Lasers in the Conservation of Artworks XIII – Siano & Ciofini (eds)

A new approach for the restoration of gilded surfaces: Revealing original decors of the "Bargueño" (16th century) by Er: YAG laser processing controlled by Optical Coherence Tomography

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ABSTRACT: During the meticulous restoration of "the Bargueño," an exquisite gilded travel cabinet dating back to the 16th century and hailing from the historic Château de Pau in France, an intricate conundrum surfaced. It was a puzzle involving the presence of two superimposed layers bonded by the same adhesive, a quandary insurmountable by conventional restoration techniques. The physical-chemical attributes of the materials posed a formidable challenge in the quest for an effective remediation strategy. Analysis revealed a duality in gilding techniques; the wooden portions were adorned with water gilding, while the ivory sections exhibited oil gilding. To address this exceptional restoration challenge, a groundbreaking method was embraced. A feasibility study was conducted employing a pulsed Er: YAG laser operating at 2940 nm in a µs regime, meticulously applied to gilded ivory prototypes. This laser methodology facilitated the precise ablation of layers, completely circumventing direct material contact. The degree of precision could be finely tuned by manipulating laser parameters. The laser ablation assessments on prototypes, varying in gilding layer thickness, were executed under the vigilant watch of optical coherent tomography (OCT). This innovative approach permitted the meticulous removal of layers during the restoration process of the ornate twisted and gilded columns, unequivocally affirming its efficacy in the preservation of gilded surfaces.

1 INTRODUCTION

During the transitional period spanning the fifteenth and sixteenth centuries, a distinctive style known as the plateresque emerged. This style drew inspiration from various artistic currents, namely the Italian Renaissance, the late Gothic, and Mudejar art. Initially conceived as ornate altarpieces, the plateresque design extended its exuberant embellishments to encompass facades of both furniture and edifices. Notable examples of this ornate aesthetic include the façade of the Santa Cruz Hospital in Toledo.

The plateresque style exhibited a lavish array of ornamentation, skillfully blending elements of architecture and goldsmithing, with the Spanish term "platero" denoting a goldsmith. During this era, the frontages of furniture pieces underwent a transformation, adorned with sculptures, columns, medallions, and other intricate details. Additionally, sumptuous crimson velvet found its way beneath the metallic embellishments. The Italian influence on this style continued to gain prominence.

By the sixteenth century, Spanish travel furniture, particularly the renowned "Bargueño," became an essential commodity. Consequently, it comes as no surprise that artisan guilds formed to meet the demand during colonial expeditions to the New World.

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The Bargueño, housed within the National Museum and Castle of Pau, embodies the essence of Mudejar art, primarily produced in the province of Toledo. Exhibiting a plateresque demeanor, it derives inspiration from the Italian Renaissance, late Gothic, and Mudejar artistic traditions. This remarkable piece of furniture comprises two key components: a base housing a wooden box, sealed with a flap. The chest's interior is designed akin to an altarpiece, featuring registers of elements distributed across five distinct sizes and functions. Four doors, each equipped with key locks, serve to embellish the four corners, while 22 drawers, in various configurations, include seven secret compartments. The front of the Bargueño is resplendent with a diverse array of decorations, including sculptures, arcades, columns, medallions, miniature frames, inlays, painted motifs, shells, and religious symbols such as Christian crosses and celestial clouds—inspired by the portable chests of pilgrims en route to Santiago de Compostela.

However, an unintended application of oil gilding led to a shift in the gilded work's appearance and artistic expression. Thus, it becomes imperative to undertake its removal while ensuring the preservation of the original surface's integrity.

The mechanical technique of shrinkage poses a considerable challenge in this context, owing to the difficulty of distinguishing between layers in the stratigraphy visually. This challenge is exacerbated by the close colorimetry of the preparations. Furthermore, the extremely thin binders, measuring between 0.18 to 0.21 μm, introduce an additional layer of complexity to the shrinkage process. In addressing these issues, laser cleaning techniques have been applied in cultural heritage preservation since 1992 (Lopez, et al. 2020). By meticulously selecting laser parameters such as wavelength, pulse duration, and fluence, the laser-material interaction can selectively remove undesirable substances like dirt, corrosion layers, alterations, paint, and accretions from artworks (Wilkie-Chancellier & Detalle, 2020, Lopez 2020, Sawicki et al. 2009). The most commonly employed laser for conservation cleaning has been the Nd: YAG laser with wavelengths of 1064 nm, 532 nm, and 266 nm. However, when dealing with similar chemical compositions between the material to be removed and the material to be preserved, challenges arise.

