Observations on the Use of OCT to Examine the Varnish Layer of Paintings

Derek Nankivil[1], Adele DeCruz[2], and Joseph A. Izatt[1]

1: Department of Biomedical Engineering and the Fitzpatrick Center for Photonics; Duke University; Durham, NC 27708
2: Departments of Chemistry and Biology, Duke University, Durham, NC 27708

Purpose

The purpose of this study is to demonstrate that Optical Coherence Tomography (OCT) can be used to:

1) Measure the varnish layer thickness of paintings, and
2) Verify that the varnish layer has been removed after laser ablation-based conservation efforts.

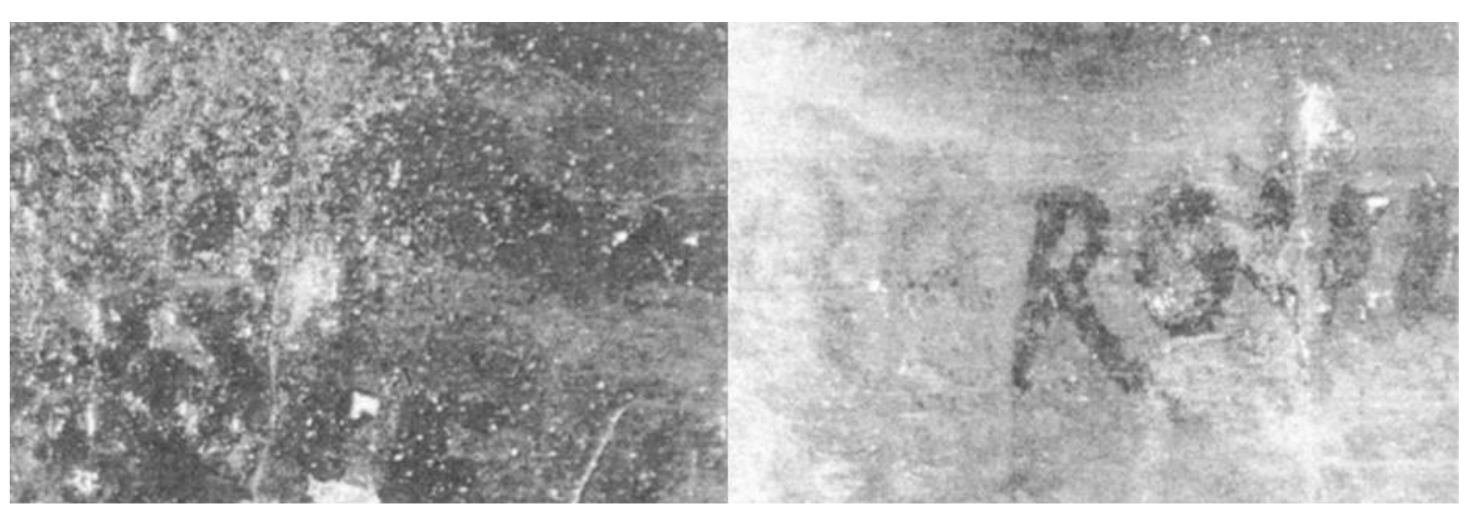
Introduction

To restore the original intent of the artist, art conservation is moving towards an increased use of laser ablation to remove varnish layers, which have become encrusted with contaminants or have been otherwise altered over the years[1-9]. It should be possible to guide the restoration process with imaging modalities that provide information about the varnish layer. In paintings where the encrustation has not rendered the varnish completely opaque, OCT has the potential to provide details about the structure and thickness of the varnish layer in a non-invasive manner[10,11].

Background

Optical coherence tomography enables fast, noninvasive, high resolution, three-dimensional imaging of the **internal microstructure** of weakly scattering objects. Conventional OCT systems are coherence-gated interferometers wherein the optical measurement technique known as low coherence interferometry is used to measure the magnitude and echo time delay of backscattered light. In its simplest manifestation, time-domain OCT (TDOCT), the illumination is split and sent to both a reference arm and to the sample. Light returning from the sample interferes with light returning from the reference arm, and interference fringes are observed provided that the reference and sample path lengths are matched to within the coherence length of the source. Scanning the reference path length results in a series of interference fringes that correspond to different depths in the sample. The photodetector signal is demodulated to reconstruct each A-scan.

