

ORIGINAL ARTICLE

Volume:4 Issue:1 Year:2026

<https://doi.org/10.5281/zenodo.18900021>**Surgical Management and Pathological Outcomes of Pet-Avid Solitary Pulmonary Nodules: A Single-Center Retrospective Cohort**Özgür Cengiz¹, Cenk Balta¹¹Antalya City Hospital, Department of Thoracic Surgery, Antalya, Türkiye**ABSTRACT**

Introduction: Fluorodeoxyglucose positron emission tomography/computed tomography (FDG-PET/CT) is frequently used to estimate malignancy risk in solitary pulmonary nodules (SPNs), yet false-positive uptake is common in inflammatory and granulomatous disease.

Objective: To describe our surgical management of PET-avid SPNs and to evaluate the association between maximum standardized uptake value (SUVmax) and malignancy.

Method: We retrospectively reviewed 69 consecutive patients with SPNs (≤ 3 cm) showing increased FDG uptake (SUVmax ≥ 2.5) who underwent surgery between December 2008 and September 2011 at Akdeniz University. All patients lacked a definitive diagnosis after noninvasive or minimally invasive attempts. The initial procedure was diagnostic wedge resection with intraoperative frozen section; surgery was terminated for benign lesions, whereas primary lung cancer prompted anatomic resection with systematic mediastinal lymph node sampling. Categorical variables were compared with chi-square and continuous variables with Student's t-test or Mann-Whitney U test as appropriate ($p < 0.05$).

Results: The cohort included 46 men (66.7%) and 23 women (33.3%), with a mean age of 58.16 ± 12.11 years. Final pathology showed benign disease in 46.4%, primary lung cancer in 42.0%, and metastasis in 11.6%. Wedge resection was performed in 55.1% and anatomic resection in 44.9%. Mean SUVmax was significantly higher in malignant than benign nodules (10.54 ± 7.30 vs 4.61 ± 2.27 ; $p < 0.001$).

Conclusion: Nearly half of PET-avid SPNs were benign, underscoring the limited specificity of FDG-PET/CT in endemic inflammatory settings. Higher SUVmax was associated with malignancy, but surgical resection remains a valuable diagnostic and potentially curative strategy when tissue diagnosis cannot be obtained otherwise.

Keywords: Solitary Pulmonary Nodule, FDG-PET/CT, SUVmax, Video-Assisted Thoracoscopic Surgery, Frozen Section.

INTRODUCTION

A solitary pulmonary nodule (SPN) is classically defined as a discrete, round or ovoid opacity within the lung parenchyma measuring ≤ 3 cm in maximal diameter, surrounded by aerated lung and unaccompanied by atelectasis, post-obstructive pneumonia, mediastinal/hilar lymphadenopathy, or pleural effusion (1,2). With ongoing advances in cross-sectional imaging and the expanding use of thoracic computed tomography, SPNs are detected with increasing frequency, most commonly as incidental findings on imaging performed for unrelated indications. On chest radiography, the reported prevalence of SPN detection ranges from 0.1% to 0.2% (2).

The clinical importance of SPNs lies in the substantial overlap in radiological appearance between benign entities and early-stage lung malignancies. Although the majority of SPNs are ultimately benign, approximately 20–30% of primary lung cancers may initially manifest as an SPN (3). Accordingly, timely and accurate risk stratification and selection of an appropriate diagnostic–therapeutic strategy are pivotal, as early-stage disease offers the greatest opportunity for curative resection.

Fluorine-18 fluorodeoxyglucose positron emission tomography/computed tomography (18F-FDG PET/CT) is a key noninvasive modality for characterizing indeterminate pulmonary nodules by assessing increased glucose metabolism. In routine clinical practice, 18F-FDG is the most widely used radiotracer, and the maximum standardized uptake value (SUVmax) serves as a semiquantitative surrogate of metabolic activity. SUVmax is therefore frequently incorporated into clinical algorithms for benign–malignant discrimination in SPNs (4).

