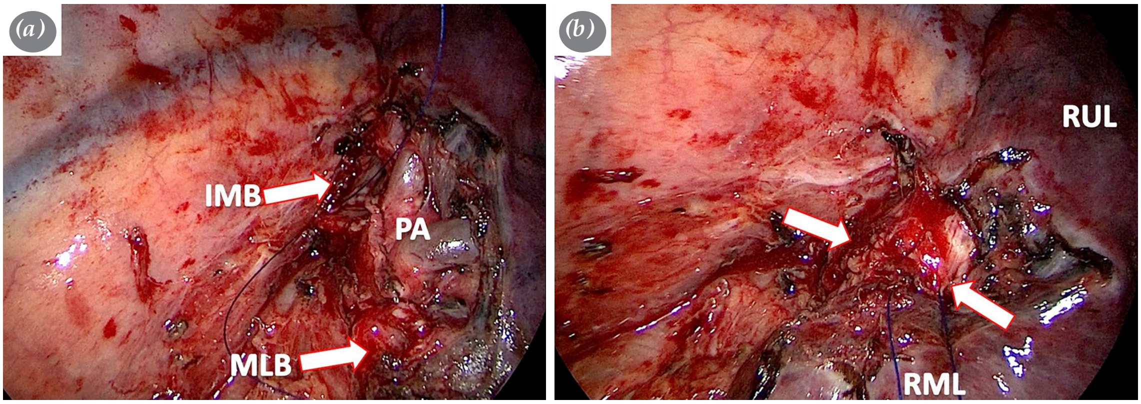

Figure 4. Image of the patient who underwent right lower lobe bronchial sleeve resection **(a)** before anastomosis and **(b)** after end-to-end bronchial anastomosis with the continuously running suture technique using double-needle monofilament 3-0 polypropylene single suture (arrows point to the anastomosis line).

IMB: Intermediate bronchus; MLB: Middle lobe bronchus; PA: Pulmonary artery; RUL: Right upper lobe; RML: Right middle lobe.

Table 1. Patient demographics and outcomes (n=10)

	n	%	Mean±SD	Median	IQR
Age (year)			53.8±16.9		
Sex					
Male	5	50			
Female	5	50			
Symptom					
Cough	5	50			
Dyspnea	1	10			
Hemoptysis	2	20			
Other	2	20			
Resection type					
RUL	3	30			
RML	1	10			
RLL	1	10			
LUL	1	10			
LLL	3	30			
Lung sparing	1	10			
Histopathology					
SCC	5	50			
Typical carcinoid	3	30			
Mucus gland adenoma	1	10			
Lipoma	1	10			
Tumor size (mm)			30.0±19.3		
Resection time (min)			264.2±40.5		
Anastomosis time (min)			86.0±20.3		
Estimated blood loss (mL)			92.0±73.9		
Complication					
Bleeding	0	0			
Prolonged air leak (>5 days)	0	0			
Atelectasis	2	20			
Pneumonia	1	10			
Chest tube removal (day)				2	1-3
Length of stay (day)				4	3-13
Follow-up (month)			12.2±11.8		

ZD: Standard deviation; IQR: Interquartile range; RUL: Right upper lobe; RML: Right middle lobe; RLL: Right lower lobe; LUL: Left upper lobe; LLL: Left lower lobe; SCC: Squamous cell carcinoma.

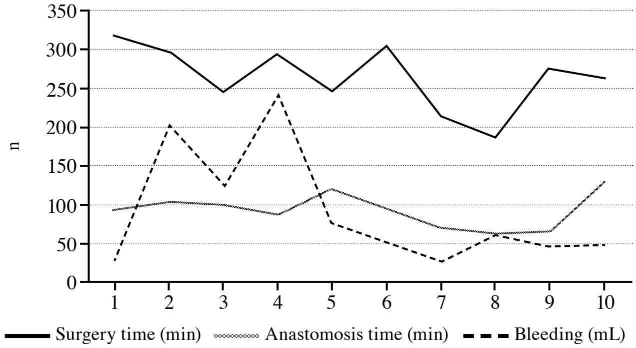

Figure 5. Diagram showing the comparison of uVATS BSR performed after preoperative 3D modeling in terms of surgery time (p=0.138), anastomosis time (p=0.008), and amount of estimated blood loss (p=0.377).