This paper introduces a novel approach that employs the Er: YAG laser with a wavelength of 2940 nm for clearing gilded surfaces. Given the nature of the laser cleaning process, it allows for more controlled and less damaging cleaning operations. The objective of this study is to investigate the interaction of Er: YAG laser radiation with oil gilding layers and determine if clearance can be achieved at different levels within the same layer.

In antiquity, various techniques influenced by Carolingian and Roman methods were practiced to varying degrees across regions. Alchemists, clerks, and clerics actively exchanged and disseminated their knowledge, as evidenced by historical treatises like that of the monk Theophilus from the early 12th century, Jean le Begue's "Different receipts on the colors," and A. Félicien's "Dictionary of the terms proper to architecture, painting and other arts dependent on it." During the Middle Ages, two prevalent gilding techniques were employed on gilded wooden surfaces of decorative art furniture: gilding with mordants and gilding with distemper (de l'Escalopier 1863, Le Begue 1431, Félicien, 1676). These techniques led to a plethora of recipes and required the use of natural binders and mixtures, including substances like gum Arabic, gum tragacanth, animal and fish glues, casein, egg white, vegetable oils, egg yolk, garlic, and honey, either individually or in combination.

Beginning in the 14th century, political and commercial ties between Italy, Catalonia, the Kingdom of Aragon, and Valencia facilitated the exchange of knowledge and techniques. Cennino Cennini, among others, documented these ancient processes, outlining the use of mordants for gilding (Cennino Cennini, 2009 edition). The technique of gilding with mordant involves the application of one or more layers to create adhesion on the support while isolating it and providing a surface for attaching the gilded material. Mordants, whether aqueous or fatty, required a drying period to achieve material hardening upon exposure to oxygen. The longevity of the mordant varied, lasting from 8 days to 4 days or overnight before the gold leaf was applied.

This research presents a novel restoration approach to clean gilded surfaces on wood. By employing Optical Coherence Tomography (OCT), it becomes possible to differentiate between various layers within the gilding mixture stratum. This innovative technique offers a solution previously unattainable through traditional clearing methods. With the aid of this protocol, one can thoroughly investigate and control the effects of the laser beam on both the gold leaf and the organic layers comprising the gilded surface on wood. This protocol serves the purpose of optimizing cleaning processes without entirely removing the layer, thereby preserving any concealed evidence of repaints that may elude the naked eye.

2 MATERIALS AND METHODS

2.1 *Observations of the gilding surface*

In a previous study, the stratigraphy of this furniture was investigated and shown in Figure 1. The entire golden surface consists of a gilding mixtion. The film forming is organic, opaque, orange, and topped with a gold leaf. The study of the miniature frames, the carved and gilded wooden ornaments, and the turned and gilded ivory ornaments reveals the presence of important gaps on the gilded surface.

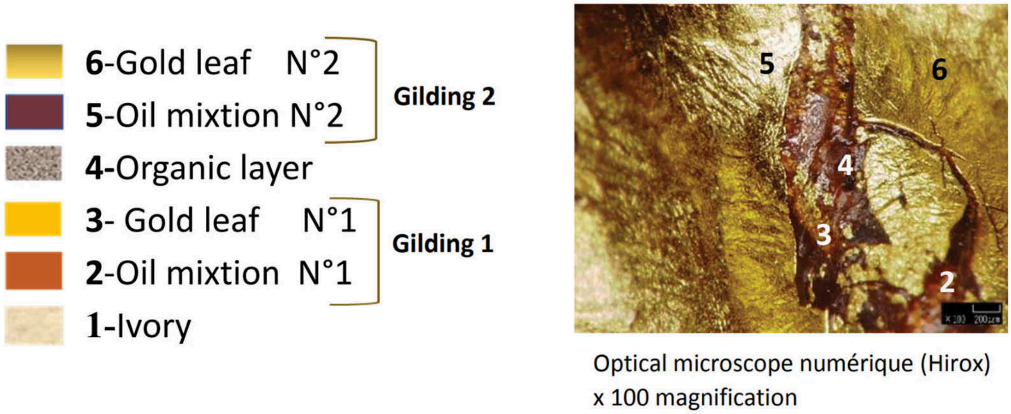


Figure 1. Stratigraphy and observations of the gilding surface.

