Development and validation of a convolutional neural network to identify regions of interest in lumpectomy margins using optical coherence tomography

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Background.
Optical coherence tomography (OCT) is the optical analog of high frequency ultrasound and produces real-time, high-resolution imaging with a tissue penetration depth up to 2 mm. Multi-reader studies of OCT have demonstrated the ability to differentiate normal breast parenchyma from neoplasms including DCIS and invasive carcinoma, with greater than 85% sensitivity and specificity. Intraoperative evaluation of breast lumpectomy specimens using OCT may aid in achieving negative margins at the time of primary surgery and avoid second visits for re-excision of positive margins. Artificial Intelligence analytical tools can be trained to recognize regions of interest (ROI) in OCT images of lumpectomy margins that are suspicious for malignancy. The purpose of this study was to develop and validate an automated convolutional neural network (CNN) to screen OCT images of lumpectomy margins to identify ROIs.

Methods.
Following IRB approval/patient consent, the margins of lumpectomy specimens from 126 patients with ductal malignancy were imaged using OCT. Images were then compared to the corresponding permanent histology and annotated by board- certified breast pathologists to create a training set of 25,000 control ROIs. A CNN algorithm was developed with 3 convolutional layers, a 3x3 kernel, and 3 fully connected layers to perform binary classification of images as “suspicious” or “non-suspicious” for malignancy. A weighted loss function was implemented to balance the training data available for non- suspicious vs. suspicious images and to tune sensitivity and specificity. Once trained and properly weighted, the CNN was tested in a prospective study using OCT images of margins from 29 lumpectomy specimens from 29 patients with biopsy-proven ductal carcinoma in situ (DCIS), invasive ductal carcinoma (IDC), or both. Results from the CNN were compared to permanent histology.

Results.
The patient population was 61.5 ± 7.3 years old, 100% female, with Stage 0-1 disease. Disease types included invasive ductal (n=20), invasive lobular (n=2), ductal carcinoma in situ (n=27), mixed (n=74), atypical ductal hyperplasia (n=24), as well as benign findings including subjects with atypical lobular hyperplasia (n=19), lymphatic invasion (n=13), lobular carcinoma in situ (n=12), usual ductal hyperplasia (n=35), and duct ectasia (n=17). Following primary surgery, fresh lumpectomy specimen margins were scanned using OCT and image volumes were analyzed by the CNN. Approximately 1.9 M OCT ROIs were assessed in testing, identifying 101,099 ROIs as suspicious for malignancy. Three hundred and eighty-four (384) ROIs were correctly identified, yielding a 70% true positive and 5.2% false positive detection rate; the sensitivity and specificity were 70% and 96%, respectively.

Conclusions.
Automated analysis of OCT images using a trained CNN to identify regions of interest suspicious for DCIS or IDC in breast lumpectomy specimens is feasible, demonstrating a high concordance with permanent pathology. These findings indicate the utility of CNN for screening OCT images with potential utilization for intraoperative evaluation of the status of breast lumpectomy margins immediately following resection, before permanent pathology. A pivotal prospective clinical trial will be necessary to evaluate breast specimens in real time to determine if this application may improve re-excision rates in lumpectomy.