Diagnosing Lung Carcinomas with Optical Coherence Tomography

Lida P. Hariri^{1,2,3,5}, Mari Mino-Kenudson^{2,5}, Michael Lanuti^{4,5}, Alyssa J. Miller^{1,3}, Eugene J. Mark^{2,5}, and Melissa J. Suter^{1,3,5}

¹Division of Pulmonary and Critical Care Medicine, Department of Medicine, ²Department of Pathology, ³Wellman Center for Photomedicine, and ⁴Division of Thoracic Surgery, Department of Surgery, Massachusetts General Hospital, Boston, Massachusetts; and ⁵Harvard Medical School, Boston, Massachusetts

Abstract

Rationale: Lung carcinoma diagnosis on tissue biopsy can be challenging because of insufficient tumor and lack of architectural information. Optical coherence tomography (OCT) is a high-resolution imaging modality that visualizes tissue microarchitecture in volumes orders of magnitude larger than biopsy. It has been proposed that OCT could potentially replace tissue biopsy.

Objectives: We aim to determine whether OCT could replace histology in diagnosing lung carcinomas. We develop and validate OCT interpretation criteria for common primary lung carcinomas: adenocarcinoma, squamous cell carcinoma (SCC), and poorly differentiated carcinoma.

Methods: A total of 82 *ex vivo* tumor samples were included in a blinded assessment with 3 independent readers. Readers were trained on the OCT criteria, and applied these criteria to diagnose adenocarcinoma, SCC, or poorly differentiated carcinoma in an OCT validation dataset. After a 7-month period, the readers

repeated the training and validation dataset interpretation. An independent pathologist reviewed corresponding histology.

Measurements and Main Results: The average accuracy achieved by the readers was 82.6% (range, 73.7–94.7%). The sensitivity and specificity for adenocarcinoma were 80.3% (65.7–91.4%) and 88.6% (80.5–97.6%), respectively. The sensitivity and specificity for SCC were 83.3% (70.0–100.0%) and 87.0% (75.0–96.5%), respectively. The sensitivity and specificity for poorly differentiated carcinoma were 85.7% (81.0–95.2%) and 97.6% (92.9–100.0%), respectively.

Conclusions: Although these results are encouraging, they indicate that OCT cannot replace histology in the diagnosis of lung carcinomas. However, OCT has potential to aid in diagnosing lung carcinomas as a complement to tissue biopsy, particularly when insufficient tissue is available for pathology assessment.

Keywords: optical biopsy guidance; *in vivo* microscopy; lung cancer; transbronchial fine needle aspiration guidance; optical frequency domain imaging

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Correspondence and requests for reprints should be addressed to Melissa J. Suter, Ph.D., Massachusetts General Hospital, 55 Fruit Street, Warren Building, Room 407, Boston, MA 02114. E-mail: msuter@partners.org

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Diagnosis of lung cancer must be made on the microscopic level, which at present can only be accomplished with light microscopy (1). Accurate diagnosis of the

specific lung cancer type is essential to determine optimal treatment, as incorrect diagnoses may result in administration of inappropriate therapies with potentially

life-threatening consequences (2–6). Approximately 70% of lung cancers are not resectable at the time of presentation, and thus trans-thoracic and transbronchial

biopsy and fine needle aspiration (FNA) are often the only method of diagnosis for many patients with lung cancer (6–8). However, pathology diagnosis on these small specimens can be difficult because of inadequate tumor volume and/or lack of tissue architecture (1, 7–14). When an equivocal diagnosis is made on biopsy/FNA specimens, patients often must undergo repeat biopsy or more invasive surgical procedures, such as thorascopic wedge resection, to obtain more tissue for definitive diagnosis. These procedures have increased risk of morbidity, and delay diagnosis and therapy initiation.

The ability to assess larger tissue volumes and visualize tissue architecture in lung carcinomas could significantly improve the ability to render a definitive pathology diagnosis. However, acquiring larger physical tissue samples requires invasive, higher risk surgical procedures. Optical imaging can provide high-resolution visualization of large tissue volumes without physical tissue removal. Optical coherence tomography (OCT) is an optical imaging tool that rapidly generates high-resolution (<10 μm) cross-sectional images of tissues with penetration depths approaching 2–3 mm (15–17). OCT can be used to conduct large-volume *in vivo* microscopy of tissue with resolutions comparable to low-power microscopy (18). OCT has been used to accurately detect and diagnose pathology *in vivo* for a number of years (17–24) and has been used to assess the fine microarchitectural features in both normal and pathologic lung (25–43).