Mechanical wear of the gold leaf, loss of cohesion of the mix on the gilding in tempera and oil, gaps in the preparatory layers and structural damage. These alterations are linked in this case to the superposition of different materials treated with different techniques. The study of the twisted columns in gilded ivory indicates the presence of a single gilding mix on the relief of the flutes and of two gilding mixes superimposed in the hollows of the twists. Thus, under the modern mixtion, which we will call “mixtion N°2,” we can distinguish a mixtion that we call “mixtion N°1.”

The mixtion gilding in the hollows of the twisted columns is made up of a gold leaf, worn in places but in a very good state of conservation. The adhesive is of the same nature, so chemical removal is impossible, and mechanical removal is dangerous, given the thinness of the layers, if the original gilding is to be preserved. It should be noted that the original decoration is made with mixed gilding techniques. It can be seen that the tempera gilded surfaces are covered with the same gilding in mixtion N°2, which indicates that this intervention is not original.

2.2 *Discussions and propositions for the conservation and the restoration*

The original gilded surfaces are treated with different techniques that give the decorations an abundance of play of material, relief, brilliance, and color that give a preciousness to the art object. It should be noted that during the dismantling and disassembly of the three columns that had been reassembled inverted during a later intervention, we were able to observe the reverse side of them and note that no intervention was visible. The gilder had redecorated the surface without dismantling the columns, so the gilding with the mixtion, which was only located in the concave zones of the columns, was the original decoration, shown in Figure 2. This testimony allowed us to observe that the gold leaf N°1 was worn but was in a satisfactory condition for a museum presentation. In order to reconstitute the hidden decoration of the twisted columns, prototypes were made. This consisted of making prints with the "Gros blanc marqué" (Large White, definition) covered with gold leaf and painted. This reconstitution accompanied and validated a proposal for intervention which consisted of removing the mixtion and gold leaf N°2 on the reliefs of the ivory column. Initially, comparisons of removal techniques were necessary.

