

## COMPARATIVE STUDY OF AQUEOUS CLEANING SYSTEMS FOR WAX SCULPTURES

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### *Abstract*

The accumulation of particles of dirt on the surface of ceroplastic sculptures is a major cause of deterioration and has negative consequences for the conservation of the collections. To eliminate these deposits of contamination, the specialised literature proposes the use of a range of physical and chemical methods. This article evaluates various aqueous systems, with and without surfactants, that are specifically adapted to this type of object, including an emulsion formulated using a gel thickened with a polyacrylic acid derivative. All of the cleaning systems tested have been chemically analysed by gas chromatography/mass spectrometry (GC-MS) and infrared spectroscopy (FTIR-ATR), in addition to observing the surfaces under optical magnification before and after applying the cleaning substance. The results obtained are presented based on a qualitative analysis of the effectiveness demonstrated by each of the systems tested.

**Keywords:** *Ceroplastics; Sculpture; Scientific collections; Conservation; Cleaning test; Solubility.*

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### **Introduction**

The ceroplastic collection conserved at the Complutense Veterinary Museum is made up of forty-one sculptures which were created during the 19<sup>th</sup> century at the Royal Veterinary School in Madrid. From its beginnings, the School was endowed with a Laboratory for manufacturing wax pieces for the Anatomical Cabinet which began to function in 1805, when the Italian modeller Luigi Francesqui took up his post as ‘head maker’. Francesqui’s skill and virtuosity in this type of art were recognised thanks to the figures he had made, in collaboration with the sculptor Juan Cháez and the dissector Ignacio Lacaba, for the San Carlos Royal College of Surgery. He was succeeded in 1829 by the Vice Professor of Anatomy, Cristóbal Garrigó. After undergoing a period of training under his master, Pedro Pablo Sánchez Osorio, the second maker of anatomical pieces for the above-mentioned Royal College, Garrigó would go on to produce a rich and varied collection of artificial models aimed at improving the teaching of anatomy at the Royal Veterinary School, a production which only ended with his death in 1863 [1].

Over time, and for a variety of reasons, these objects have suffered significant damage which is a reflection of their own material history. Some of the wear occurred as a result of their original functionality, as they were created for teaching purposes and to serve as instruments in

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the classroom. Some deterioration is a consequence of the natural aging processes of the materials of which they are made, which has in turn been exacerbated by inadequate exhibition and storage. The accumulation of particulate matter leads to a grey colouring and, as a result, the clear yellow wax takes on a dark brown tone, which is exacerbated by the thickness and density of these layers (Fig. 1).



**Fig. 1.** Initial state of conservation with accumulation of deposits of dirt on the wax surface of the sculptures: a. Model *Horse heart* (MV633); b. Model *Horse head* (MV670); c. Model *Hindquarters of a horse* (MV679)

Because of this situation, which compromises not only the aesthetic, plastic and perceptive value of the sculpture but also its preservation, it has proven necessary to carry out a cleaning treatment of the surface which is compatible with the nature of the wax support and the coatings of paint. This cleaning process also needed to be gradual and selective in its removal of the dirt. Furthermore, due to the thermoplastic and electrostatic nature of wax, part of the deposited matter is encapsulated in the outer layer of the sculpture paste.

In order to identify the cleaning systems used to date in collections with similar characteristics, a thorough review of the scientific literature was carried out, and this confirmed that numerous materials and methods have been used in recent years to clean this type of objects. The reference articles consulted mention various organic solvents: a saturated hydrocarbon such as Isooctane ( $f_d$  100) [2], alcohols such as Ethanol ( $f_d$  36) and 2-propanol ( $f_d$  38) [2-8], which have even been applied, in some cases, after being diluted in de-ionized or demineralized water [6, 7]. However, certain studies [2, 4, 5, 9-11] question their use in free form due to the fact that a softening effect has been observed on the wax paste as well as the possibility that they cause a leaching of the fatty acids present in its composition (around 12-14% in virgin beeswax).

Furthermore, given the position of water with regard to wax in Teas graph [12], it has been considered as an ideal solvent and therefore numerous authors have been inclined to favour aqueous solutions.

Traditionally, anionic surfactants such as Howards® B30 [3], Vulpex® [9] and Orvus®, have been used [13-15], as have nonionic surfactants, for example Tween®20 [7, 13, 16-18], Lissapol® [9, 14], Symperonic® N [2] and Triton® [2, 7], and cationic surfactants, such as Desogen® [6].