Further, prior work (Figure 1) has shown that using lasers for art conservation may offer advantages over conventional methods with solvents and scalpels[1-9]. Some contaminants and encrustations require very strong solvents or cannot be removed with a solvent without removing some of the paint itself: solvent may saturate the substrate, causing it to swell, materials (from the substrate) may leach into the solvent, and the conservator may be exposed to toxic fumes from the solvent.



Before　After

Figure 1. The Turkish Noble (Bashi Bazouk) 1859. Charles Bargue (1826-1883). French. Oil and bitumen on artist board, 5"x7". Detail of signature.

Methods

In this study, OCT was used to visualize and quantify the varnish layer of paintings and to verify the success of efforts by conservators to remove the varnish layer using laser ablation. A free-running Er:YAG (MonaLaser, Orlando, Florida) laser with a central wavelength of 2.94 µm, a reputation rate of 15 kHz and an optical power of 1 mW was used to remove the varnish. A spectral domain OCT (SDOCT) system with a Michelson topology was constructed using a broadband superluminescent diode (SLD-371, Superlum, Carrigtwohill, Ireland) with a central wavelength of 840 nm and a 50 nm bandwidth and a line scan CMOS sensor (AViiVA, e2v Inc., Milpitas CA) with a 20 kHz line rate. The sample arm design utilized a 4f relay between the first and second galvanometer (scanner) and a telecentric beam delivery system to minimize optical distortions. The OCT system provided an 8.5 µm axial and 7.5 µm lateral resolution, a sensitivity of 105 dB, an imaging range of 0.8 mm (6dB fall off) and a field of view of 5 x 5 mm.

Samples, including pigment, varnish and substrate, approximately 1 mm^2 in size, were removed from an oil painting on panel (San Giorgio Maggiore) by Martin Rico (1833-1908) and imaged using Environmental Scanning Electron Microscopy (ESEM). Varnish thickness obtained from OCT was validated by similar measurements obtained from ESEM. In addition, other paintings, including a late 18th century landscape, signed Thomas Gainsborough, were imaged with OCT to compare neighboring regions before and after laser treatment and to examine the layering of the artist's signature in an effort to determine its authenticity.

Methods (Continued)