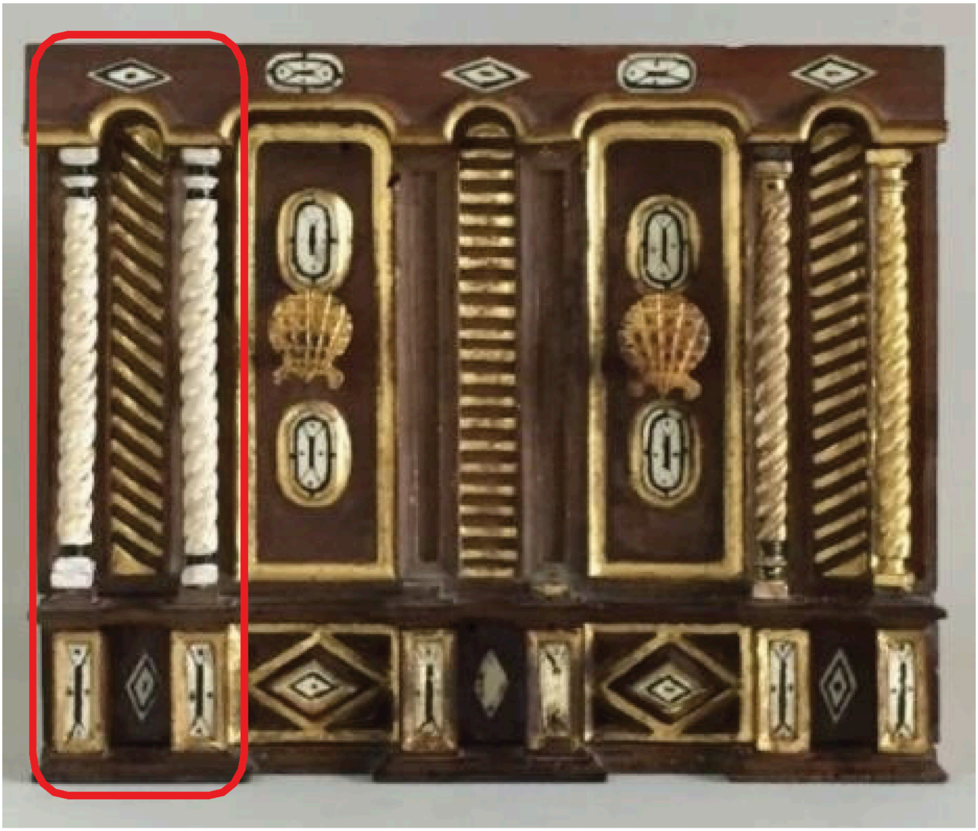


Figure 2. Drawer N°13, reconstruction of the original decoration on the ivory columns.

2.3 *Instrumentation and examination of cleaning protocol*

A pulsed microsecond Er: YAG laser (El.En.'s LightBrush2 500 mJ) of a wavelength at 2.94 μm was used. This laser can be operated with three pulse durations in the range of a hundred of microseconds. The output laser pulse energy can be tuned between 50 and 500 mJ. It is equipped a handpiece allowing the operator to change the distance between the output and the surface in order to control the ablated zones.

Figure 3. Conservator used the laser on the gilding surface, photographic images of the Laser ER:YAG and Optical Coherence Tomographic (OCT).

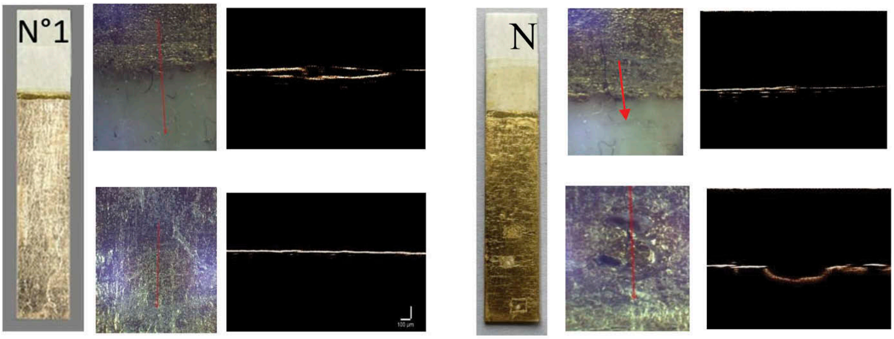
For getting the control, the optical coherence tomography (OCT) imaging was used to obtain a referential and examined the cleaning results. Presented in Figure 3. A commercial SD-OCT (Thorlabs GAN220-OCT Base Unit with a Thorlabs OCTP900M Scanner) equipped with a super luminescent diode ($\lambda c = 912$ nm, $\Delta\lambda = 803.8$ nm - 1021.5 nm). This system allows the measurement at high frequency (36 kHz) with an axial resolution of 3 µm in air and 2 µm in a transparent material such as varnish (n = 1.5) in a non-invasive way. By acquiring a line (side-by-side measurement points or A-scan), one can visualize a slice of the sample (called B-scan) and measure the thickness of the different layers of the stratigraphy. By acquiring side-by-side B-scans, one can obtain a volume representation in which the operator can choose any 2D plane in any direction and also study surface topography with a lateral resolution of 6.5 µm in Y and 3.3 µm in X.