uVATS: Uniportal videothoracoscopic; BSR: Bronchial sleeve resection; 3D: Three-dimensional.

lobe, one middle lobe, one right lower lobe, and one left upper lobe bronchial sleeve resection (Table 1). The anatomical landmarks determined by preoperative 3D modeling were 100% consistent with the intraoperative findings. The visual relationship of the tumor and lymph nodes with the bronchovascular structures was similar to that of 3D modeling. In one patient, despite the anticipated relationship of the tumor to the bronchial system in 3D modeling, VATS conversion to open thoracotomy was necessitated by histologically positive surgical margins. Subsequently, bronchial sleeve resection was performed by expanding the resection margin.

The procedures were completed using a uniportal approach in 90% of the patients. Only in the case of conversion to open thoracotomy was the anastomosis line supported by autologous tissue (pericardial fatty tissue flap). No anastomotic complications developed in any of the patients. Atelectasis was diagnosed as an early complication in two patients. The patients were treated with pulmonary physiotherapy.

The mean resection time was 264.2±40.5 min, and the mean anastomosis time was 86.0±20.3 min. The mean perioperative estimated blood loss was 92.0±73.9 mL. The duration of all procedures was compared. Anastomosis times shortened with increasing experience (p=0.008, Figure 5). The median postoperative chest tube follow-up time was 2 days (IQR, 1-3 days), and the median hospital stay was 4 days (IQR, 3-13 days).

The mean tumor diameter was 30.0±19.3 mm. Histopathological examination revealed keratinized squamous cell carcinoma in five (50%) patients, typical carcinoid in three (30%) patients, mucous gland adenoma in one (10%) patient, and endobronchial lipoma in one (10%) patient. The mean follow-up period was 12.2±11.8 months. The follow-up of the 10 patients remains in progress with no mortality.

DISCUSSION

This study examines the impact of preoperative planning utilizing 3D modeling on intraoperative guidance and postoperative outcomes in bronchial sleeve resections. Three-dimensional modeling was conducted for all patients based on conventional multislice CT images using open-source software. These models were then transferred to mobile devices for intraoperative use. Videos uploaded to the mobile devices enabled surgeons to perform a 360° examination of vascularization and the bronchial tree in the operating theatre. Intraoperative dissection and visualization closely mirrored the features depicted in the 3D models, achieving a concordance rate of 100%.

For bronchial procedures, three different bronchoplastic methods have been described: simple, wedge, and sleeve bronchoplasty.[10] Sleeve resections, in contrast to other methods, are complex procedures that demand expertise for execution and are conducted with acceptable rates of morbidity and mortality.[11] Experience from VATS procedures indicates that VATS BSR is a safely applicable method for all age groups.[12,13] Zhou et al.[14] compared a series of VATS BSR procedures with open thoracotomy, demonstrating better postoperative outcomes while maintaining similar survival rates. Similarly, Deng et al.[15] conducted a meta-analysis, which revealed that VATS BSR procedures were associated with significantly reduced intraoperative bleeding and shorter hospital stays compared to open thoracotomy. In our study, findings in parallel to the literature were observed. No adverse effects on patients were noted despite prolonged operation times. The median duration of chest tube placement was 2 days (IQR, 1-3 days), and the median length of stay was 4 days (IQR, 3-13 days).

Uniportal VATS BSR, first reported by Gonzales-Rivas et al.[3] in 2013, has subsequently been adopted by many surgeons.[16] Previous studies have argued that this procedure has advantages over open thoracotomy and conventional VATS.[16,17] Bertolaccini et al.[18] reported that the uniportal approach has adequate visualization for thoracic exploration and sleeve procedures. The most notable feature of the uVATS technique is the provision of a visual perspective similar to that of open thoracotomy for the surgeon. This visual advantage is crucial for aligning surgical instruments along the same axis. Gonzales-Rivas et al.[19] recommended, based on their shared experience, that surgeons intending to perform uVATS BSR should undertake a minimum of 200 VATS lobectomies and at least 20 open sleeve procedures to establish a solid foundation for anatomical and operative techniques. Despite these recommendations, advancements in digital technologies and detailed preoperative simulations, coupled with the visual advantages of intraoperative videothoracoscopy, have enabled surgeons to perform complex procedures using uVATS. The surgeon's first case in this study was their 42nd anatomical resection using uVATS, despite having no prior experience with sleeve resection in open surgery.[20] We believed that the ability to perform uVATS BSR without prior experience in sleeve resection with open thoracotomy could be achieved through detailed preoperative planning. Despite no changes in the total resection time as experience increased, we demonstrated a reduction in anastomosis times. Nevertheless, regardless of surgical duration, we believe that adherence to oncological principles to complete the resection and perform patient suturing according to the bronchial suture technique with patience is more crucial in preventing postoperative complications.