OCT provides visualization of (1) tissue volumes orders of magnitude larger than standard biopsy/FNA and (2) the architectural context of tumors that cannot be appreciated with physical tissue biopsy. Because of these abilities, it has been proposed that OCT could potentially replace tissue biopsy as a form of *in vivo* microscopy. In this study, we assess whether OCT can be used to diagnose primary lung carcinomas. We develop OCT interpretation criteria for the most common primary lung carcinomas: adenocarcinoma, squamous cell carcinoma, and poorly differentiated carcinomas. OCT interpretation criteria are validated in an *ex vivo* blinded assessment with three independent readers, including a pathologist, thoracic surgeon, and OCT expert.

Methods

Specimens

A total of 82 lung tumor samples, including 38 adenocarcinomas, 22 squamous cell carcinomas (SCCs), and 22 poorly differentiated carcinomas (13 poorly differentiated adenocarcinomas and 9 poorly differentiated SCCs), from 39 *ex vivo* surgical lung resection specimens were included in this study. The Partners Human Research Committee Institutional Review Board approved this study (protocol 2010-P-002214/1).

OCT Imaging

Lung specimens were imaged fresh, within 1–2 hours of surgical resection. Before imaging, registration marks separated by 7–10 mm were placed, using India ink, to define the imaging window (44). Volumetric OCT imaging was performed using a 1,310-nm swept source system (axial resolution, 6 μm ; transverse resolution, 30 μm) and either a 2.4–5.1 Fr (0.8–1.7 mm diameter) helical scanning catheter or benchtop galvanometric scanner as previously described (16, 18). The OCT images were generated from the raw datasets offline, using custom software. Longitudinal representations were prepared with ImageJ 1.45s software (National Institutes of Health, Bethesda, MD) and were displayed using a grayscale lookup table. Out-of-frame averaging (over two or three frames) was performed to reduce speckle noise. The image datasets were oriented to ensure that all tissue between the ink marks was visible for interpretation. Ten consecutive OCT frames spanning 30–50 μm in the z-direction were available for review for each tissue specimen.

Histology

After imaging, tissues encompassing the two registration marks were fixed in 10% formalin, processed and sectioned according to standard histology procedures, and stained with hematoxylin–eosin. Two independent pathologists reviewed the histology for each case and rendered a diagnosis of adenocarcinoma, SCC, or poorly differentiated carcinoma based on recommendations by the classification strategies proposed by the 2004 World Health Organization classification of lung tumors and the 2011 International Association for the Study of Lung Cancer

(IASLC)/American Thoracic Society (ATS)/European Respiratory Society (ERS) classification of lung adenocarcinoma (2, 3). Poorly differentiated carcinoma was defined as tumor in which no morphologic features of glandular or squamous differentiation could be seen between the registration ink marks. In these cases, the final carcinoma type was ultimately determined by either (1) features of glandular or squamous differentiation in tumor regions within the same mass but outside the registration ink marks, or (2) immunohistochemical staining profiles using the classification strategies proposed by the 2004 World Health Organization and the 2011 IASLC/ATS/ERS (2, 3).

Table 1. Optical coherence tomography interpretation criteria for primary lung carcinomas

Squamous Cell Carcinoma: (A) is required	
A. Signal-intense (bright) nests, round or irregularly shaped	
• “Signal intense” means that nests are brighter than the surrounding adjacent tissues	
• Must contain some nests that are >0.2 mm in diameter	
• May have ill-defined borders in fibrosis	
B. May have variably sized, irregularly shaped signal-poor areas of necrosis	
• Either admixed with nests or in center of nests	
Adenocarcinoma: (A) and (B) are required	
A. Round or angulated signal-poor to signal-void structures	
• Borders have same signal intensity as adjacent tissues	
• Typically small, but may vary in size	
• May be subtle when mixed with fibrosis	
B. Lack of signal-intense (bright) nests	
Poorly Differentiated Carcinoma: (A) and (B) are required	
A. Lack of round/angulated signal-poor structures	
B. Lack of signal-intense (bright) nests	

Note: Clarifications made to the interpretation criteria in the second training session are italicized and include clarifying the term “signal-intense nest” and establishing a size criterion for signal-intense nests in squamous cell carcinoma.