2.4 *Samples*

Firstly, the specimens were made with the same stratigraphy and representative of the problem encountered on the Bargueño golden ivories, presented in figure N°4. The ageing of these surfaces was carried out in two stages, the first ageing was carried out on mix N°1 and the second, made up of the same parameters, on the two superimposed mixes. These samples deposited in the ageing chamber made it possible to obtain ductibility and reticulation of the N°1 mix. In order that the Er: YAG laser tests could be carried out on surfaces close to the gold surfaces of the object. In a second step, with the observation under optical coherence tomography (OCT), we were able to measure the thickness of each layer in order to establish a reference. The gold leaf N°1, the mixtion N°1, the interface, the gold leaf N°2 and the mixtion N°2 were characterized, as well as the two gildings and their stratigraphy. This is shown in Figure 4. In this case, it is important to note that these observations were possible thanks to the openings in the thickness of the material, present in the stratum allowing the penetration. These openings in the material correspond to gaps, cracks, crazing, oxidation and other types of alterations. The Stratigraphy of the mockup N°2 presented in Figure 5.

2.5 *Comparison of cleaning techniques*

Upon conducting a secondary evaluation, it became imperative to juxtapose the outcomes of material clearance tests employing both a scalpel and a laser. The results, as depicted in Figure 6 and scrutinized via Optical Coherence Tomography (OCT), unearthed distinctive disparities.



Control with OCT before the irradiation *Control by OCT, next to send a pulse instead the*

Figure 4. Control with the OCT, for compare the removal layers with ER:YAG.

Figure 5. Stratigraphy of two gildings mixtion for the ivory of the mockup.

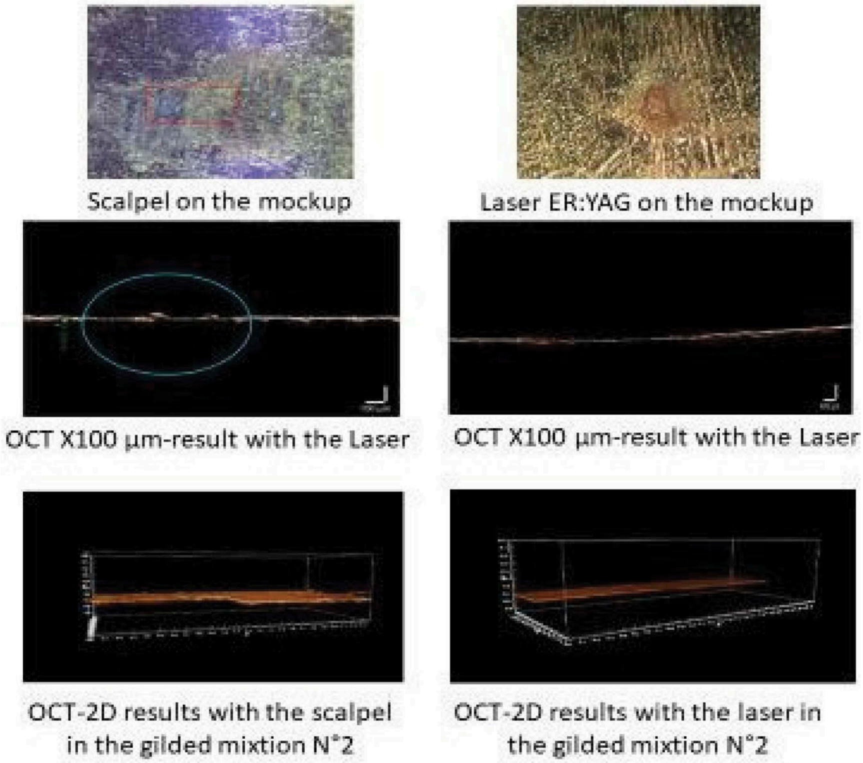


Figure 6. Observation of removal with the Laser Er: YAG and the scalpel by OCT.

In the case of scalpel utilization, we observed material fragmentation, irregularity in the removal process, and discernible tool marks. Conversely, laser-based clearance trials revealed circular releases measuring 2 millimeters in diameter, corresponding to the beam's shape, at a depth of 0.013 μm. The laser's pulsatile action ensured residue-free outcomes, with uniformity throughout the layer's thickness. Noteworthy is the temporal factor; the scalpel procedure demanded significantly more time and imposed greater restrictions compared to Er:YAG laser treatment. To illustrate, one centimeter of clearance with a scalpel, conducted under binocular scrutiny, necessitated 1 minute and 40 seconds, while the laser achieved the same in a mere 7 seconds, with the added advantage of not requiring return visits. Consequently, the laser technique was deemed compelling and selected for the release of Mixture No. 2.