Corresponding Author: Özgür Cengiz, e-mail: drozgurcengiz@gmail.com

Received: 09.11.2025, Accepted: 19.02.2026, Published Online: 10.03.2026

Cited: Cengiz Ö, et al. Surgical Management and Pathological Outcomes of Pet-Avid Solitary Pulmonary Nodules: A Single-Center Retrospective Cohort. Acta Medica Ruha. 2026;4(1):6-11. <https://doi.org/10.5281/zenodo.18900021>



Nevertheless, FDG uptake is not specific to malignancy. Granulomatous and other inflammatory or infectious processes may demonstrate increased FDG avidity, resulting in false-positive PET/CT findings (5). Consequently, in patients with PET-avid SPNs in whom a definitive diagnosis cannot be established through noninvasive or minimally invasive techniques, surgical resection may assume a central role as both a diagnostic and potentially curative therapeutic intervention (6).

In the present study, we retrospectively reviewed our institutional surgical management of patients with PET-positive solitary pulmonary nodules, focusing on operative approach, extent of resection, and final histopathological diagnoses. In addition, we evaluated the association between SUVmax and malignancy. Our objective was to provide evidence that may refine surgical decision-making in the management of PET-avid SPNs.

METHODS

Study Design and Patient Selection

This study was designed as a retrospective cohort analysis of patients with solitary pulmonary nodules who underwent surgical management at the Department of Thoracic Surgery, Akdeniz University Faculty of Medicine, between December 2008 and September 2011, and whose FDG-PET/CT findings were suggestive of malignancy.

A total of 69 consecutive patients were included if they met the definition of SPN (maximum diameter ≤ 3 cm), demonstrated increased FDG uptake with an SUVmax ≥ 2.5 on PET/CT, and lacked a definitive histopathological diagnosis despite prior noninvasive or minimally invasive diagnostic attempts. The SUVmax threshold of 2.5 was selected because it is the most commonly used and clinically accepted cut-off in the literature for defining malignant metabolic activity in pulmonary nodules (7).

Exclusion Criteria

Patients were excluded if they met any of the following criteria:

- Absence of FDG uptake suggestive of malignancy on PET/CT
- Pathologically enlarged mediastinal lymph nodes on thoracic CT
- Evidence of lymphatic or hematogenous distant metastasis
- Unsuitability for surgery due to poor general condition or inadequate pulmonary reserve
- Refusal of surgical intervention

Preoperative Evaluation

All patients underwent comprehensive preoperative evaluation, including detailed medical history and physical examination. Standard laboratory testing (including complete blood count and coagulation profile), electrocardiography, pulmonary function testing, and arterial blood gas analysis were performed. Thoracic computed tomography and FDG-PET/CT were obtained in all cases.

Surgical Approach

In all patients, the initial procedure was a diagnostic wedge resection, and the resected specimen was submitted for intraoperative frozen-section analysis. If frozen section indicated a benign lesion, the operation was concluded. When primary lung malignancy was identified, an anatomic resection was performed with systematic mediastinal lymph node sampling. For metastatic lesions, wedge resection or lobectomy was undertaken according to lesion characteristics and intraoperative assessment. Surgical access was achieved via video-assisted thoracoscopic surgery (VATS) or posterolateral thoracotomy.

Statistical Analysis

Statistical analyses were performed using an appropriate statistical software package. Continuous variables are presented as mean \pm standard deviation or as median (minimum–maximum), as appropriate. Categorical variables are summarized as counts and percentages. Categorical variables were compared using the chi-square test, whereas continuous variables were compared using Student's t-test

or the Mann–Whitney U test, depending on data distribution. A two-sided p value <0.05 was considered statistically significant.

Ethical Declaration

All procedures were conducted in accordance with the ethical standards of the institutional and/or national research committee and with the Declaration of Helsinki (1975), as revised in 2008. Institutional ethics committee approval was obtained. Given the retrospective design, informed consent was not required.

RESULTS

Sixty-nine patients with solitary pulmonary nodules (SPNs) showing increased FDG uptake on PET/CT who underwent surgical management at the Thoracic Surgery Clinic of Akdeniz University Faculty of Medicine Hospital between 2008 and 2011 were included. The cohort comprised 46 men (66.7%) and 23 women (33.3%). Mean age was 58.16 ± 12.11 years, and 88.4% of patients were ≥41 years. The mean hospital length of stay was 7.66 ± 4.00 days, and the mean ICU stay was 2.43 ± 1.81 days. The mean pathological nodule diameter was 19.55 ± 7.50 mm, whereas the mean diameter measured on PET/CT was 21.85 ± 7.13 mm (Table 1).