Nevertheless, it is considered that aqueous solutions should be applied in a buffered form. Given that the pKa value of the fatty acids in beeswax is 8, a non-alkaline pH safety range of between 6.00-7.00 is recommended for working, though up to pH = 7.50 is acceptable [11].

The main objective of the research carried out in the framework of this Project has focussed on determining the action of each of the formulations proposed for the cleaning of wax objects in order to establish which materials and methodology are the most effective, once the final result of the treatment and its effects on the morphology of the wax surfaces has been evaluated. To do this, it was necessary to consider the role of each of the components present in

the mixtures and qualitatively assess, by means of the appropriate chemical analyses, the possible presence of residues. This was particularly true in those mixtures that included some kind of surfactant, a problem that has been discussed in the scientific literature [13, 19-21].

### Experimental

Bearing in mind the above-mentioned premises, a set of aqueous solutions was prepared to be used in free form, with or without a surfactant, as well as an aqueous gel with and without an organic solvent additive (Table 1). In both cases, the mixtures were prepared to pH values of between 7.00 and 7.50 and the electrical conductivity (EC) adjusted to 0.40 mS/cm in order to obtain isotonicity with the areas to be treated [19, 22].

**Table 1.** Cleaning systems proposed with their composition

Type of cleaning system	Components
Buffered aqueous systems	BisTris–hydrochloric acid without additives
	BisTris–hydrochloric acid with surfactant Tween® 20
Chelating buffered aqueous systems	Chelating solution of citric acid-sodium hydroxide without additives
	Chelating solution of citric acid-sodium hydroxide with surfactant
Aqueous gels of polyacrylic acid derivatives	Pemulen® TR2 without additives
	Pemulen® TR2 with absolute ethanol

In order to determine these working parameters, it was first necessary to know the characteristics of the objects to be treated; on the one hand, the sensitivity of the surfaces by means of the contact angle [22, 23] (Table 2), and on the other hand, their pH value and EC (Table 3).

**Table 2.** Classification of the degree of wettability of a liquid (relationship between the contact angle and the type of surface)

Contact angle	Degree of wettability Type of surface	Type of surface
$\theta = \approx 0$	perfect	superhydrophilic
$\theta = 0-30^\circ$	medium	hydrophilic
$\theta = 30^\circ- 85 \text{ o } 90^\circ$	High	hydrophilic
$\theta = 85 \text{ o } 90-150^\circ$	Low	lipophilic/hydrophobic
$\theta = 150^\circ - 180^\circ$	Nil	Superlipophilic/superhydrophobic

With regard to the first of these issues, it was confirmed that there was an increase in surface wetting capacity when the sculptures had a film of pine-resin coating (Fig. 2).

In order to obtain the pH and EC measurements, small agarose gel discs were used [21-26], prepared with de-ionized water, using a methylparaben-based preservative as an additive. After removing the looser dust with a soft-haired brush and a micro-vacuum cleaner with adjustable pressure, the discs were placed according to the different fields of colour and coatings, obtaining stable readings after between 3 and 5 minutes of contact (Fig. 3). The data from the readings are attached in Table 3 and confirm average results for pH of between 6.30 and 6.70, and an EC which varies between 0.30 and 0.50 mS/cm (Table 3).

**Table 3.** Values of electrical conductivity and pH taken on the wax surfaces

Model	Piece	Smooth extraction area	EC measurement	pH measurement
<i>Hindquarters of a horse</i>	MV679	Thick deposits of dirt on a wax surface with varnish.	0.66 mS/cm	6.6 pH
		Wax surface without varnish. Yellow wax	0.33 mS/cm	6.6 pH
		Wax surface with varnish. Yellow wax	0.31 mS/cm	6.7 pH
		Wax surface with varnish. Red wax	0.38 mS/cm	6.5 pH
		Wax surface without varnish. Red wax	0.46 mS/cm	6.4 pH



**Fig. 2.** Testing of contact angle of a drop of water deposited on the wax surface of an anatomical model from the collection: a. drop on the film of coating; b. drop placed directly on the wax



**Fig. 3.** Gathering data from the model *Horse head* (MV670): measuring pH and electrical conductivity

***Subject of the study and identification of the materials employed in the sculptures***

In a scientific and artistic collection such as the one selected for this Project, made up of an ensemble of pieces that is highly heterogenous in terms of formats, manufacturing techniques and deterioration processes, it is essential to perform a thorough organoleptic examination and an analytical study. On the basis of the information thus obtained, one of the most representative pieces, known as the *Hindquarters of a horse* (MV679), was selected as it has characteristics that can be considered common to the collection as a whole.