The selection of parameters for laser testing was meticulous, involving three trials on a mockup utilizing the Er:YAG laser. These trials, detailed in Figure 6, were integral to our assessment of removal methods.

2.6 *Laser cleaning applied to the Mockup*

The Er:YAG laser, featuring a fixed beam diameter of approximately 50 mm and a pulsating mechanism at each focal point, each lasting 2 seconds, was subjected to close scrutiny. Monitoring at each pulse was accomplished through Optical Coherence Tomography (OCT) to ensure precision in beam impact. Xenon Power supply XPS-100 Xenon Lamp and a Nikon DS-RI1 camera, supplemented by NISS-Element Software, facilitated this meticulous oversight. Further examination was carried out using a Nikon Eclipse LV 100 ND optical microscope.

In the first trial, we employed "Short mode," characterized by a pulse duration of 150 μs, a 5Hz frequency, and 100 mJ energy, with fluence set at 3 to 5 J/cm², all maintained at a constant distance of about 5 centimeters. Results are eloquently depicted in Figure 7.

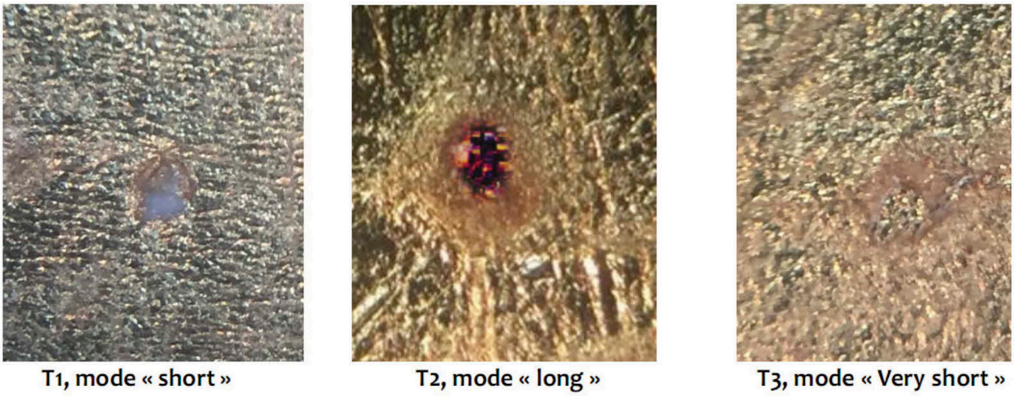


Figure 7. Er:YAG results with different modes.

Subsequently, a series of distinct tests were conducted to evaluate the removal of gilding No. 2. Test 2 employed "Long mode," mirroring the parameters of Test 1, while Test 3, denoted as "Very short" mode, maintained the same pulse duration, frequency, energy, fluence, and distance conditions. These experiments illuminated variations in the removal process, particularly in the case of dark surfaces where calcination of binders became apparent due to heightened absorption.

The most compelling results emanated from Test 3, wherein "Very short" mode engendered an abrasion process blending mechanical and thermal action. Employing a pulse duration of 150 μs, a frequency of 5 Hz, 100 mJ energy, and a fluence of 3 to 5 J/cm² at a consistent distance of approximately 5 centimeters, this approach yielded homogeneous ablation in a single pass, achieving a 90% removal of Mixture No. 2 while preserving a delicate 10% film. This 10% threshold was strategically retained to serve as a visible demarcation, ensuring the safeguarding of gold leaf No. 1.

It’s important to note that the ablation thickness ranged between 0.35 and 0.73 µm, which underscored the meticulous control necessitated by the Optical Coherence Tomography. This protocol, integrating laser and OCT with an optical microscope, enabled precise measurement of ablation thickness.

3 RESULTS

Laser removal on the columns for the restoration procedure creates physical and chemical reactions visible to the naked eye. These changes are observed by the modification of the color, brightness, opacity and of pulsed particles result in visible deposits on clothing and surfaces. The impact of the laser beam is visible to the naked eye, however, thickness control is not possible with the naked eye and optical coherence tomography is the appropriate measuring device, it allows a measurement of the thickness of the ablated layers. The protocol set up to compare and measure the ablation thickness of the surface consists in coupling the laser with the OCT and the optical microscope. Presented in the Figure 8. The release tests of gilding N°2 have shown that different levels of ablation can be achieved.