Figure 1. Optical coherence tomography (OCT) of squamous cell carcinoma. (A) OCT of squamous cell carcinoma shows rounded or irregularly shaped, signal-intense nests (arrows) that display higher signal intensity than the surrounding tissues. Squamous cell carcinomas may contain variably sized, irregularly shaped signal-poor areas of necrosis either in the center of the nests (circled region) or admixed with the nests. (B) Corresponding histology stained with hematoxylin-eosin shows nests of malignant squamous cell carcinoma (arrows), some of which contain central necrosis (circled region). This example of squamous cell carcinoma was included in both OCT training sessions. Scale bars: 1 mm.

The histology diagnoses rendered by the two independent pathologists were in agreement for all cases.

OCT Interpretation Criteria for Primary Lung Carcinomas

Five of the lung tumor cases (two adenocarcinoma, two SCCs, and one poorly differentiated carcinoma) from five *ex vivo* lung resection specimens were randomly

selected to develop OCT image interpretation criteria (Table 1). The OCT criteria were developed in conjunction with the corresponding histology to reflect the histological features used to diagnose each type of carcinoma. OCT interpretation criteria for SCC require the presence of rounded or irregularly shaped, signal-intense nests (Figure 1). Adenocarcinoma requires both the presence of rounded or

angulated signal-poor structures and a lack of signal-intense nests (Figure 2). Poorly differentiated carcinoma requires a lack of both signal-intense nests and rounded or angulated signal-poor structures (Figure 3).

Initial OCT Interpretation Criteria Training and Blinded OCT Validation

Initial training on OCT interpretation criteria. The five tumor cases used to develop OCT criteria were used as training cases in the initial training session. Three OCT readers were trained in a 20-minute formal training session. The training cases were not included in the subsequent validation dataset. The OCT readers included an OCT expert, a pathologist with expertise in lung cancer histology, and a thoracic surgeon who routinely performs bronchoscopy and bronchoscopic biopsy procedures.

Initial blinded interpretation of OCT validation data. Immediately after the initial training session, the readers were asked to assess the randomized validation dataset consisting of the remaining 77 lung tumor cases, including 36 adenocarcinoma, 20 SCC, and 21 poorly differentiated carcinoma (13 poorly differentiated adenocarcinoma and 8 poorly differentiated SCC) samples from 37 *ex vivo* resection specimens. The readers were blinded to histologic diagnosis and independently reviewed the validation cases offline. Readers were not allowed access to the training cases while interpreting the validation dataset, but had access to the OCT interpretation criteria. Readers were instructed to record a diagnosis of adenocarcinoma, SCC, or poorly differentiated carcinoma for each case. The length of time to complete interpretation and document answers was recorded for each reader.

Second OCT Interpretation Criteria Training and Blinded OCT Validation

Second training on OCT interpretation criteria. Seven months after the initial training and validation assessment, the readers underwent a second training and testing session. In the second training session, readers were retrained on the OCT interpretation criteria in a more extensive 40-minute session. The readers were trained on a total of 13 OCT training cases (6 adenocarcinomas, 6 SCCs, and 1 poorly

Figure 2. Optical coherence tomography (OCT) of adenocarcinoma. (A) OCT of adenocarcinoma shows rounded or angulated signal-poor structures (arrows) and a lack of signal-intense nests. (B) Corresponding histology stained with hematoxylin-eosin confirms the presence of lung adenocarcinoma (arrows). This example of adenocarcinoma was included in both OCT training sessions. Scale bars: 1 mm.

Figure 3. Optical coherence tomography (OCT) of poorly differentiated carcinoma. (A) OCT of poorly differentiated carcinoma lacks both signal-intense nests and small, round signal-poor structures. (B) Corresponding histology stained with hematoxylin-eosin. This example of poorly differentiated carcinoma was included in both the initial and second training sessions for the OCT readers. Scale bars: 0.5 mm.

differentiated carcinoma), which included the initial 5 OCT training cases plus an additional 8 new training cases. All training cases were excluded from the subsequent validation dataset. In this second training session, readers were retrained on the original diagnostic criteria and clarifications made to the diagnostic criteria (Table 1), such as clarifying the term “signal-intense nests” and inclusion of a size criterion for signal-intense nests in SCC (must be >0.2 mm in greatest dimension). Diagnostic challenges uncovered in the first validation test were specifically addressed in the second training session, including (1) the presence of fibrosis resulting in more subtle, ill-defined imaging features (Figure 4) and (2) distinguishing signal-intense SCC nests with central necrosis from large, dilated glands in adenocarcinoma. A diagnostic algorithm flow chart was created to help guide readers with diagnostic decision-making during the second validation assessment (Figure 5).