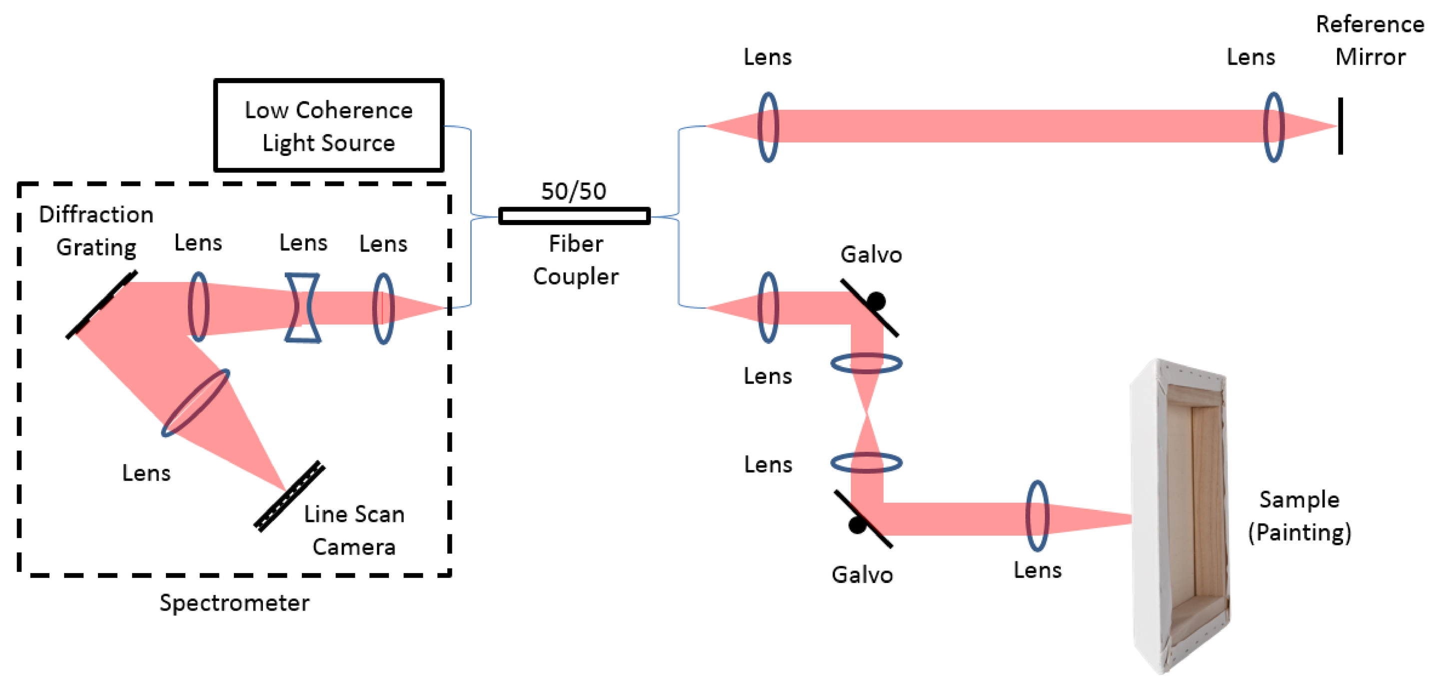


Figure 2. SDOCT system with Michelson topology. SDOCT permits faster image acquisition and higher signal-to-noise ratio than the predecessor TDOCT technology. Through the use of spectral interferometry, depth information is collected without movement of the reference mirror. Backscattered light from the sample and reference interfere, and the broadband interference pattern is measured with spectrally discriminate detectors. Thus, measurements of the power spectral density of the interferogram as a function of wavelength are obtained. Since the temporal coherence function (also called the autocorrelation function) and the power spectral density form a Fourier transform pair (Wiener-Khinchin theorem), the A-scan can be reconstructed by merely taking the inverse Fourier transform of the broadband interferogram.

Results

Figure 3. San Giorgio Maggiore, Venice, Martin Rico (1833-1908), oil on panel, 6x12" circa 1890. The signature Rico is in the painting's lower left covered by discolored varnish. In the Lighter areas the discolored yellow-orange varnish has been removed with laser ablation.