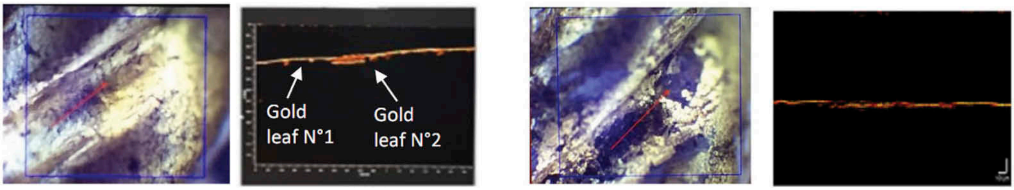


Figure 8. After pulsing with the laser Er: YAG, we observed under the OCT two gold leafs.

The observation under OCT, also allowed us to note that it is possible to ablate the layer on different levels, without changing the parameters of the Er: YAG, the factors: distance and time of pulsation are elements to be taken into account. Figure 10. During the first ablation, level only the gold foil is pulsed.

The second ablation level allows the gold foil to be pulsed and 20% of the mix n°2.

The third level allows the ablation of the gold foil and 90% of the mixtion n°2. The choice turns to a level 3 release, the veil of 10% of mixtion allows to obtain a threshold visible to the naked eye and protects the gold leaf n°1 (Castillejo et al. 2002, Ciofini et al. 2016, Castillejo, et al. 2003).

It is possible to obtain three different results A: we pulsing the gold foil only, or we pulsing the gold leaf. B: The gold leaf and 40% of the mixtion No. 2. C: we pulsing the gold leaf and 90% of the mixtion and the gold leaf No. 2. and without altering the underlying layers, the different layer thicknesses vary between 0.1 and 0.7 µm, visible in the Figure 9.

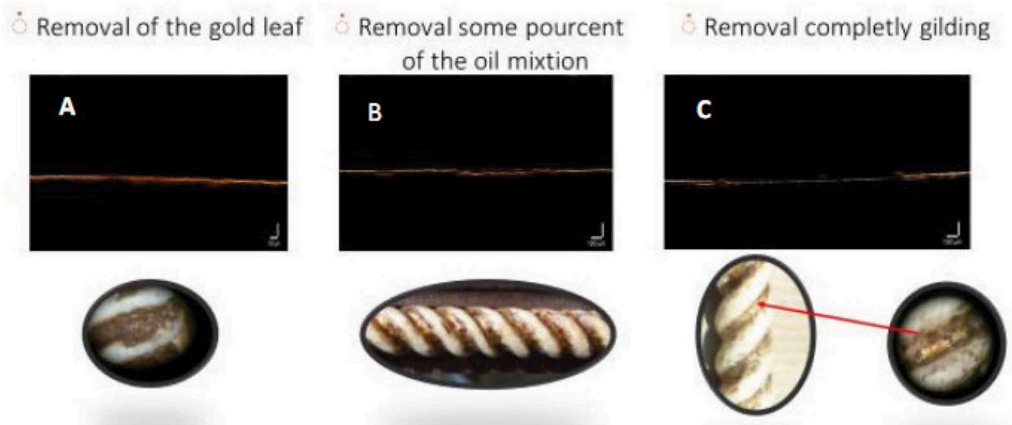


Figure 9. By the OCT, results of the different levels in the mixtion N°2.

The application of laser removal in the restoration process of columns brought about visible physical and chemical transformations, discernible to the naked eye. These transformations manifested through alterations in color, luminosity, and material structure.

He intervention yielded a nuanced revelation of the original decoration, unveiling stylistic references and showcasing the gilder's artistry on the gilded surfaces of the Bargueño. The condition of the gilded and painted surfaces post-removal of paint was deemed satisfactory, with selective retouching performed using gum Arabic, mica, or watercolors.

The juxtaposition of results before and after clearance is illustrated in Figure 10.