After completion of the second training session, the readers independently participated in an interactive mock test session with the trainer to assess understanding of the material and to clarify teaching points as needed. In this mock testing session, the readers were asked to provide a diagnosis for each of the training cases and were given immediate feedback on

their performance through discussions with the trainer.

Second blinded interpretation of OCT validation data. Immediately after the second training session, the readers were asked to independently assess the remaining 76 OCT cases (35 adenocarcinomas, 20 SCCs, and 21 poorly differentiated carcinomas, including 13 poorly differentiated adenocarcinomas and 8 poorly differentiated SCCs) after rerandomization. Readers had access to the OCT interpretation criteria and the diagnostic algorithm only and, as in the initial validation, were instructed to record a diagnosis of adenocarcinoma, SCC, or poorly differentiated carcinoma for each case.

Statistics

The accuracy, sensitivity, and specificity of OCT criteria for diagnosing adenocarcinoma, SCC, and poorly differentiated carcinoma were calculated by comparison with the corresponding histologic diagnoses. In the poorly differentiated carcinoma cases, answers from the OCT readers of either poorly differentiated carcinoma or the correct subtype of the poorly differentiated carcinoma (SCC or adenocarcinoma) were accepted as correct answers. The statistics were calculated for the first and second validation assessment for each reader.

The OCT inter- and intraobserver variability was quantified by the Cohen kappa test of concordance.

Results

Initial Validation Assessment

The results of the OCT validation tests are summarized in Table 2. In the first validation assessment, the average accuracy achieved by all three OCT readers was 81.8%. The average sensitivity and specificity for adenocarcinoma were 80.6 and 85.4%, respectively; for SCC they were 80.0 and 89.5%, respectively; and for poorly differentiated carcinoma they were 85.7 and 96.4%, respectively. There was a wide range in the results obtained among the three OCT readers (Table 2), suggesting potential for improvement with additional training. The interobserver agreement (kappa statistic) ranged from 0.51 to 0.53. The average time to interpret each case and record the diagnosis was about 38 seconds/case (range, 26–44.5 s/case).

Second Validation Assessment

After receiving a more extensive OCT training session, the readers underwent a second validation test and obtained an average accuracy of 83.3%. The sensitivity and specificity achieved for adenocarcinoma were 80.0 and 91.9%, respectively; for SCC they were 86.7 and 84.5%, respectively; and for poorly differentiated carcinoma they were 85.7 and 98.8%, respectively. One OCT reader demonstrated dramatic improvement in the second validation, but the other two readers demonstrated either modest improvements or declines in sensitivity/specificity (Table 2). Interobserver agreement (kappa statistic) ranged from 0.39 to 0.60. The average time to interpret each case and record the diagnosis was about 30 seconds/case (range, 29–32 seconds/case).

Correct Classification of Poorly Differentiated Carcinoma

The blinded readers were able to diagnose the subtype of poorly differentiated carcinoma (SCC or adenocarcinoma) in an average of 71% of cases over the two validation assessments. In the first assessment, 82% of poorly differentiated adenocarcinoma cases were correctly diagnosed as adenocarcinoma and 54% of poorly differentiated SCCs were correctly diagnosed as SCC. In the second validation,

Figure 4. Optical coherence tomography (OCT) of lung carcinomas with fibrosis. Fibrosis appears as bright, signal-intense tissue on OCT. (A and B) OCT and corresponding histology of squamous cell carcinoma with dense fibrosis. The signal-intense nests (arrows) are more difficult to appreciate when intermixed with fibrosis. (C and D) OCT and corresponding histology of adenocarcinoma with fibrosis. Fibrosis makes the signal-void structures of adenocarcinoma (arrows) more difficult to visualize. Histology sections are stained with hematoxylin–eosin. Scale bars: 1 mm.

56% of poorly differentiated adenocarcinomas were correctly diagnosed as adenocarcinoma and 92% of poorly differentiated SCCs were correctly diagnosed as SCC.

Intraobserver Agreement

Intraobserver agreement (kappa statistic) between the two validation assessments for

the OCT expert, thoracic surgeon, and pathologist was 0.68, 0.49, and 0.40, respectively.