In preoperative planning, pulmonary 3D modeling can be utilized to identify anatomical landmarks, as in segmentectomy, even in centrally located tumors. The greatest advantage of 3D modeling is facilitating better recognition of anatomical structures during surgery.[21] Two-dimensional image series of contrast-enhanced CT can provide all the necessary data to analyze lung anatomy. However, these images are not always sufficient to fully recognize the spatial relationships between anatomical structures.[22] Three-dimensional lung modeling facilitates surgeons' rapid and intuitive recognition of anatomy and associated bronchovascular anomalies.[23] Sardari Nia et al.[24] argued that preoperative 3D modeling would allow for a detailed anatomical delineation of the tumor, enabling surgeons to perform anatomical radical resections instead of pneumonectomy. Additionally, the images can be shared for educational purposes and utilized for preoperative and intraoperative simulations.[25] In their review, Sandri and Brunelli[26] stated that with the advancement of new technologies and the development of virtual reality, virtual simulation will become more widely available in a cost-effective manner, thereby enabling the safe application of uVATS in all procedures. In this study, 3D modeling, initially implemented for segmentectomy surgeries, was utilized in preoperative planning for centrally located tumors. We found that preoperatively marked anatomical landmarks accurately guided the surgeon intraoperatively, indicating the regions where bronchovascular structures are located with high precision. We believe that this advantage provided by preoperative 3D modeling positively influences the prevention of intraoperative complications.

The primary goal for sleeve resection is to preserve nonresectable parenchymal anatomical structures during dissection and anastomosis. The bronchial anastomosis part has been the primary reason that led surgeons to prefer open thoracotomy over VATS BSR.[5] In uVATS, bronchial anastomosis principles are the same as in open surgery: tension-free anastomosis, preservation of bronchial vascularization, use of monofilament sutures, and tying knots outside the bronchial lumen.[27] Gonzales-Rivas et al.[19] have suggested the use of monofilament absorbable sutures for proper placement and to prevent knot displacement. The use of instruments and placement of sutures require more attention in the uVATS approach compared to open thoracotomy. Initially, the technique of individually placed sutures, applied in open thoracotomy, was also preferred in uVATS BSR.[4,10,28,29] Over time, the continuously running suture technique has been adopted due to its advantages over the individual suture technique.[5,7,8] Additionally, Zhu et al.[30] have recommended the use of the continuously running suture technique, as no anastomosis-related complications such as bronchopleural fistula or anastomotic stenosis were observed, ensuring a safe anastomosis. In our study, all anastomoses were performed using the continuously running suture technique. With attention to anastomotic tension and suture spacing, this technique resulted in no occurrences of anastomotic dehiscence or bronchopleural fistula in our cases.

The most common causes of morbidity and mortality following bronchial sleeve resections are pneumonia, atelectasis, and complications related to the anastomosis.[14] However, the most significant complications for BSR are bronchial anastomotic complications, such as bronchopleural fistula, anastomotic stenosis, and anastomotic dehiscence. In this study, only two patients developed postoperative atelectasis, while the rates of postoperative complications vary in different reports. Gonzales-Rivas et al.[11] proposed that VATS BSR is superior to open surgery in terms of overall complications, cardiopulmonary complications, and atelectasis.

