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Virtual 3D registration of anatomic wax sculptures

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SUMMARY

This study presents the symbiosis between science and art through the analysis of anatomy and the wax-modelling technique. For this purpose, an eighteenth-century anatomical wax model showing the gestation process was selected. This model belongs to the collection of the Javier Puerta Museum of Anatomy (Complutense University of Madrid, Spain). The work has attempted to analyze, interpret and disseminate the process of producing the anatomical wax model using the latest 3D registration technologies. The methodology was established in two phases: a first phase of data collection using a GO! SCAN50 laser scanner from CREAFORM and VXelements software, and a second phase of post-processing of the collected data. The result was a very high resolution 3D virtual model that allowed the analysis and interpretation without the need to manipulate the original. The animated 3D model is viewable at 360º via interactive virtual platforms and under multiple angles and textures. This has made it possible to locate signs and proofs about the process of making the anatomical model, confirming the hypothesis that it seems to have been carried out by the artists during the elaboration of the piece. In short, 3D recording has proved to be a non-destructive and very graphical analysis method, allowing data collection, real-time monitoring and visualization without any manipulations.

Key words: 3D registration – Javier Puerta Anatomy Museum – Anatomical wax sculptures – Interactive models

INTRODUCTION

During the 18th century, anatomical wax models became a tool of great interest to doctors, surgeons and scholars of the human body for the sake of knowledge, understanding and learning of medicine and, more specifically, therapeutic procedures (Lemire, 1993; Micó, 2015). The anatomical treatises of William Smellie, William Hunter or Jan Van Rymsdyk were the point of connection with the new imperishable reality more in line with the investigation of this period. Their work of the waxy material was a breakthrough for the anatomical studies, mainly because it allowed to solve, to a great extent, the deficiencies related to the rapid deterioration of the bodies, the bad smell or the fear of infections.

It also brought a new dimension to the existing anatomical treaties which, despite their precision, were limited to two dimensions. Thus, the appearance of the three-dimensional models in wax made it possible to illustrate the outcome of several dissections or reproduce very complex structures, which on paper were difficult to represent, in order to have a clear perception of the real scale and have valuable didactic tools (Lotti et al., 2006; Dietrich, 2010). The splendid collection of anatomical pieces from the Speccola Museum in Florence is a clear example of what the rise of this type of creations meant (Märker, 2006).

Wax quickly became the favorite sculptural material of medical artists, because it could be easily modelled and coloured in a variety of shades, which increased the similarity of the work with the

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original object, until it almost came to represent a double. The degree of similarity (colour, texture, refraction and translucency) was such that theatrical models began to be made, as if the ephemeral body was fixed in time, that they allowed to understand and acquire knowledge in a very fast and intuitive way, which significantly reduced the border between art and science. With this, the wax sculptor was able to create the illusion of a body full of life instead of "a corpse with holes, stinking and amputated" (Panzanelli, 2008; Sánchez and Micó, 2014; Micó, 2015). The Treatise by Dr. Ignacio Lacaba highlights the meticulous use of materials and the development of the wax modelling technique or "The art of working anatomical pieces in wax" (Bonells and Lacaba, 1800).

Nowadays, the handmade technique of the anatomical wax modelling has disappeared. Wax continues to be used in artistic works and forensic anatomy studies (Chen et al., 1999; Maerker, 2005); however, the true work of coloured wax, such as those developed by the sculptor Gaetano Giulio Zumbo or Juan Chaez, and many other colleagues, has not been recovered again (Riva et al., 2010). They were true architects in the treatment of materials, modelling techniques and reproduction. Undoubtedly, they were lovers and virtuosos of their profession, which was considered artisan's work rather than merely artistic.

