# Deep learning aided epidural needle guidance by a forward-view polarization-sensitive optical coherence tomography system

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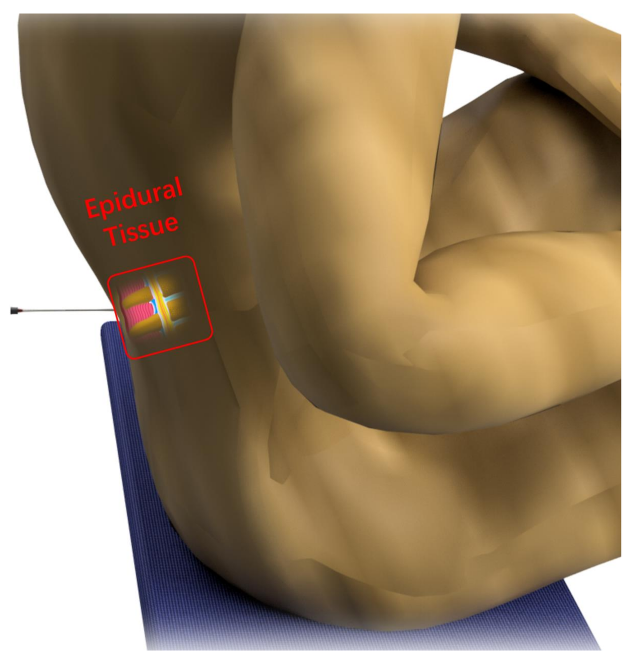
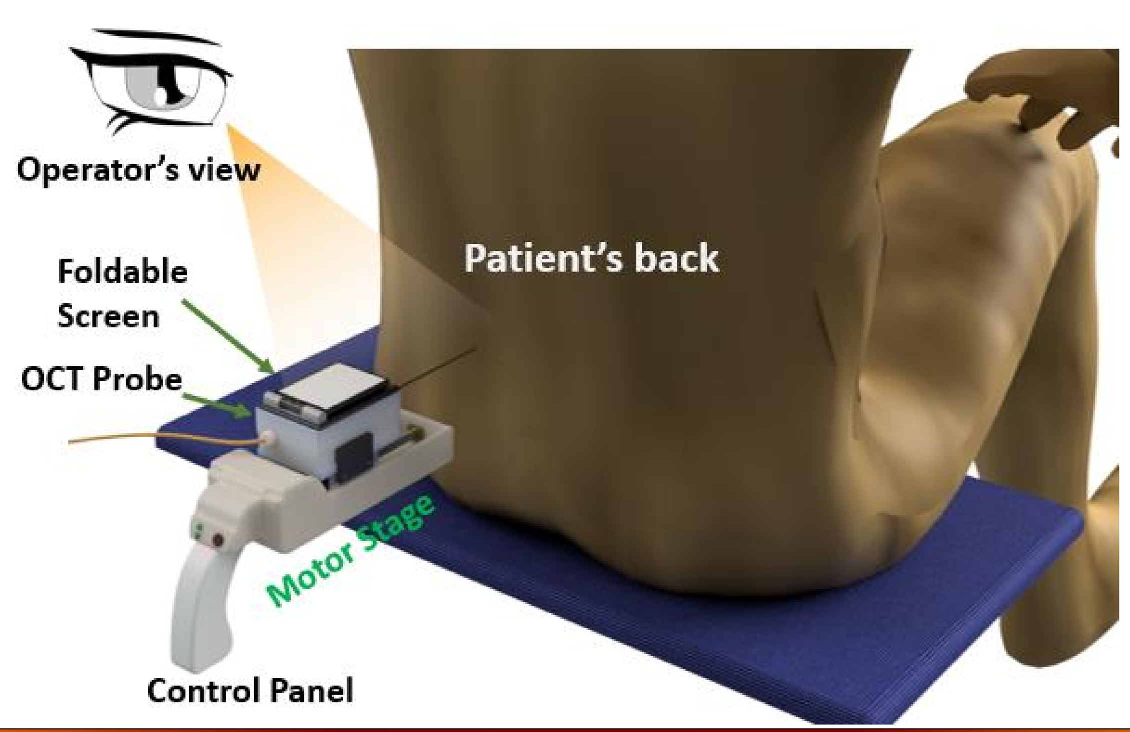
## Background and Motivation