Furthermore, the documentary sources relating to the Royal Veterinary School in Madrid, which are conserved in the Archive of the Complutense University in the same city, were decisive when it came to discovering the materials used in the construction of the artificial

models. This historical dossier contains entries relating to the payments made for the acquisition of virgin beeswax, bleached beeswax, turpentine, rosin and vegetable oil, ingredients which used to be mixed together to modify the initial properties of the wax and thus adapt the paste to the requirements of the sculpting process.

The data obtained from the documentary sources complemented the information from the analytical study carried out on a selection of micro samples extracted from small loose fragments and locations on the sculpture that were less conspicuous. Samples were also from the *Horse heart* (MV663) and *Horse head* (MV670), with all three of them being representative of the technological aspects that characterise the ensemble as a whole.

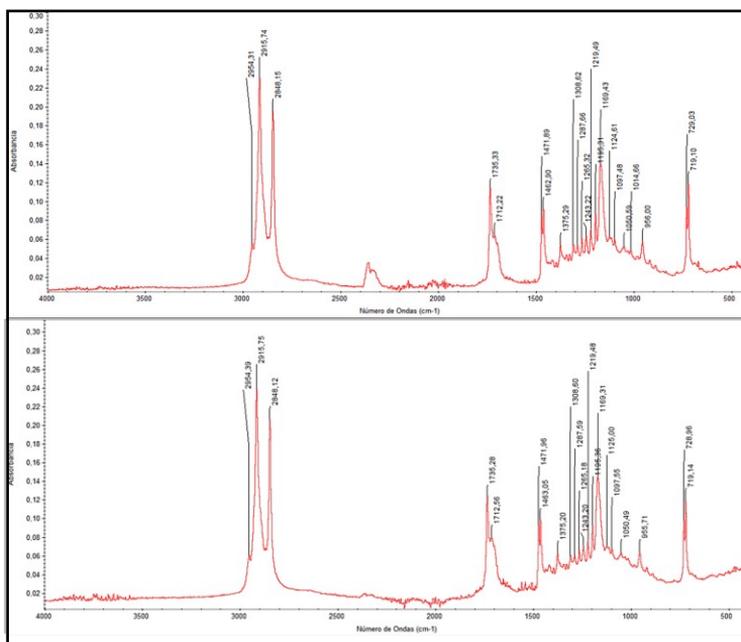
All the extractions are accompanied by a morphological study and a chemical analysis. The characterisation of the inorganic components was carried out using optic microscopy (OM) and sweeping electronic microscopy with energy dispersive X-ray spectroscopy (SEM-EDX), while data regarding the organic components were obtained using Fourier-Transform Infrared Spectroscopy (FTIR-ATR) as well as gas chromatography/mass spectrometry (GC-MS), thereby permitting a more precise identification of the latter and of the minority components. Table 4 shows the samples analysed, the reference allocated by the restoration team for the purposes of identification and a brief description together with additional observations.

**Table 4.** Samples analysed for the characterisation of materials (anatomical models MV679, MV633, MV670)

Sculpture	Model	Ref.	Description of the sample	Characteristics of the sample
<i>Hindquarters of a horse</i>	MV679	MT4	Wax paste with original film of coating	Solid sample
		MC1	Deposits of surface dirt	Sample in hydrophilic cotton with absolute ethanol
		MC2	Original varnish	Sample in hydrophilic cotton with absolute ethanol
<i>Horse heart</i>	MV663	MT8	Red pigmented wax paste	Solid sample
		MT9	Blue pigmented wax paste	Solid sample
<i>Horse head</i>	MV670	MT1	Red pigmented wax paste	Solid sample. Piece detached from the base.
		MT3	Blue pigmented wax paste	Solid sample. Piece detached from the base.
		MT2	Wax paste	Solid sample. Piece detached from the base.

The chromatograms confirm the use of common materials in the construction of the anatomical models under study, although some small differences were observed between them. The component found most frequently is virgin beeswax, to which animal fat, vegetable fats and a pine resin were added in varying proportions (Fig. 4). As regards the film of coating employed by the artists to preserve the surfaces during the use and exhibition of the pieces, the presence of a natural pine resin was also detected, with the exception of the sample taken from the *Heart* (MV663) model, where copal resin was found.

Based on the pH and EC readings from the pieces, and on the result obtained from the analytical characterisation, a range of aqueous solutions were formulated to conduct cleaning tests on the piece *Hindquarters of a horse* (MV679) (Fig. 5), made by Cristóbal Garrigó in 1830. This piece is unusual in that it features two types of texture in the wax (grooved and smooth), which responded differently during the cleaning and rinsing process.