Discussion

In this study, we assessed whether OCT can be used to diagnose primary lung

carcinomas. We developed and validated OCT interpretation criteria for the most common primary lung carcinomas (adenocarcinoma, SCC, and poorly differentiated carcinoma) in a blinded assessment. The overall average accuracy achieved by the readers was 82.6% (range, 73.7–94.7%), with good sensitivity (80.3–85.7%) and specificity (83.3–97.6%) for each of the carcinoma types over the two validation assessments. The sensitivities and specificities achieved in this study are comparable to those reported in prior studies validating OCT criteria in esophageal (23, 24) and cardiovascular pathology (19).

Although these results are quite encouraging, the sensitivities and specificities are not high enough to support OCT as a complete replacement for tissue biopsy. In the OCT validation, many of the false positive and false negative adenocarcinoma and SCC cases were diagnosable on the corresponding hematoxylin–eosin stain based on histologic features. A study reported that the diagnostic agreement between lung FNA specimens and subsequent lung tumor resections is 96.2% in adenocarcinomas and 84.7% in SCCs when the FNA contains sufficient diagnostic material (45). Although our OCT interpretation results approach these diagnostic accuracies, they do not meet or surpass them, particularly in the case of adenocarcinomas.

There are also other significant hindrances to the replacement of tissue biopsy with optical diagnostics. In this study, only the most common primary lung carcinomas were included in the training and validation assessments. This was done to keep the training manageable for our readers and prevent confusion by educating them on too many entities in a short period of time. However, the differential diagnosis for a lung nodule is much more vast, including a variety of other types of primary neoplasms (i.e., neuroendocrine carcinomas), metastatic neoplasms, and nonneoplastic entities such as nodular organizing pneumonia and granulomatous diseases. Given the array of potential etiologies for a lung nodule, it would be challenging to develop OCT criteria to distinguish all these entities with high-enough sensitivity and specificity to replace tissue biopsy. In addition, performing *in vivo* high-resolution optical diagnostics in lung masses requires access to the mass,

Figure 5. Diagnostic algorithm flow chart. This diagnostic algorithm flow chart was provided to the optical coherence tomography (OCT) readers in the second validation assessment to help guide diagnostic decision-making.

which can be achieved through either bronchoscopic or trans-thoracic approaches. Needle-based OCT probes have been developed in the research setting (46–50). Given that access to the mass is required, it can be inferred that a concurrent biopsy/FNA tissue sample could be readily collected in addition to OCT imaging to complement one another for diagnostic interpretation. With the

advances in targeted therapeutics, physical tissue must be collected for molecular testing to determine whether tumors harbor mutations that would benefit from targeted therapy. This requirement precludes replacement of tissue biopsy with OCT and other *in vivo* optical biopsy techniques because, to date, they are unable to provide this essential mutational information (5, 6).

Although the results of this study do not support the use of OCT as a complete replacement for tissue biopsy, these results do indicate that OCT provides useful information about tissue microarchitecture that is difficult to achieve with standard tissue biopsy. OCT could be used to guide intramass tissue sampling toward areas of diagnostic material. New therapeutic discoveries have driven a dramatic effort to subtype poorly differentiated carcinomas as either SCCs or adenocarcinomas even on small tissue specimens (2, 4–6), but one study showed that only 32% of poorly differentiated carcinomas could be accurately subtyped on FNA by morphology alone (45). Immunohistochemical studies can be performed to aid subtyping, but these studies do not always provide a clear answer and there is also significant concern regarding tissue preservation for molecular testing work-ups (2, 4–6). In this study, the readers were able to correctly diagnose the carcinoma subtype (SCC or adenocarcinoma) with OCT in 71% of poorly differentiated carcinoma cases that could not be subtyped by morphological features on histology. Also, the specificity for poorly differentiated carcinomas was quite high (97.6%; range, 92.9–100%), indicating that the readers were able to identify when architectural features were present in OCT images. We have shown in previous studies that OCT has potential to

Table 2. Validation of optical coherence tomography criteria for primary lung carcinomas

	Initial Validation Test		Second Validation Test	
	Sensitivity	Specificity	Sensitivity	Specificity
OCT expert				
AdenoCA	72.2	92.7	91.4	97.6
SCC	95.0	80.7	100.0	94.6
PDC	85.7	100.0	95.2	100.0
Total accuracy		81.8		94.7
Pathologist				
AdenoCA	88.9	80.5	65.7	87.8
SCC	70.0	96.5	80.0	75.0
PDC	81.0	92.9	81.0	98.2
Total accuracy		81.8		73.7
Thoracic surgeon				
AdenoCA	80.6	82.9	82.9	90.2
SCC	75.0	91.2	80.0	83.9
PDC	90.5	96.4	81.0	98.2
Total accuracy		81.8		81.6

Definition of abbreviations: AdenoCA = adenocarcinoma; OCT = optical coherence tomography; PDC = poorly differentiated carcinoma; SCC = squamous cell carcinoma.