Martin-Ucar et al.[31] reported a mortality rate of 10.5% (four of 38 patients) due to anastomotic complication in BSR with open thoracotomy. Nevertheless, two studies have shown that VATS BSR can be performed safely without significant complications.[14,32] In our study, only two cases of postoperative atelectasis were observed in patients undergoing uVATS BSR, and there was no mortality. These results are consistent with previous studies in terms of the frequency of postoperative complications and mortality rates. The postoperative atelectasis improved with pulmonary physiotherapy. Zhou and Sun[33] recommended perioperative respiratory physiotherapy to prevent early postoperative complications during lung surgeries. Agostini et al.[34] reported that bronchial drainage with pain control and physiotherapy, in combination with VATS, prevented postoperative atelectasis. However, these findings should be carefully interpreted, as all cases were performed by a single experienced surgeon in uVATS. Additionally, Seitlinger et al.,[35] in their study comparing VATS lobectomies with VATS sleeve resections, demonstrated a higher rate of conversion to open thoracotomy in VATS sleeve resections. In this study, conversion to open thoracotomy from uVATS BSR occurred in only one patient, which was presumed to be associated with the surgeon's experience.

Some limitations should be considered for this study. First, this is a single-center retrospective study. In addition, a small number of patients were included in the study, and the evaluation was based on the operation performed by a single surgeon. Consequently, the generalizability of our findings may be constrained.

In conclusion, preoperative planning with three-dimensional modeling has significantly contributed to the successful implementation of uniportal video-assisted thoracoscopic surgery - bronchial sleeve resection. Despite being a complex procedure, uniportal video-assisted thoracoscopic surgery-bronchial sleeve resection with preoperative planning using three-dimensional modeling is an approach that can be safely applied with increasing experience. The use of three-dimensional modeling in preoperative planning has positively impacted visualization, bronchovascular dissection, demarcation of bronchotomy margins, and identification of anatomical landmarks for bronchial reconstruction. In the future, we believe that patient-specific three-dimensional models will enable the preparation of complex procedures for simulation devices during the preoperative period, facilitating the surgeon's practice.

Ethics Committee Approval: The study protocol was approved by the Ondokuz Mayis University Clinical Research Ethics Committee (date: 27.12.2023, no: 2023/494). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/concept: S.G., A.Ş.; Design: S.G, A.Ş, H.G. N.G.T; Control/supervision: S.G., A.Ş., Y.B.B., M.G.P., N.G.T., Y.S., A.T.S., H.G. A.B.; Data collection and/or processing: S.G., M.G.P., N.G.T., Y.S., A.T.S., H.G.; Analysis and/or interpretation: S.G., A.Ş.; Literature review: A.Ş., A.B.; Writing the article: S.G., A.Ş., Y.B.; Critical review: A.Ş., Y.B., A.B.; References and fundings: S.G.

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REFERENCES

1. Sezen CB, Kocaturk CI, Bilen S, Kalafat CE, Cansever L, Dincer SI, et al. Long-term outcomes of carinal sleeve resection in non-small cell lung cancer. Thorac Cardiovasc Surg 2020;68:190-8. doi: 10.1055/s-0039-1679959.
2. Santambrogio L, Cioffi U, De Simone M, Rosso L, Ferrero S, Giunta A. Video-assisted sleeve lobectomy for mucoepidermoid carcinoma of the left lower lobar bronchus: A case report. Chest 2002;121:635-6. doi: 10.1378/chest.121.2.635.
3. Gonzalez-Rivas D, Fernandez R, Fieira E, Rellan L. Uniportal video-assisted thoracoscopic bronchial sleeve lobectomy: First report. J Thorac Cardiovasc Surg 2013;145:1676-7. doi: 10.1016/j.jtcvs.2013.02.052.
4. Liu L, Mei J, Pu Q, Ma L. Thoracoscopic bronchovascular double sleeve lobectomy for non-small-cell lung cancer. Eur J Cardiothorac Surg 2014;46:493-5. doi: 10.1093/ejcts/ezu103.
5. Xie D, Deng J, Gonzalez-Rivas D, Zhu Y, Jiang L, Jiang G, et al. Comparison of video-assisted thoracoscopic surgery with thoracotomy in bronchial sleeve lobectomy for centrally located non-small cell lung cancer. J Thorac Cardiovasc Surg 2021;161:403-13.e2. doi: 10.1016/j.jtcvs.2020.01.105.
6. Gonzalez-Rivas D, Yang Y, Stupnik T, Sekhniaidze D, Fernandez R, Velasco C, et al. Uniportal video-assisted thoracoscopic bronchovascular, tracheal and carinal sleeve resections†. Eur J Cardiothorac Surg 2016;49 Suppl 1:i6-16. doi: 10.1093/ejcts/ezv410.
7. Gonzalez-Rivas D, Yang Y, Sekhniaidze D, Stupnik T, Fernandez R, Lei J, et al. Uniportal video-assisted thoracoscopic bronchoplastic and carinal sleeve procedures.