**Fig. 4.** FTIR-ATR spectrum, model *Hindquarters of a horse* (MV679):  
 a. Solid sample of wax paste ML0 (smooth area);  
 b. Solid sample of wax paste ML0A (grooved area)



**Fig. 5.** Formulations prepared for carrying out cleaning tests on model *Hindquarters of a horse* (MV679)

**Selection of the cleaning systems**

As mentioned previously, the use of alcohols and additives such as surfactants in the cleaning processes is not without risk, as these can cause the partial dissolving of the pastes and coatings, or leave permanent residues, respectively.

More recent studies [11, 18] propose the use of buffered aqueous methods using a weak chelating agent and a weak, non-ionic surfactant as additives. Indeed, the choice of a chelating agent proved effective in cleaning surface deposits, above all for pieces which are located in an urban environment as is the case of the ceroplastic collection of the Complutense Veterinary Museum in Madrid.

In our study we propose a comparison between this system and another thickened using a polyacrylic acid gel, with and without the addition of between 10% and 20% Absolute Ethanol. This solvent permits the elimination of fatty dirt which is strongly adhered to the surfaces and, in spite of its high polarity ( $f_d$  36), the wax and the varnish coating were not affected.

A tertiary amine, in this case Bis-tris, was chosen as a buffer substance, as it has a pKa of 6.50 at a temperature of 25°C (which coincides with the average pH of the wax pieces in the collection) and a buffer range of pH = 5.80 - 7.20.

In order to increase the wetting power of the mixture, 2-3% of the surfactant Tween®20 was added to the buffer, which meant we remained within the percentage recommended by the bibliography [7, 17, 28]. Although it is estimated that one drop for every 100ml of buffer is sufficient for cleaning paintings [23], the hydrophobic nature of waxy materials (including contemporary works), means that this amount can be increased up to a total of 5 drops for every 25ml of buffer solution [11].

The choice of a surfactant such as Polyoxyethylene [20] sorbitan monolaurate (Tween®20), instead of others which are also non-ionic, such as polyoxyethylene lauryl ether (Brij®35) [24], is due to the fact that the latter has a greater affinity with the fatty acids present in the wax [23].

As some of the anatomical models in the Veterinary Museum collection also have uneven surfaces and given that wax tends to retain contaminants due to static electricity, the need to use a weak chelating agent was also considered. A Citric Acid buffer with a pH = 7.00 was prepared and tests were carried out with and without the previously mentioned surfactant [23].

As far as the thickening system is concerned, from among the products with rheological characteristics we chose a gel formulated using a derivative of polyacrylic acid, Pemulen™TR2, which has a dual function as thickener and emulsifier, meaning that this formulation could presumably prove more effective than a solution with surfactant [23, 27]. In this respect, we should point out that Triethanolamine, present in the original formulas as a neutralising base for the preparation of the gel, has been replaced in recent years by a basic solution of NaOH 1M [13, 28, 29, 30]. As indicated previously, between 10% and 20% of Absolute Ethanol was added to this gel.

**Methodology of application**

The formulations used in the surface cleaning and the rinsing systems proposed and tested are shown in Table 5. With regard to the working methodology, the Bis-tris buffer was applied by rolling a swab which had been soaked in the mixture for approximately 2 minutes, and the area thus treated was dried using a dry swab.

**Table 5.** List of samples for analysis of possible residues and extraction of components of the wax paste after tests with the cleaning systems and rinsing with the buffer solution (Anatomical model Hindquarters of horse)

	Sample	Cleaning system	Rinsing system
Smooth area	ML0	Reference sample. Area close to the cleaning tests.	-
	ML1	Bis tris-HCl buffer pH 7.00 + surfact Tween®20	Bis tris-HCl buffer pH 6.5
	ML2	Pemulen™TR-2 Gel	Bis tris-HCl buffer pH 6.5
	ML3	Pemulen™TR-2 el + absolute ethanol	Bis tris-HCl buffer pH 6.5
	ML4	Chelating solution: citric acid-NaOH pH 7.00	Bis tris-HCl buffer pH 6.5
	ML5	Chelating solution citric acid pH 7.00 -NaOH + Tween®20	Bis tris-HCl buffer pH 6.5
Grooved area	ML0-A	Reference sample. Area close to the cleaning tests.	Bis tris-HCl buffer pH 6.5
	ML1-A	Bis tris-HCl buffer pH 7.00 + surfactant Tween®20	Bis tris-HCl buffer pH 6.5
	ML2-A	Pemulen™TR-2 gel	Bis tris-HCl buffer pH 6.5
	ML3-A	Pemulen™TR-2 gel + absolute ethanol	Bis tris-HCl buffer pH 6.5
	ML4-A	Chelating solution: citric acid-NaOH pH 7.00	Bis tris-HCl buffer pH 6.5
	ML5-A	Chelating solution pH 7.00 + Tween®20)	Bis tris-HCl buffer pH 6.5