Table 1. Demographic and Clinical Characteristics of Patients

| Characteristic | n=69 | |
|--------------------------------------|----------------------------------|-----------|
| Sex n(%) | Female | 23 (33.3) |
| | Male | 46 (66.7) |
| Age n(%) | <40 years | 8 (11.6) |
| | >40 years | 61 (88.4) |
| Age mean ±SD | 58.16±12.11 | |
| Length of hospital stay mean ± SD | 7.66 ±4 | |
| Length of ICU stay mean ±SD | 2.43±1.81 | |
| Pathological nodule size (mean ± SD) | 19.55 ±7.5 | |
| Nodule size on PET/CT (mean ± SD) | 21.85 ±7.13 | |
| Margin Characteristics n(%) | Spiculated | 31 (44.9) |
| | Nodular | 28 (40.6) |
| | Lobulated | 10 (14.5) |
| Side n(%) | Right | 36 (52.2) |
| | Left | 33 (47.8) |
| Localization n(%) | Upper lobe | 41 (59.4) |
| | Lower lobe | 24 (34.8) |
| | Middle lobe | 4 (5.8) |
| Resection Type n(%) | Wedge resection | 38 (55.1) |
| | Anatomical resection (Lobectomy) | 31 (44.9) |
| Pathological Diagnosis n(%) | Benign | 32 (46.4) |
| | Primary Lung Cancer | 29 (42) |
| | Metastasis | 8 (11.6) |

Clinical and Radiological Characteristics

Nodules were right-sided in 52.2% of patients and left-sided in 47.8%. Lobar distribution showed a predominance of upper-lobe lesions (59.4%), followed by lower-lobe (34.8%) and middle-lobe lesions (5.8%). Regarding margin morphology, spiculated contours were most frequent (44.9%), followed by smooth/nodular margins (40.6%) and lobulated margins (14.5%) (Table 1). There were no significant differences between benign and malignant groups in age, sex, laterality, lobar location, margin characteristics, or other radiological features (all p > 0.05) (Table 2).

Surgical Approach and Extent of Resection

Wedge resection was performed in 55.1% of patients, whereas anatomic resection was undertaken in 44.9%. Among anatomic resections, upper lobectomy was the most common procedure (30.4%) (Table 1).

Histopathological Outcomes

Final histopathology demonstrated benign disease in 46.4% of cases, primary lung cancer in 42.0%, and metastatic lesions in 11.6% (Table 1). Among primary lung cancers, adenocarcinoma was the predominant subtype (29.0%), followed by squamous cell carcinoma (10.1%). Within the benign group, the most frequent diagnoses were organizing pneumonia (11.6%), abscess (10.1%), granuloma (5.8%), and hamartoma (4.3%).

Association Between SUVmax and Malignancy

Mean SUVmax was significantly higher in malignant than in benign nodules (10.54 ± 7.30 vs. 4.61 ± 2.27), corresponding to an approximately twofold increase; this difference was statistically significant ($p < 0.001$) (Table 2).

Table 2. Comparison of Benign and Malignant Cases

| Characteristics | | Benign (n=32) | Malignant (n=37) | P value |
|-----------------------------|----------------|----------------|------------------|---------|
| Sex n (%) | Female | 9 (39.1) | 14 (60.9) | 0.393 |
| | Male | 23 (50.0) | 23 (50.0) | |
| Age n(%) | Under 40 years | 6 (75.0) | 2 (25.0) | 0.084 |
| | Over 40 years | 26 (42.6) | 35 (57.4) | |
| Margin characteristics n(%) | Spiculated | 13 (41.9) | 18 (58.1) | 0.609 |
| | Nodular | 15 (53.6) | 13 (46.4) | |
| | Lobulated | 4 (40.0) | 6 (60.0) | |
| SUVmax Mean \pm SD | | 4.6 \pm 2.27 | 10.5 \pm 7.3 | <0.001 |

DISCUSSION

Solitary pulmonary nodules (SPNs) are being encountered with increasing frequency in parallel with advances in radiological imaging and are most often identified incidentally. Although the majority of SPNs are benign (approximately 60–70%), their clinical relevance is substantial because they may represent early-stage lung cancer. Indeed, 20–30% of primary lung cancers initially present as an SPN, and prognosis is strongly stage-dependent. Consequently, the principal objective of the initial evaluation is to achieve benign–malignant discrimination using the least invasive approach feasible (8).