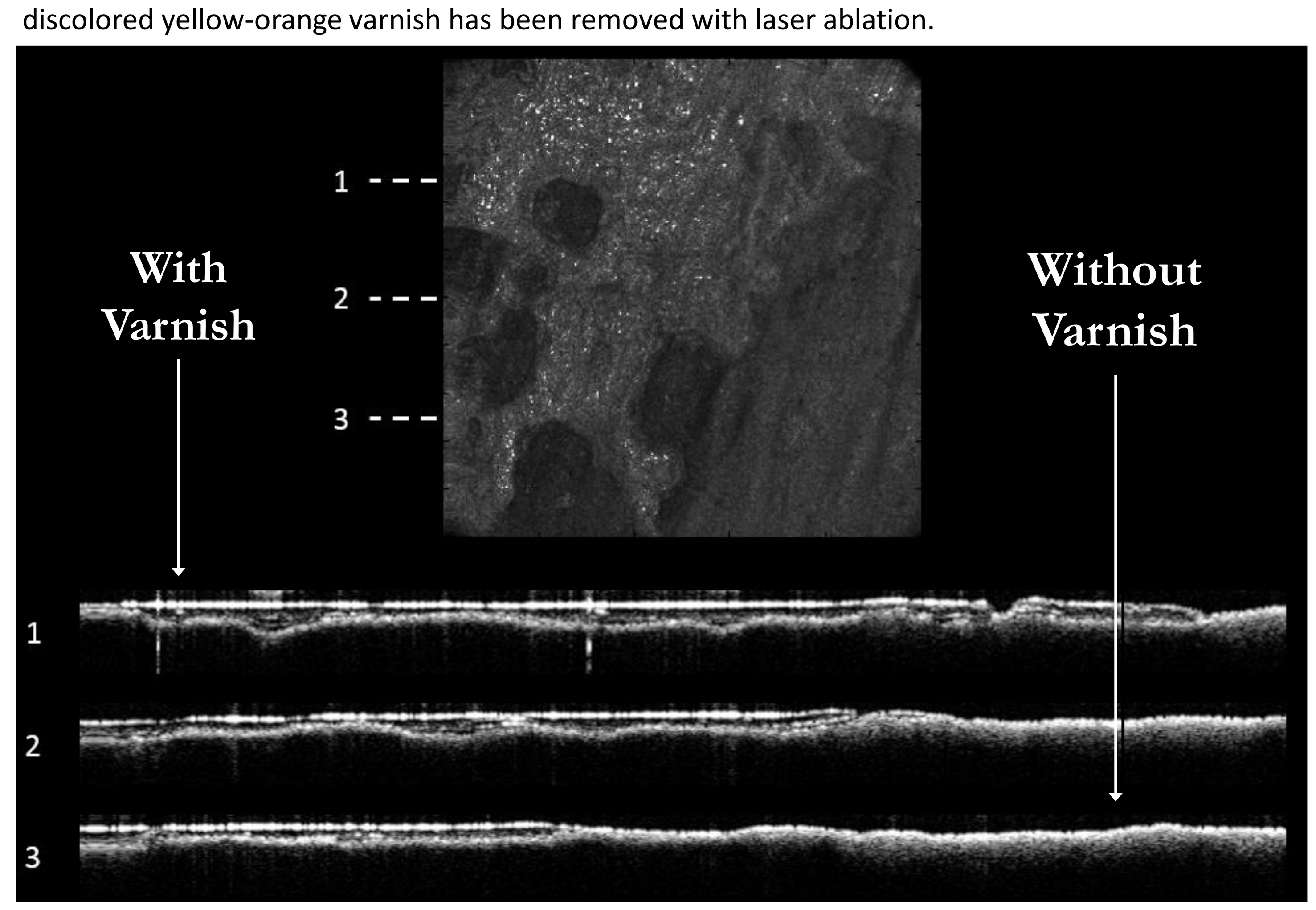


Figure 4. A late 18th century landscape, signed Thomas Gainsborough, imaged in a region with and without varnish. (top) Summed voxel projection (SVP) showing ablation craters in the varnish layer on the left, along with corresponding cross-sections taken at locations 1-3. Notice the retreating edge of the varnish layer, which has been removed with the Er:YAG laser in each cross-section.

Results (Continued)