Although the restoration team had opted to use those formulations that were simplest in terms of the number of components, the decision was taken to apply the Pemulen™TR2 gel to

certain grooved surfaces where the cleaning process required successive repetitions, bearing in mind that it could contain Absolute Ethanol as an additive. In order to verify the effect of the cleaning, this procedure was also tested on smooth areas. For all surfaces, the gel was stirred for 2-3 minutes with a brush after it was applied. The product was then immediately removed with a dry swab and the surface was rinsed (Fig. 6).

In the same way, in those cases where it was necessary to add a surfactant to the buffer (between 2% and 3% Tween®20 v/v) in order to remove the layer of dirt, or use a citric acid buffer with a chelating action, or both at the same time, the final rinse was carried out after 72 hours [31], using the Bis-tris buffer with a pH equal to that of the piece being cleaned (6.50) and an EC of 0.40 mS/cm.

At the same time, a control was carried out on the solvent action of the mixtures on the varnish being treated, using a digital microscope equipped with two types of LED light sources and the option of switching between white and ultraviolet light.

**Analytical characterisation**

In addition to the preliminary analytical study to identify the constituent materials and coatings, after the cleaning treatment was applied the surfaces were analysed to find out if any of the components of the wax pastes and the varnish had been extracted during this process, as well as to detect possible non-volatile residues (Fig.7).



Fig. 6. a. Application of Pemulen® TR2 gel with a brush; b. Process of removing contaminant particles and removal of the gel; c. Final rinse of treated surface



Fig.7. Map showing the location of the various samples taken from the areas tested after cleaning with the aqueous solutions and Pemulen® TR2 gel for the purposes of physical and chemical characterisation

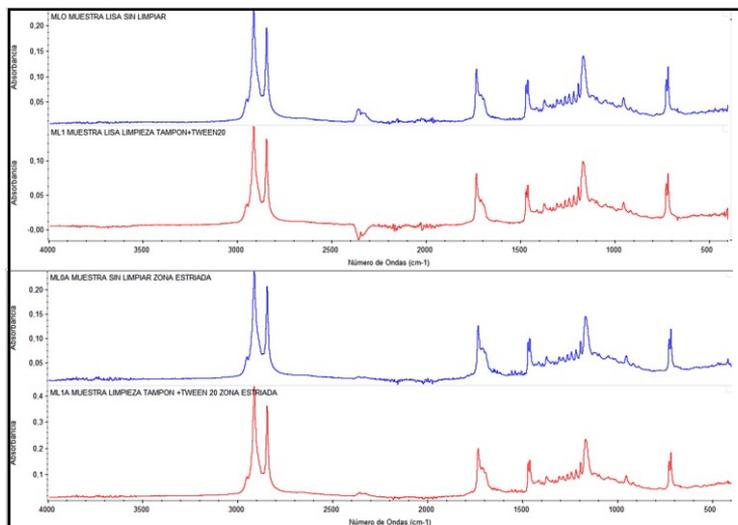
**Results and discussion**

*Testing on the smooth area of the anatomical model*

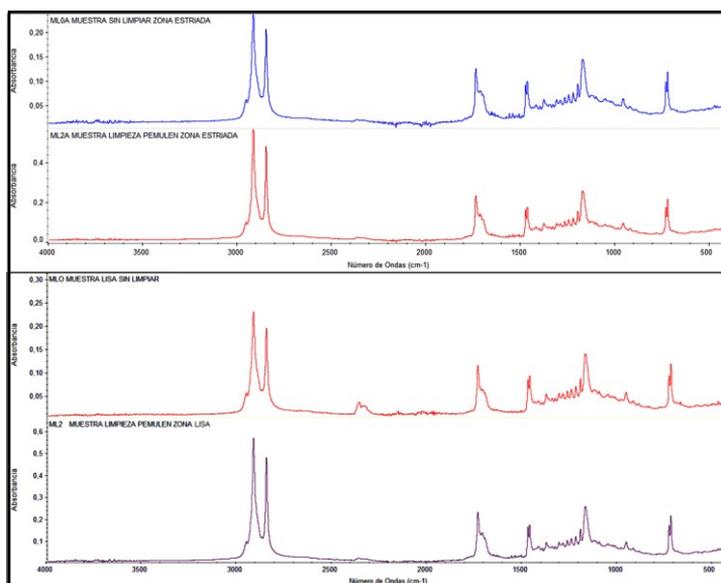
The analyses carried out by FTIR-ATR permitted a comparison of the spectrum corresponding to the wax sample from the smooth area (ref. MLO, the references to the initials used to classify the cleaning systems and the samples extracted are shown in Table 5) of the anatomical model before cleaning and the spectrum resulting from the analysis of each of the samples taken after the various formulations had been applied. In all the tests, the spectrums