- Epidural anesthesia is commonly used anesthetic technique that has enhanced pain relief and increased patient satisfaction. The procedure is applicable across the cervical, thoracic, and lumbar positions for a variety of operations. Epidural anesthesia requires inserting a needle into the epidural space, followed by administering a local anesthetic around the spine. This process effectively inhibits the transmission of pain signals from the spinal nerves to the brain. Epidural needle traverses through subcutaneous fat, supraspinous and interspinous ligaments, and ligamentum flavum before reaching the epidural space where the spinal cord is situated. Incorrect needle placement can result in significant complications, such as post-dural puncture headache (PDPH), epidural hematoma, cerebrospinal fluid hypertension, etc. Imaging techniques such as ultrasound and fluoroscopy have been utilized to improve the precision of epidural needle navigation. However, the limitations of resolutions and contrast make it difficult to accurately recognize different tissues.
- In this study, we developed an endoscopic polarization-sensitive optical coherence tomography (PS-OCT) system for epidural needle guidance. PS-OCT is a progression based on traditional intensity OCT by facilitating the capture of polarization-related features through birefringence and diattenuation optical signals. Because tissues like nerve fibers have strong polarization features, so PS-OCT has potential to improve the epidural tissue recognition.




## Material and Methods

- The experimental setup of our endoscopic PS-OCT system is shown in Fig. 1. We incorporated a gradient index (GRIN) lens into the sample arm to achieve a forward view of the endoscope. In this study, we tested our system using five human epidural tissue samples. Different tissues: 1) subcutaneous fat, 2) supraspinous ligament, 3) interspinous ligament, 4) ligamentum flavum, 5) epidural space, 6) dura, 7) spinal cord, were imaged by our system. Images in four different imaging mode, including 1) intensity; 2) Phase retardation; 3) Optic Axis; 4) Degree of polarization uniformity (DOPU), were obtained.
- To help better distinguish different epidural tissues, convolutional neural network (CNN) methods were used to make the tissue recognition automatic. ResNet50 model was selected as a widely used image classification architecture. For each tissue type, we obtained 3,600 images for each PS-OCT imaging mode.

## Experimental Results

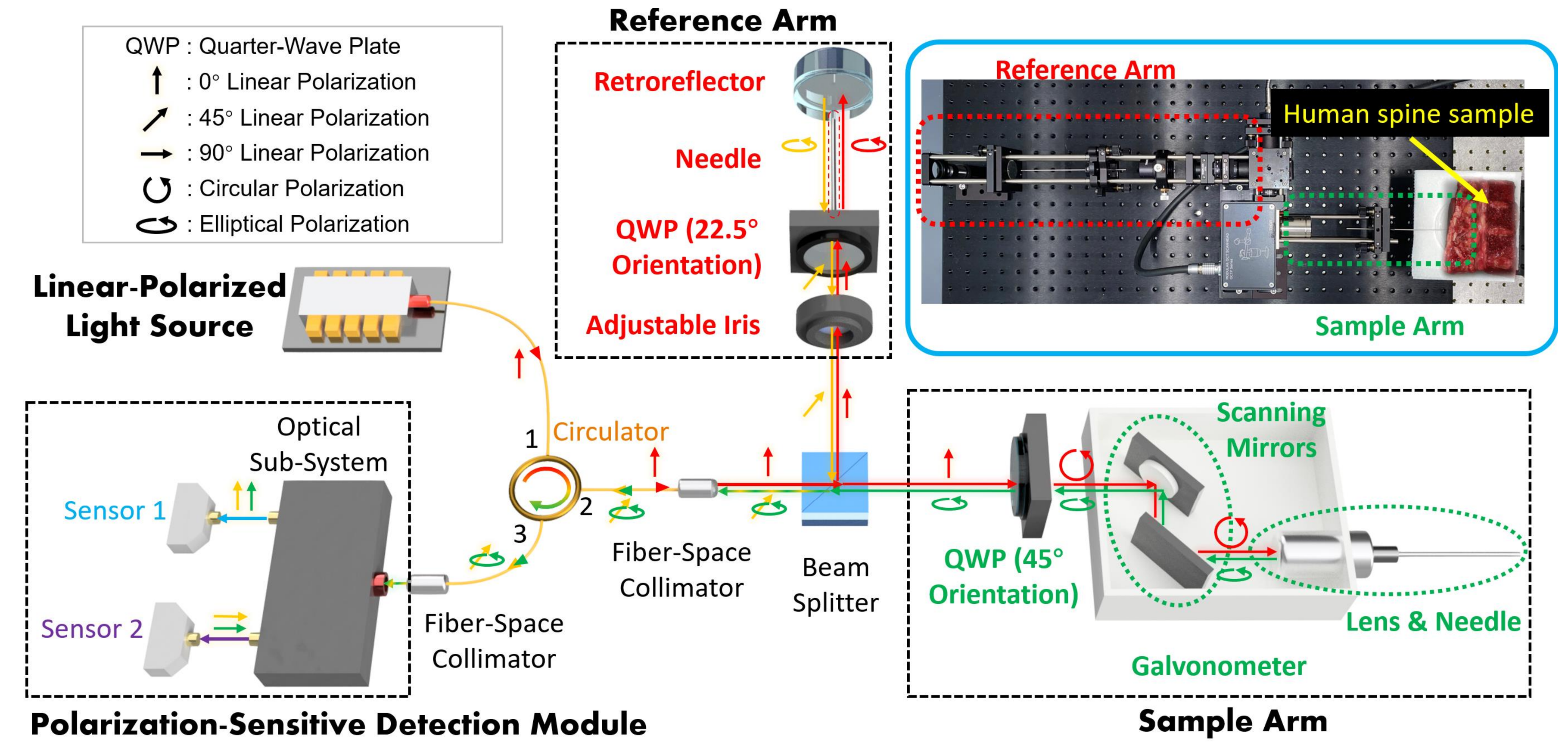
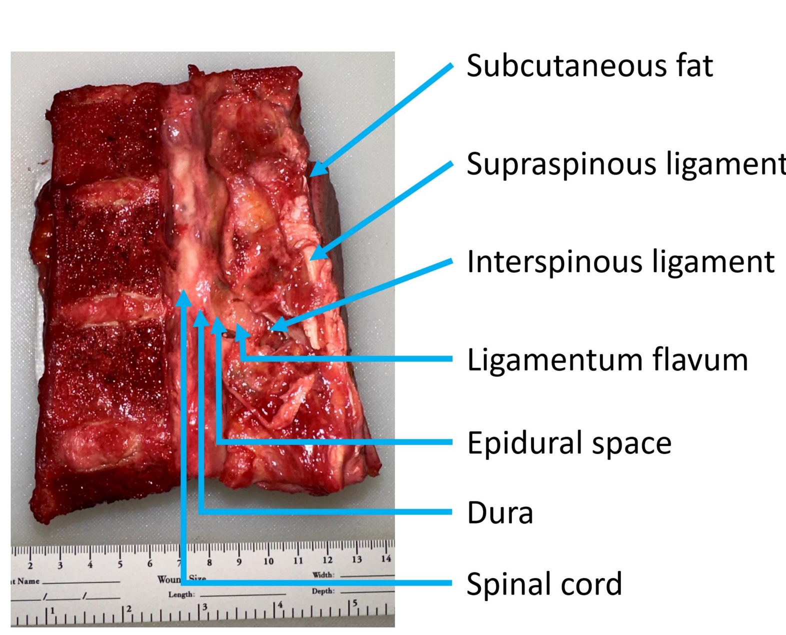