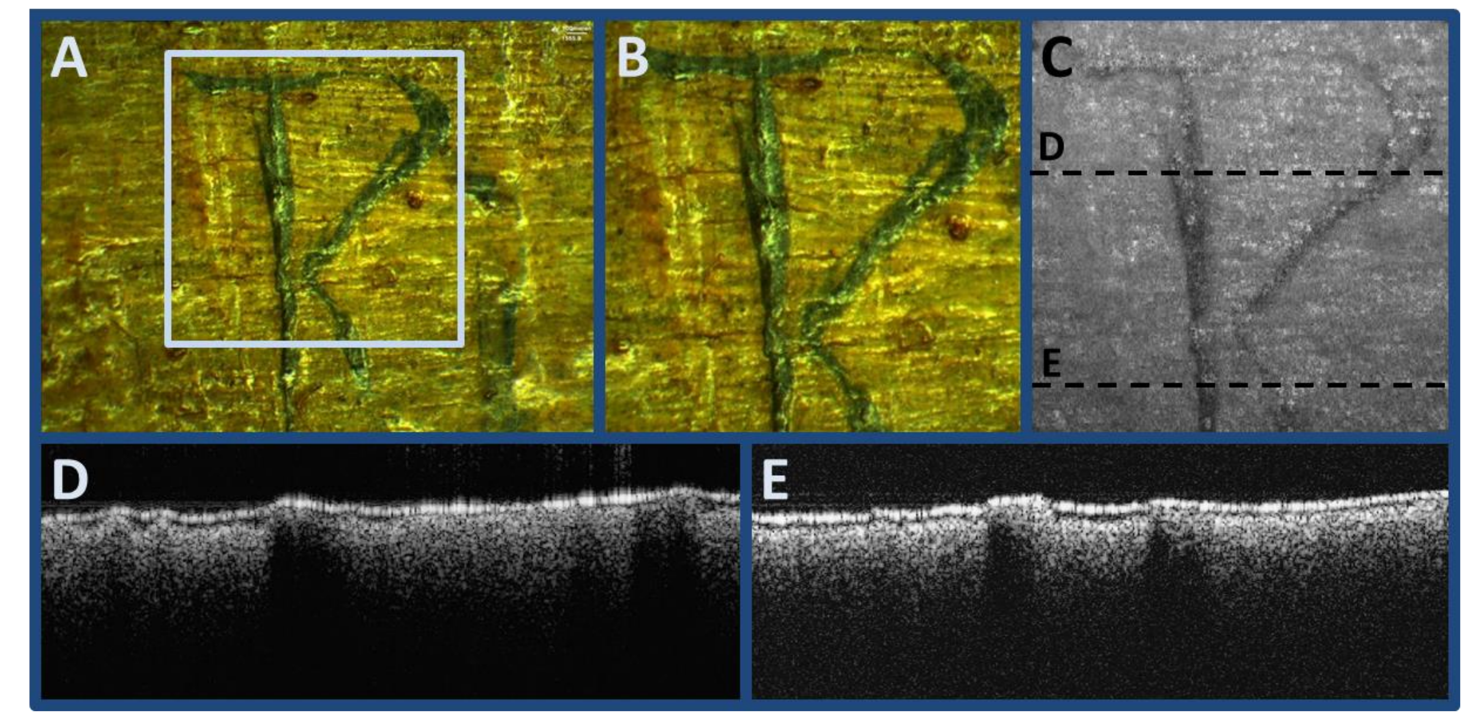
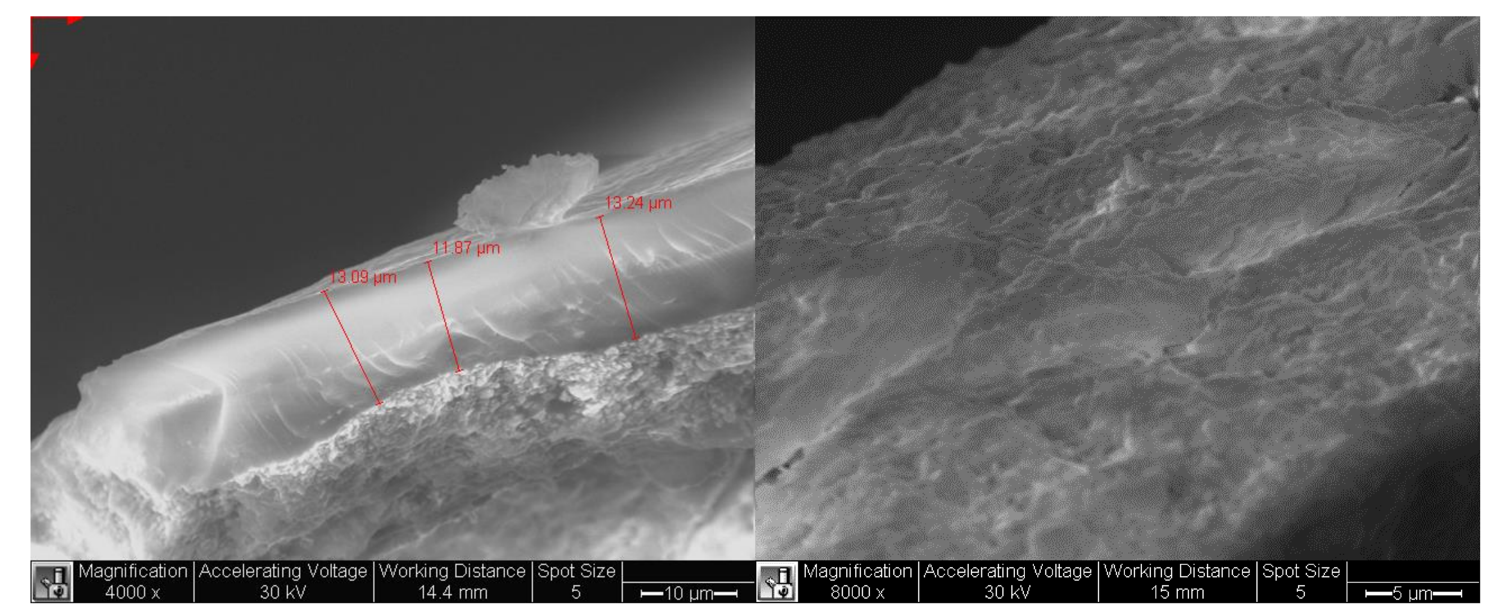


Figure 5. Images of the signature on an oil on wood 19th century Venetian landscape painting by Rico. Microscope image of the R in the signature acquired at 4x magnification (A), close-up of A indicated by the light blue box (B), OCT SVP of the same region shown in B (C), OCT cross-sectional images (D & E) acquired along the dotted lines shown in C.