obtained before and after testing coincide completely, with no bands observed that could be attributed to the products used. We can therefore conclude that none of them left traces which can be detected using this analytical technique.

Indeed, in the case of the extraction which coincided with the area where the Bis-tris with surfactant Tween<sup>®</sup>20 (ref. ML1) was applied, the most significant bands of this product were not detected (*ca.* 3329, 1071 and 605cm<sup>-1</sup>) (Fig. 8a).



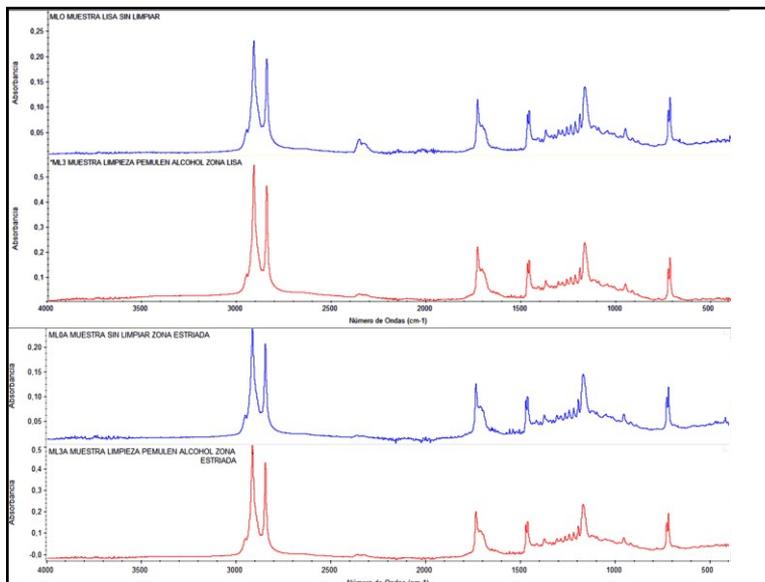
**Fig.8.** a. FTIR-ATR spectrum of sample ML0 (smooth area) prior to cleaning in order to compare it with sample ML1 after cleaning with surfactant Tween<sup>®</sup> 20 dissolved in BisTris-HCl buffer;  
b. FTIR-ATR spectrum of sample ML0A (grooved area) a prior to cleaning it with sample ML1A after cleaning with the above-mentioned aqueous solution



**Fig. 9.** a. FTIR-ATR spectrum of sample ML0 (smooth area) compared with sample ML2 after cleaning with Pemulen<sup>®</sup> TR2 (MB2) gel;  
b. FTIR-ATR spectrum sample of ML0A (grooved area) compared with sample ML2A after cleaning the area with the above-mentioned gel, sample MB2

The same occurred with Pemulen™TR2 gel (ref. ML2), given that no significant bands were observed in the FTIR-ATR spectrum that could be attributed to this product (ca. 3339, 1551, 1034 and 446cm<sup>-1</sup>) (Fig. 9a).

These results were repeated in the test carried out with the gel mixture of Pemulen™TR2 and Absolute Ethanol (ref. ML3), because when we compared the spectrums of the wax paste before and after cleaning, we observed that they were similar and therefore no significant bands of the formulation were detected (ca. 3339, 1550, 1400, 1036 and 495cm<sup>-1</sup>) (Fig. 10a).