Although SPNs may occur at any age, patient age at presentation is among the most influential determinants of malignancy risk, with probability increasing steadily with advancing age. Swensen et al. reported that a considerable proportion of resected nodules in patients older than 50 years proved to be primary lung cancer (9). In contrast, SPNs in younger individuals are more commonly benign. In regions where granulomatous diseases are endemic, malignancy rates among patients younger than 35 years have been reported to be as low as 7%, and most malignant nodules in this age group are metastatic rather than primary lung tumors (10). In the present series, the overall malignancy rate was 53.6%; malignancy was observed in 25% of patients younger than 40 years and increased to 57.4% among those aged 40 years and older.

Conventional imaging assessment relies on morphological features including nodule size, margin characteristics, surrounding parenchymal changes, and internal components such as calcification or macroscopic fat. However, given the considerable overlap between benign and malignant entities, morphology alone is frequently insufficient to establish a definitive diagnosis (8). Therefore, nodule growth kinetics, transthoracic needle biopsy, and functional imaging—particularly PET—should be interpreted alongside clinical risk factors to improve diagnostic accuracy (11).

FDG-PET/CT aids in discrimination by depicting metabolic activity. In a meta-analysis by Gould et al., FDG-PET demonstrated high diagnostic performance in characterizing pulmonary nodules (12). Nonetheless, PET/CT has important limitations. False-positive findings may occur in infectious or inflammatory conditions, whereas false-negative results can be seen in indolent or low-metabolic malignancies (12). Tuberculosis, sarcoidosis, and aspergillosis are well-recognized causes of increased FDG uptake in benign disease (12,13). In our cohort, 32 PET-positive nodules (46.4%) were benign on final pathology; the most frequent diagnoses were organizing pneumonia (n=8) and abscess (n=7),

followed by granuloma, hamartoma, tuberculosis, silicoanthracotic nodules, hydatid cyst, aspergilloma, and inflammatory pseudotumor—findings consistent with prior reports.

SUVmax values may also vary by histopathological subtype. High FDG avidity is typical of many non-small cell lung cancers (NSCLCs), including squamous cell carcinoma and adenocarcinoma, whereas mucinous tumors and indolent neoplasms (e.g., carcinoid tumors) may demonstrate relatively low uptake (11). In our study, mean SUVmax was 15.9 for squamous cell carcinoma and 10.54 for adenocarcinoma, whereas carcinoid tumors (3.0) and bronchioloalveolar carcinoma (2.8) exhibited lower values. Although an SUVmax threshold of 2.5 is widely used in clinical practice, it does not provide absolute discrimination. Bryant and Cerfolio reported that the probability of malignancy increases progressively with rising SUVmax (7). Our findings are concordant with this observation; however, given the potential for false positivity, SUVmax should be interpreted within the broader clinical and radiological context.

Margin morphology has also been associated with malignancy risk. While spiculation is traditionally considered a suspicious feature, it may be observed in benign processes as well (14,15). In our series, 58.1% of spiculated nodules and 60% of lobulated nodules were malignant, underscoring that margin characteristics alone are insufficient for reliable differentiation.

This study has several limitations. First, its retrospective, single-center design may restrict the generalizability of the findings. Second, the inclusion of only PET-positive nodules managed surgically introduces selection bias; consequently, comprehensive diagnostic performance measures for FDG-PET/CT (e.g., sensitivity, specificity, positive/negative predictive values, and accuracy) cannot be reliably calculated from this cohort. Future research should involve larger, prospective, multicenter studies that include both PET-positive and PET-negative SPNs to better define diagnostic performance and refine management algorithms across broader clinical settings.

CONCLUSION

Solitary pulmonary nodules are increasingly encountered and often require a multidisciplinary approach to diagnosis and management. FDG-PET/CT is a useful tool for estimating the probability of malignancy and for identifying potential nodal involvement or distant metastatic disease; however, its limited specificity—particularly in the setting of inflammatory and granulomatous conditions—should be carefully considered.

Because surgical resection offers the potential for cure in early-stage lung cancer, operative management should be contemplated as both a diagnostic and therapeutic strategy in PET-avid SPNs when a definitive diagnosis cannot be established by noninvasive or minimally invasive methods.