Before Varnish Removal　After Varnish Removal

Figure 6. ESEM images before and after varnish removal. Note, ESEM imaging required removal of a small (approximately 1 mm^2) portion of the painting. Measured varnish layer thickness in three locations: 13.09 µm, 11.87 µm and 13.24 µm. In the image acquire after Er:YAG removal, the surface of the paint appears devoid of varnish, and the texture of the surface of the painting appears fluid-like with pockets of smoothed areas.

Varnish layer thickness was 10.8 ± 3.8 µm and 12.7 ± 0.7 µm measured by OCT and ESEM respectively. Complete varnish layer removal was observed in several regions of paintings after laser treatment with occasional residual varnish in regions of significant surface topological variation. Additionally, the presence of over-paint and differences in penetration depth were observed in the OCT cross-sections.

Conclusions

- We believe that this is the first demonstration of the application of OCT to show that the varnish is removed by Er:YAG laser treatment.
- In conclusion, we demonstrate that OCT may provide a non-invasive technique that provides measures of the varnish layer and verification of its removal after laser ablation-based conservation efforts.

References and Acknowledgements

1. Asmus JF, More light for art conservation, IEEE Circuits and Devices, March: p. 6,1986.
2. Maravelaki PV, Zafiropulos V, Kylikoglou V, Kalaitzaki M, Fotakis C. Laser induced breakdown spectroscopy as a diagnostic technique for the laser cleaning of marble. Spectrochim. Acta B, 52:41, 1997.
3. Georgiou S, Zafiropulos V, Anglos D, Balas C, Tornari V, Fotakis C. Excimer laser restoration of painted artworks: procedures, mechanisms and effects. Appl. Surf. Sci., 127–129,:738, 1998.
4. Maravelaki-Kalaitzaki P, Zafiropulos V, Fotakis C. Excimer laser cleaning of encrustation on pentelic marble: procedure and evaluation of the effects. Appl. Surf. Sci., 148:92, 1999.
5. Scholten JH, Teule JM, Zafiropulos V, Heeren RMA. Controlled Laser cleaning of painted artworks using accurate beam manipulation and on-line LIBS-detection, J. Cult. Heritage, 1:S215, 2000.
6. Klein S, Stratoudalsi T, Marakis Y, Zafiropulos V, Dickmann K. Comparative study of different wavelengths from IR to UV applied to clean sandstone. Appl. Surf. Sci., 157:1, 2000.
7. De Cruz A, Wolbarsht ML, Hauger SA. Laser removal of contaminants from painted surfaces, J. Cult. Heritage, 1:S173, 2000.
8. Bracco P, Lanterna G, Matteini M, Nakahara K, Sartiani O, De Cruz A, Wolbarsht ML, Adamkiewicz E, and Colombini MP. Er:YAG laser: an innovative tool for controlled cleaning of old paintings: testing and evaluation. J. Cult. Heritage, 4:202s-208s, 2003.
9. Pouli P, Paun I-A, Bounos G, Georgiou S, Fotakis C. The potential of UV femtosecond laser ablation for varnish removal in the restoration of painted works of art. Appl. Surf. Sci., 254:6875-6879, 2008.
10. Liang H, Cid MG, Cucu RG, Dobre GM, Podoleanu AG, Pedro J, Saunders D. En-face optical coherence tomography – a novel application of non-invasive imaging to art conservation. Optics Express, 13;16:6133-6144, 2005.
11. Gora M, Targowski P, Rycyk A, Marczak J. Varnish ablation control by optical coherence tomography. Laser Chemistry, 2006.

This project was funded by the Fitzpatrick Foundation (Scholar - DN), the Michael J. Boberschmidt Fund, and the Ottmar Foundation.

Corresponding Author Email Contact: derek.nankivil@duke.edu