Figure 10. Results of the restoration of the gilding surfaces.

Er:YAG laser ablation yielded satisfactory outcomes, albeit with conspicuous alterations discernible through visual inspection. These changes were evident in terms of color modification and surface brightness.

The clearance procedure, while promising, revealed specific challenges yet to be addressed within traditional clearance methodologies. Future investigations should encompass the application of Er:YAG laser ablation to coatings, oily repaints, metallic repaints, and oxidized materials. Additionally, research aimed at controlling material destructuring should be pursued vigorously. The inclusion of solvents to enhance material interaction stands as a promising avenue for further refinement of clearance protocols for gilded surfaces.

The potential for collaboration between laser technology and Optical Coherence Tomography, as showcased in this study, underscores the need for systematic thickness control for precision. This alliance empowers the comprehensive measurement of ablated layer thicknesses, thereby advancing the field of art restoration.

4 DISCUSSION

The research presented in this document delves extensively into the application of Er:YAG laser technology for the intricate and challenging task of restoring cultural artifacts, with a particular focus on gilded surfaces. The comprehensive study has unearthed numerous noteworthy findings that shed light on the potential of this laser technology in the realm of art restoration.

To begin with, the laser clearance tests conducted as part of this research have vividly demonstrated the remarkable precision and efficacy of the Er:YAG laser when it comes to removing gilding and paint layers from delicate surfaces. What stands out prominently is the laser's focused 2-millimeter diameter beam, which exhibited minimal impact on the underlying substrates, showcasing its suitability for preserving the integrity of the original artifact.

The study embarked on an in-depth exploration of three distinct laser operation modes, each characterized by variations in pulse duration and energy levels. Among these modes, the "Very Short" mode emerged as the most effective, with its specific settings of a 150 μs pulse duration, 5Hz frequency, and 100 mJ energy. This particular mode proved to be adept at achieving homogeneous removal of gilding while minimizing any harm to the substrate. Notably, Optical Coherence Tomography (OCT) played a pivotal role in monitoring the laser's influence on the material, providing precise measurements of ablation thickness and enabling the differentiation of various ablation levels.

Furthermore, the "Very Short" mode exhibited a unique ability to preserve the gold leaf, retaining a remarkable 10% of the original gilding. This preservation was achieved while creating a visible threshold discernible to the naked eye, showcasing an unprecedented level of precision that traditional restoration methods struggle to match. Importantly, the utilization of laser-based removal led to material destructuration, characterized by physical and mechanical alterations, including the development of micro-fractures.

These micro-fractures, as it turns out, played a pivotal role in facilitating solvent penetration and the subsequent removal of residues, underscoring the multifaceted advantages of laser technology in art restoration. Further analysis through Scanning Electron Microscope (SEM) uncovered the presence of different fillers in the gold mixtures, highlighting the importance of considering the ductility and texture of layers when implementing laser technology in restoration efforts.

In summary, this research not only showcases the immense potential of Er:YAG laser technology in the restoration of cultural artifacts, especially those with gilded surfaces but also provides valuable insights into the nuanced techniques and considerations required for achieving optimal results in this delicate and important field.

5 CONCLUSIONS

This work emphasizes the Er:YAG laser's indispensable role in augmenting the array of tools at the disposal of conservators and restorers. Its unrivaled precision, impeccable cleanliness, and minimal utilization of chemical agents firmly establish it as a complementary asset to conventional restoration techniques. Furthermore, this research ardently promotes the comprehensive comprehension of an artifact's material history through non-invasive methods before embarking on the restoration journey. This knowledge should not only steer material research but also, when deemed necessary, guide invasive analyses. Although laser clearance techniques have undeniably excelled on gilded surfaces, this study hints at untapped research avenues, especially in the realm of other materials such as coatings, oily repaints, metallic repaints, and oxidized materials. Furthermore, it encourages the exploration of approaches aimed at managing material destructuration and optimizing interactions through solvent-based release protocols. In conclusion, this study vividly illustrates the enormous potential of modern laser technology in the field of art restoration while underscoring the significance of melding these innovative methodologies with established traditions to achieve the utmost precision and preservation in the restoration of our invaluable cultural heritage.

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