Whenever feasible, video-assisted thoracoscopic surgery (VATS) should be the preferred approach given its favorable morbidity and mortality profile. If required, conversion to thoracotomy should be undertaken without hesitation to ensure procedural safety and oncologic adequacy. In patients who decline surgery or are deemed inoperable due to limited cardiopulmonary reserve, close radiological surveillance may represent a reasonable alternative. Nevertheless, in operable patients without contraindications, surgical resection should be considered an acceptable-risk option with potential curative benefit.

DESCRIPTIONS

No financial support.

No conflict of interest.

REFERENCES

1. Truong MT, Ko JP, Rossi SE, Rossi I, Viswanathan C, Bruzzi JF, Marom EM, Erasmus JJ. Update in the evaluation of the solitary pulmonary nodule. *Radiographics*. 2014;34(6):1658-79. doi: 10.1148/rg.346130092. PMID: 25310422.
2. Wyker A, Sharma S, Henderson WW. Solitary Pulmonary Nodule. 2024 Aug 12. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. PMID: 32310603.

3. Hodnett PA, Ko JP. Evaluation and management of indeterminate pulmonary nodules. *Radiol Clin North Am.* 2012 Sep;50(5):895-914. doi: 10.1016/j.rcl.2012.06.005. PMID: 22974777.
4. Niyonkuru A, Chen X, Bakari KH, et al. FDG PET/CT in the evaluation of solitary pulmonary nodules. *Cancer Med.* 2020;9:3845–3854.
5. Deppen S, Putnam JB Jr, Andrade G, Speroff T, Nesbitt JC, Lambright ES, Massion PP, Walker R, Grogan EL. Accuracy of FDG-PET to diagnose lung cancer in a region of endemic granulomatous disease. *Ann Thorac Surg.* 2011 Aug;92(2):428-32; discussion 433. doi: 10.1016/j.athoracsur.2011.02.052. Epub 2011 May 18. PMID: 21592456; PMCID: PMC3186439.
6. Jiménez MF; Spanish Video-Assisted Thoracic Surgery Study Group. Prospective study on video-assisted thoracoscopic surgery in the resection of pulmonary nodules: 209 cases from the Spanish Video-Assisted Thoracic Surgery Study Group. *Eur J Cardiothorac Surg.* 2001 May;19(5):562-5. doi: 10.1016/s1010-7940(01)00650-9. PMID: 11343931.
7. Bryant AS, Cerfolio RJ. The maximum standardized uptake values on integrated FDG-PET/CT is useful in differentiating benign from malignant pulmonary nodules. *Ann Thorac Surg.* 2006 Sep;82(3):1016-20. doi: 10.1016/j.athoracsur.2006.03.095. PMID: 16928527.
8. Erasmus JJ, Connolly JE, McAdams HP, Roggli VL. Solitary pulmonary nodules: Part I. Morphologic evaluation for differentiation of benign and malignant lesions. *Radiographics.* 2000;20(1):43-58.
9. Swensen SJ, Jett JR, Sloan JA, Midthun DE, Hartman TE, Sykes AM, et al. Screening for lung cancer with low-dose spiral computed tomography. *Am J Respir Crit Care Med* 2002;165:508-13.
10. Gümüş S, Deniz Ö, Örs F, Çiçi F, Tozkoparan E, Yücel O ve ark. Genç hastalarda soliter pulmoner nodüllerin etiyolojisi. *Solunum* 2007;9:99-104.
11. Erasmus JJ, McAdams HP, Connolly JE. Solitary pulmonary nodules: Part II. Evaluation of the indeterminate nodule. *Radiographics* 2000;20:59-66.
12. Gould MK, Maclean CC, Kuschner WG. Accuracy of positron emission tomography for diagnosis of pulmonary nodules and mass lesions. *JAMA* 2001;285:914-924.
13. Detterbeck FC, Falen S, Rivera MP. Seeking a Home for a PET, Part I Defining the Appropriate Place for Positron Emission Tomography Imaging in the Diagnosis of Pulmonary Nodules or Masses. *Chest* 2004; 125:2294-2299.
14. Lillington GA. Management of solitary pulmonary nodules. How to decide when resection is required. *Postgrad Med.* 1997 Mar;101(3):145-50. doi: 10.3810/pgm.1997.03.177. PMID: 9074555.
15. Mery CM, Pappas AN, Mentzer SJ, Sugarbaker DJ. Relationship between a history of antecedent cancer and the probability of malignancy for a solitary pulmonary nodule. *Chest* 2004;125:2175-81.