Fig. 1. Schematic of PS-OCT endoscopic probe.

The PS-OCT probe is demonstrated in Fig. 1. We integrated two GRIN lenses in the sample arm and reference arm of the OCT system, respectively. The GRIN lens in the sample arm is employed for endoscopic imaging, while the one in the reference arm aids in dispersion compensation. Our system can capture internal tissue structures by inserting the GRIN lens into the tissue.

From the results shown in Fig. 2, different epidural tissues can be distinguished based on the different OCT imaging features.



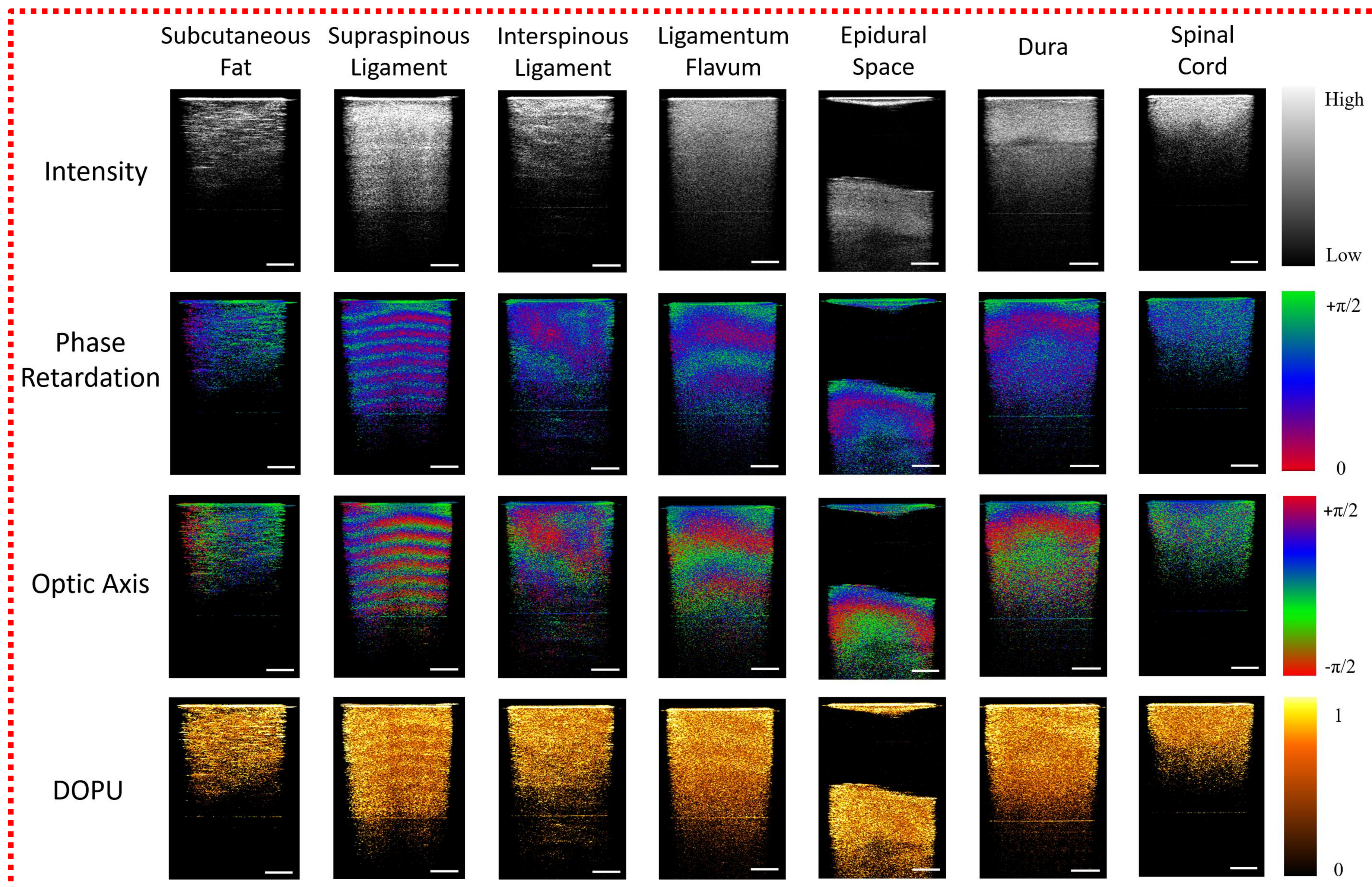




Fig. 2. PS-OCT imaging results of different epidural tissues.

## Experimental Results

Convolutional Neural Network (CNN) method was used to achieve automatic tissue recognition. In this project, ResNet50 model was used for tissue classification. Images in four modes were processed by using ResNet50, separately.

| | | | |
|---|---|---|---|
| **Subjects** | 5 Epidural Samples | | |
| **7 Classes** | 1) Fat, 2) Supraspinous Ligament, 3) Interspinous Ligament, 4) Ligamentum Flavum, 5) Epidural Space, 6) Dura, 7) Spinal Cord. | | |
| **Epochs** | 50 | | |
| **Image size** | 700 * 450 | | |
| **RGB channels** | 1 | | |
| **Learning rate** | 0.01 | **Momentum** | 0.9 |
| **Decay** | 0.01 | **Optimizer** | SGD |
| **Batch size** | 24 | | |
| **Model** | **ResNet50** | | |

Table 1. ResNet50 mode for epidural tissue classification.

| Test fold | Intensity | Retardation | Optic Axis | DOPU |
|---|---|---|---|---|
| E1 | 90.370% | 97.900% | 98.150% | 89.450% |
| E2 | 91.030% | 94.810% | 95.150% | 88.560% |
| E3 | 95.890% | 99.330% | 99.390% | 94.150% |
| E4 | 96.580% | 98.330% | 97.970% | 93.970% |
| E5 | 94.000% | 97.400% | 98.080% | 95.860% |
| Average | 93.574% | 97.554% | 97.748% | 92.398% |
| SE | 1.251% | 0.617% | 1.168% | 0.570% |

Table 2. Test accuracies of different PS-OCT imaging modes.

Compared to intensity mode, PS modes including phase retardation and optic axis provide more accurate tissue prediction results.

## Conclusion and Future Work

In this study, we developed an endoscopic PS-OCT system for epidural anesthesia needle navigation. Different epidural tissues showed different PS-OCT imaging features, so our system can help recognize the epidural tissue and help locate the epidural needle tip.

In the future, we will try to miniaturize the PS-OCT scanner to make it easier for physicians to use. Additionally, we will develop a multi-channel CNN model (using the data from 4 modes simultaneously) to improve the tissue recognition. Furthermore, we will conduct experiments on *in-vivo* animal samples.

## Acknowledgement

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