Note: Shown are diagnostic accuracies, sensitivities, and specificities for each OCT reader in the initial and second validation assessments.

improve diagnostic yield on navigation bronchoscopy by confirming needle location within the nodule before tissue collection (41, 42). In addition, OCT may be used to guide the biopsy needle to areas containing identifiable imaging features and potentially increase the probability of sampling well to moderately differentiated tumor within a mass. Furthermore, OCT could aid in pathology diagnosis as a form of large-volume virtual microscopy that complements traditional tissue biopsy specimens, especially in cases of poorly differentiated carcinoma. Future studies will need to be performed to assess whether OCT biopsy guidance and/or OCT diagnostics as a complement to tissue biopsy would increase the diagnostic accuracy on biopsy/FNA specimens.

In this study, we included a pathologist, thoracic surgeon, and OCT expert as blinded OCT readers. The pathologist was included because of their expertise in histological features of lung carcinomas. We included an OCT expert because of their experience assessing OCT image features and imaging artifacts, such as speckle noise. We also included a thoracic surgeon who regularly performs bronchoscopy, including bronchoscopic biopsies, to evaluate whether a clinician performing these procedures could potentially assess OCT imaging in real time during the procedure.

The wide range in accuracies, sensitivities, and specificities in the initial validation assessment suggested that there was potential for improvement with further training. Thus, we performed a second training session and validation assessment 7 months after the initial test to minimize the chance of recall memory from the first validation assessment. The second training included additional OCT training examples and clarifications on the OCT interpretation criteria. However, the second validation assessment still resulted in a wide

range of accuracies, sensitivities, and specificities. The OCT expert reader improved significantly in all categories, with an increase in overall diagnostic accuracy from 81.8 to 94.7%. The thoracic surgeon reader improved mildly in the assessment of both adenocarcinoma and SCC. The pathologist reader improved in the assessment of SCC but decreased in accuracy in assessing adenocarcinomas. The reason the OCT expert reader had more dramatic improvement after the second training is likely due, at least in part, to the reader's extensive prior experience with OCT imaging, identification, and validation of OCT image features, and knowledge of OCT image artifacts (i.e., speckle noise). The OCT expert's improvement may also be due to stricter adherence to the OCT criteria given the reader's lack of *a priori* pathology knowledge. It is possible that additional training/experience with OCT imaging and stricter adherence to the OCT criteria could improve sensitivity/specificity among the non-OCT expert readers. These studies were performed with state-of-the-art OCT technology. Further technological improvements in resolution and contrast could also potentially improve the ability to interpret OCT images.

Adenocarcinomas and SCCs of the lung often contain regions of fibrotic stroma. In the first validation assessment, it was noted that cases containing tumor admixed with dense fibrosis presented more of a diagnostic challenge for the readers. Fibrosis appears as bright, signal-intense tissue on OCT (32, 42) and makes the features of SCC and adenocarcinoma more difficult to visualize (Figure 4). To help address this challenge, additional examples of fibrotic SCC and adenocarcinoma were included in the second training session. However, these cases were still a diagnostic

challenge for the readers in the second validation assessment. We have previously demonstrated that polarization-sensitive optical coherence tomography (PS-OCT) can detect organized tissues, such as collagen, to identify regions of fibrotic stroma and distinguish fibrosis from tumor (42). Future studies will assess whether the addition of birefringence information from PS-OCT will impact the ability to interpret OCT images.

This study was conducted in the *ex vivo* setting to provide precisely correlated histology for accurate OCT feature characterization, which cannot be achieved with tissue biopsy samples. However, it is important to note that tissue degradation and excess blood contamination from the surgical resection in *ex vivo* tissues can negatively impact OCT image quality and is not typically encountered in the *in vivo* setting. Future *in vivo* studies will need to be performed to validate the findings of this *ex vivo* study.

This study is the first step in assessing whether optical coherence tomography could replace tissue biopsy for lung cancer diagnostics. We developed and validated OCT criteria for the most common lung carcinomas. Although the sensitivities and specificities achieved in the validation assessments were fairly high, the results were not adequate to support OCT as a complete replacement for tissue biopsy. However, OCT has potential to aid in diagnosing lung carcinomas as a complement to, rather than a replacement of, traditional tissue biopsy. ■

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