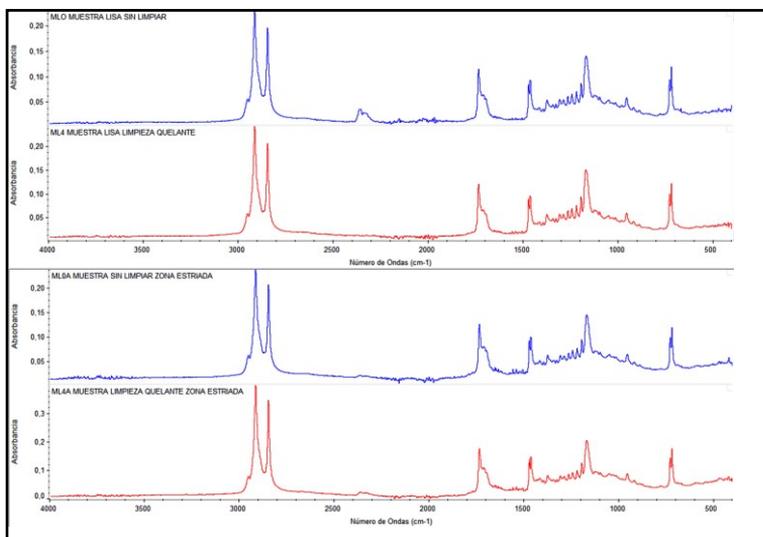
**Fig. 10.** a. FTIR-ATR spectrum of sample ML0 (smooth area) compared with sample ML3 after cleaning with Pemulen® TR2 gel + Ethanol, sample MB3;  
 b. FTIR-ATR spectrum of sample ML0A (grooved area) compared with sample ML3A after cleaning with Pemulen® TR2 gel + Ethanol

However, in both cases, the results of the GC-MS analysis (ref. MLO and ML2) and even of the dried extract of the gel indicate that the gel may have extracted components from the wax, since fatty acid esters that are characteristic of the wax were detected (Table 6).

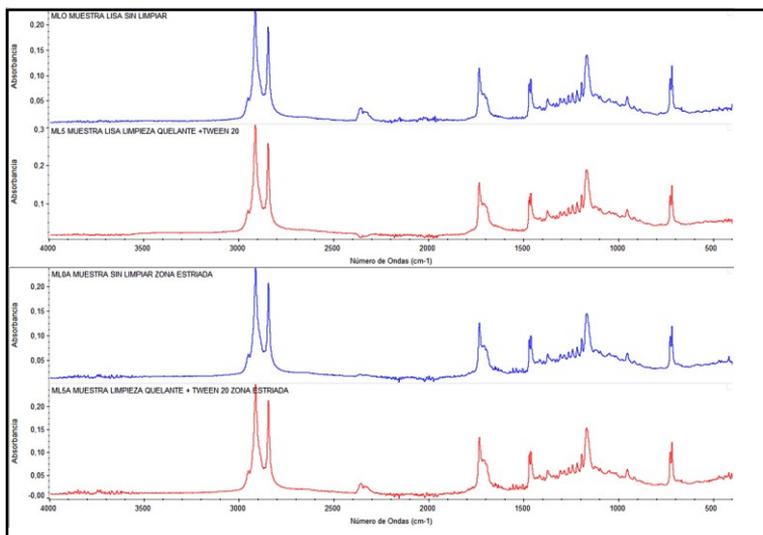
**Table 6.** Extracts with Pemulen®TR2 gel, sample MB2

Peak number	T <sub>R</sub> (min)	m/z	Compound / Carbon atoms number
1	4.97	63, 77, 85, 127, 170, 200	Aromatic derivative. It has two aromatics rings. It may be Ph-O-PH-O-CH3
2	5.14	35	Benzoic acid derivative
3	5.79	163	Dimethyl ester dibenzenecarboxylic acid
4	6.41	178	Aromatic derivative
5	10.84	74, 87, 143	Methyl palmitate (16:0)
6	12.92	67, 81, 95	Methyl ester insaturated acid (20:2)
7	13.03	67, 69, 74, 83, 97	Methyl oleate (18:1)
8	14.45	165	Unidentified compound
9	15.79	239	Frentranocarboxylic acid (dehydroabietic acid derivative)
10	16.68	119, 135, 175, 368	Aromatic derivative
11	16.76	163, 178	Aromatic derivative
12	18.50	91, 119, 135, 191, 309, 398	Unidentified compound
13	20.22	60, 141, 256	Unidentified compound
14	20.49	74, 87, 143	Tetracosanoic acid methyl ester (24:0)

The tests carried out with the Citric Acid chelating solution (ref. ML4) once again confirm that there are no residues in the area treated, as the most significant bands of this cleaning product were not detected, at 3500, 3150, 1550, 1394, 1077, 750, 650, 500 $\text{cm}^{-1}$  (Fig. 11a). These results coincide once again with those of the mixture composed of chelating solution with surfactant (ref. ML5), where the IR spectrums of the wax samples are similar before and after testing as the most significant bands of the components of the mixture are not detected at 3361, 1651, 1591, 1563, 1076, 1034, 945 and 516 $\text{cm}^{-1}$  (Fig. 12a).