J Thorac Dis 2016;8(Suppl 2):S210-22. doi: 10.3978/j.issn.2072-1439.2016.01.76.
8. Ceylan KC, Acar A, Örs Kaya Ş. The initial experience on thoracoscopic sleeve lobectomy: Continuous suturing technique of the bronchial anastomosis in 12 cases. Surg Laparosc Endosc Percutan Tech 2020;30:476-9. doi: 10.1097/SLE.0000000000000831.
9. Ikeda N, Yoshimura A, Hagiwara M, Akata S, Saji H. Three-dimensional computed tomography lung modeling is useful in simulation and navigation of lung cancer surgery. Ann Thorac Cardiovasc Surg 2013;19:1-5. doi: 10.5761/atcs.ra.12.02174.
10. Gonzalez-Rivas D, Fieira E, Delgado M, de la Torre M, Mendez L, Fernandez R. Uniportal video-assisted thoracoscopic sleeve lobectomy and other complex resections. J Thorac Dis 2014;6(Suppl 6):S674-81. doi: 10.3978/j.issn.2072-1439.2014.09.17.
11. Gonzalez M, Chriqui LE, Décaluwé H, Aigner C, Rényi-Vámos F, Opitz I, et al. Sleeve lobectomy in patients with non-small-cell lung cancer: A report from the European Society of Thoracic Surgery database 2021. Eur J Cardiothorac Surg 2022;62:ezac502. doi: 10.1093/ejcts/ezac502.
12. Toker A, Bayrak Y, Dilege S, Kalayci G. Bronchial sleeve resections for carcinoid tumor in the first decade of life. Interact Cardiovasc Thorac Surg 2004;3:280-2. doi: 10.1016/j.icvts.2003.12.006.
13. Li Y, Wang J. Video-assisted thoracoscopic surgery sleeve lobectomy with bronchoplasty. World J Surg 2013;37:1661-5. doi: 10.1007/s00268-013-2032-7.
14. Zhou S, Pei G, Han Y, Yu D, Song X, Li Y, et al. Sleeve lobectomy by video-assisted thoracic surgery versus thoracotomy for non-small cell lung cancer. J Cardiothorac Surg 2015;10:116. doi: 10.1186/s13019-015-0318-6.
15. Deng HY, Qiu XM, Zhu DX, Tang X, Zhou Q. Video-assisted thoracoscopic sleeve lobectomy for centrally located non-small cell lung cancer: A meta-analysis. World J Surg 2021;45:897-906. doi: 10.1007/s00268-020-05877-5.
16. Soultanis KM, Chen Chao M, Chen J, Wu L, Yang C, Gonzalez-Rivas D, et al. Technique and outcomes of 79 consecutive uniportal video-assisted sleeve lobectomies. Eur J Cardiothorac Surg 2019;56:876-82. doi: 10.1093/ejcts/ezz162.
17. Gonzalez-Rivas D, Sihoe ADL. Important technical details during uniportal video-assisted thoracoscopic major resections. Thorac Surg Clin 2017;27:357-72. doi: 10.1016/j.thorsurg.2017.06.004.
18. Bertolaccini L, Rocco G, Viti A, Terzi A. Geometrical characteristics of uniportal VATS. J Thorac Dis 2013;5(Suppl 3):S214-6. doi: 10.3978/j.issn.2072-1439.2013.04.06.
19. Gonzalez-Rivas D, Bosinceanu M, Manolache V, Gallego-Poveda J, Paradela M, Li S, et al. Uniportal fully robotic-assisted sleeve resections: surgical technique and initial experience of 30 cases. Ann Cardiothorac Surg 2023;12:9-22. doi: 10.21037/acs-2022-urats-23.
20. Gurz S, Temel NG, Sengul AT, Buyukkarabacak Y, Pirzirenli MG, Basoglu A. Learning curve for uniportal VATS anatomical pulmonary resections: The activity monitor operating characteristic method. Indian J Surg 2023;85(Suppl 2):434-41. doi: 10.1007/s12262-023-03667-6.
21. Heuts S, Sardari Nia P, Maessen JG. Preoperative planning of thoracic surgery with use of three-dimensional reconstruction, rapid prototyping, simulation and virtual navigation. J Vis Surg 2016;2:77. doi: 10.21037/jovs.2016.03.10.
