A study in the use of optical coherence tomography to examine depth of penetration into varnish layers ablated by the Er:YAG laser pulse at 2.94 µm

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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. It is possible to guide the restoration process with imaging modalities that provide information about the varnish layers. In paintings where the encrustation has not rendered the varnish completely opaque, Optical Coherence Tomography (OCT) has the potential to provide details about the structure and thickness of the varnish layer in a non-invasive manner.

OCT has been used, to visualize and quantify the varnish layers of paintings and to verify the success of removing 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 optical power of 1 mW was used to remove the varnish. A spectral domain OCT system with a Michelson topology was constructed using a broadband super-luminescent 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 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. Also, Two Bioptigen Envisu (Spectral Domain Ophthalmic Imaging System) systems were used: 1) R3500 2) R2300. The two systems utilize different sources and spectrometer designs, but both permitted visualization of varnish and paint, at different depths

Samples, including pigment, varnish and substrate, approximately 1 mm2 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, a late 18th century landscape, signed Thomas Gainsborough, was imaged with OCT to compare neighbouring regions before and after laser treatment and to examine the layering of the artist's signature in an effort to determine its authenticity. 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. Also, laboratory samples have been studied to provide a controlled examination of the varnish surface and paint substrate.

We believe this is the first demonstration of the application of OCT to show that the varnish removed by Er:YAG laser treatment is gradual and can be controlled to remove microns of material without penetrating into the substrate. In conclusion, we demonstrate that OCT may provide a non-invasive technique that provides measurements of the varnish layer and verification of its removal after laser ablation-based conservation.