**Fig. 11.** a. FTIR-ATR spectrum of sample ML0 (smooth area) compared with the same area ML4 after cleaning with the citric acid chelating solution-NaOH;  
 b. FTIR-ATR spectrum of sample ML0A (grooved area) compared with the same area ML4A after cleaning with the above-mentioned solution



**Fig. 12.** a. FTIR-ATR spectrum of sample ML0 (smooth area) compared with the sample ML5 after the application of the chelating solution + surfactant solution Tween® 20 + rinse with BisTris-HCl;  
 b. FTIR-ATR spectrum of sample ML0A (grooved area) compared with sample ML5A after application of the above-mentioned formulation

### ***Testing on the grooved surface of the anatomical model***

A similar method was used on the grooved areas of the wax, such as the one described above, and the analyses once again confirm the absence of any residues.

The FTIR-ATR spectrums of the sample of wax paste (ref. ML0A) and the sample taken from the same area (ref. ML1A) after cleaning with the Bis-tris buffer with surfactant Tween<sup>®</sup>20 (ref. MB1) coincide completely (Fig. 8b). A comparison of the spectrums of sample ML1A and of the dry extract of the mixture used in the testing (ref. MB1) confirms that the spectrum of sample ML1A does not show the more characteristic absorption bands of these products (*ca.* 3329, 1071 and 605cm<sup>-1</sup>).

The FTIR-ATR spectrums of the sample of wax paste (ref. ML0A) coincide with those of the sample taken from the same area (ref. ML2A) after the cleaning process using Pemulen<sup>™</sup>TR2 gel (ref. MB2) (Fig. 9b). The comparative study of the spectrum after testing and the spectrum corresponding to the dry extract of the cleaning mixture employed (ref. MB2) confirms the absence of gel residues as the more characteristic bands of the gel are not detected (*ca.* 3339, 1551, 1034 and 446cm<sup>-1</sup>).

Likewise, the data obtained after the cleaning tests carried out with mixture MB2 (Pemulen<sup>™</sup>TR2 gel + Absolute Ethanol) were similar to those already described (Fig. 10b).

These results are confirmed once again in the mixture composed of Citric Acid chelating buffer solution, with and without surfactant (Figs. 11b and 12b), as the absorption bands of the spectrum do not reveal components associated with the mixtures (*ca.* 3339, 1551, 1034 and 446cm<sup>-1</sup> and *ca.* 3361, 1651, 1591, 1563, 1076, 1034, 945 and 516cm<sup>-1</sup>, respectively).

## **Conclusions**

Due to the risks associated with the use of free organic solvents used traditionally in the cleaning of wax objects, such as Absolute Ethanol or 2-propanol, with their high polarity values ( $f_d$  38 and  $f_d$  36), and of hydrocarbons such as Isooctane ( $f_d$  100), which can affect natural resin varnishes and even cause a partial dissolving of the wax, aqueous systems provide an effective alternative, as they permit a gradual and selective cleaning process that is free of risks associated with the presence of residues after the rinsing phase.

The use of a chelating agent was considered because of its effectiveness in cleaning dirt, particularly in works conserved in an urban environment, as is the case of the ceroplastics collection of the Complutense Veterinary Museum, the subject of this study.

Given the extremely hydrophobic nature of wax it was also considered expedient to include a surfactant in the mixtures (particularly in the case of the chelating buffer solution) solely for treating the areas where the deposits are more strongly adhered. The use of this additive was avoided as far as possible, especially in the grooved areas of the wax surfaces which made rinsing more difficult; the occasional use of thickening agents was considered an advantage.

In order to verify the possible adverse effects associated with the use of the solutions tested, it was necessary to perform a laboratory study to detect possible residues and confirm that no components of the wax and the varnish had been extracted during the tests.

Based on these premises, this Project has confirmed the effectiveness of aqueous cleaning systems for removing particulate matter adhered to the wax without affecting, in any of the cases, the natural varnish resin which must be preserved intact.

With regard to the residues, it is interesting to observe that the aqueous rinsing with buffer solution eliminated any potential residue. The analyses obtained with GC-MS only indicated the possible extraction of the fatty acid esters characteristic of beeswax in the case of the formulations which used Pemulen<sup>™</sup>TR2. For this reason, it was decided to restrict the use thereof to those areas which present a particularly thick and compact layer of dirt, and always in combination with the other alternatives proposed.

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