22. Nakazawa S, Nagashima T, Kawatani N, Gedeon PC, DeSimone AK, Igai H, et al. Anatomy of the lung revisited by 3D-CT imaging. Video Assist Thorac Surg 2023;8:17. doi: 10.21037/vats-23-21.
23. Bhakhri K, Hyde ER, Mak SM, Berger LU, Ourselin S, Routledge T, et al. Surgeon knowledge of the pulmonary arterial system and surgical plan confidence is improved by interactive virtual 3D-CT models of lung cancer patient anatomies. Front Surg 2021;8:652428. doi: 10.3389/fsurg.2021.652428.
24. Sardari Nia P, Olsthoorn JR, Heuts S, Maessen JG. Interactive 3D reconstruction of pulmonary anatomy for preoperative planning, virtual simulation, and intraoperative guiding in video-assisted thoracoscopic lung surgery. Innovations (Phila) 2019;14:17-26. doi: 10.1177/1556984519826321.
25. Chen-Yoshikawa TF, Date H. Update on three-dimensional image reconstruction for preoperative simulation in thoracic surgery. J Thorac Dis 2016;8(Suppl 3):S295-301. doi: 10.3978/j.issn.2072-1439.2016.02.39.
26. Sandri A, Brunelli A. Surgical simulation for safe uniportal VATS. Video-assist Thorac Surg 2018;3:36. doi: 10.21037/vats.2018.08.06.
27. Royo-Crespo I, Vieira A, Ugalde PA. Extended uniportal video-assisted thoracic surgery for lung cancer: Is it feasible? J Vis Surg 2018;4:57. doi: 10.21037/jovs.2018.03.09.
28. Maurizi G, D'Andrilli A, Anile M, Ciccone AM, Ibrahim M, Venuta F, et al. Sleeve lobectomy compared with pneumonectomy after induction therapy for non-small-cell lung cancer. J Thorac Oncol 2013;8:637-43. doi: 10.1097/JTO.0b013e318286d145.
29. Ng CS. Thoracoscopic sleeve resection-the better approach? J Thorac Dis 2014;6:1164-6. doi: 10.3978/j.issn.2072-1439.2014.07.28.
30. Zhu XY, Ding C, Xu C, Chen J, Ju S, Pan S, et al. Techniques and outcomes of bronchoplastic and sleeve resection: An 8-year single-center experience. Transl Lung Cancer Res 2021;10:4538-48. doi: 10.21037/tlcr-21-913.
31. Martin-Ucar AE, Chaudhuri N, Edwards JG, Waller DA. Can pneumonectomy for non-small cell lung cancer be avoided? An audit of parenchymal-sparing lung surgery. Eur J Cardiothorac Surg 2002;21:601-5. doi: 10.1016/s1010-7940(02)00028-3.
32. Qu JC, Soultanis KM, Jiang L. Surgical techniques and outcome analysis of uniportal video-assisted thoracic surgery complex sleeve lung resection: A 20 case-series study. J Thorac Dis 2021;13:2255-63. doi: 10.21037/jtd-20-3002.
33. Zhou T, Sun C. Effect of physical manipulation pulmonary rehabilitation on lung cancer patients after thoracoscopic lobectomy. Thorac Cancer 2022;13:308-15. doi: 10.1111/1759-7714.14225.
34. Agostini P, Lugg ST, Adams K, Vartsaba N, Kalkat MS, Rajesh PB, et al. Postoperative pulmonary complications

and rehabilitation requirements following lobectomy: A propensity score matched study of patients undergoing video-assisted thoracoscopic surgery versus thoracotomy. Interact Cardiovasc Thorac Surg 2017;24:931-7. doi: 10.1093/icvts/ivx002.

35. Seitlinger J, Olland A, Guinard S, Massard G, Falcoz PE. Conversion from video-assisted thoracic surgery (VATS) to thoracotomy during major lung resection: How does it affect perioperative outcomes? Interact Cardiovasc Thorac Surg 2021;32:55-63. doi: 10.1093/icvts/ivaa220.