Over the years, there are still collections and pieces in wax of great importance that have to be protected. The field of Cultural Heritage Conservation is dedicated to maintaining and treating a large number of works in wax, in many cases lacking documentation. In this sense, the researchers try to solve the problems that derive from this type of works from the historical, artistic, technical and scientific point of view. In the field of conservation and restoration, prior to any direct contact with the work, it is essential to know the material, the technique and its state of conservation. Recently, with the incorporation of new digital technologies, the documentation and diagnostic processes provide real details of the elaboration process of the works. Therefore, the application of 3D registration in the study of works of art is an innovative technique that is undergoing an exponential development, since it is a non-destructive and very graphic method, as well as allowing real-time monitoring and topographic study without manipulation. From data acquisition and optimization, the 3D digital model is obtained, which constitutes a reliable copy in high resolution with respect to the original and contributes significantly to digital documentation, analysis, cartography, preservation and its dissemination (Pieraccini et al., 2001; Koller et al., 2009; Li et al., 2010; Nuñez et al., 2012; Gomes et al., 2014).

In short, this work once again presents the symbiosis between science and art, retakes the analysis of anatomy to understand the wax modelling technique. This study, in addition to documenting in order to preserve and archive a sculpture through a 3D model, attempts to analyze, interpret, dissect and disseminate the process of creating the piece in wax with respect to the real anatomical model by means of the new 3D registration technologies.

CASE REPORT

An anatomical wax model from the 18th century, attributed to Juan Chaez and Italian Luigi Franceschi under the direction of Dr. Ignacio Lacaba y Vila (Fig. 1), has been selected for the case study. This work, which documents the gestation process, along with others of similar manufacture, belongs to the collections of the Javier Puerta Museum of Anatomy, at the Complutense University of Madrid. This museum emerges within the Royal College of Surgery of San Carlos, created by Real Cédula in 1787 by Carlos III, with the help of its director Antonio de Gimbernat y Arbós (1734-1816).

This model represents the lower section of a human trunk. This develops four skins and abdominal muscles flaps, showing a gravid uterus where the right peritoneum has been removed to demonstrate the organ vascularization. Intestinal loops are displaced due to the increased uterus size. The left upper region of the uterus is covered by the greater omentum. As it can be seen, the work

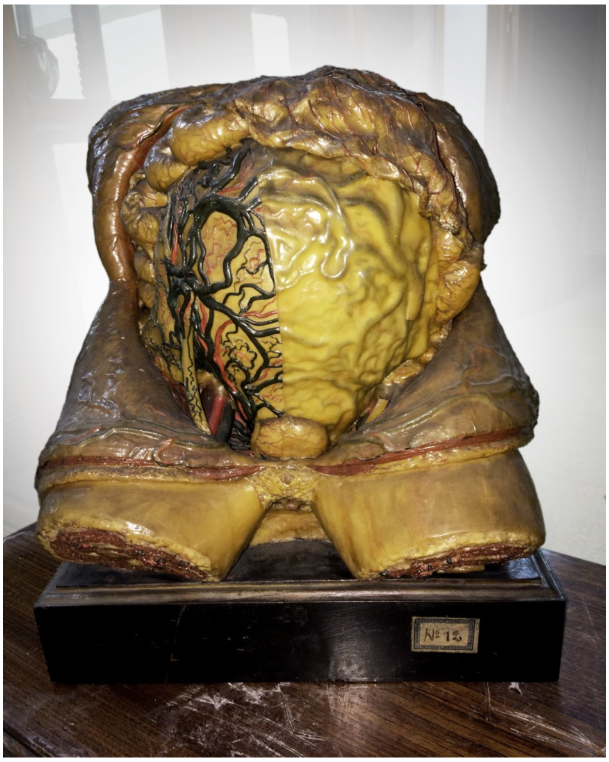

Fig 1. Anatomical model in hemi sitting position selected for the development of the study. Natural size sculpture in wax, 18th century. Javier Puerta Museum of Anatomy. Faculty of Medicine, Complutense University of Madrid. Dissection where a gravid uterus is represented at term and its vascularization.

shows a refined technique in the wax paste preparation process and, therefore, in the working procedure by incorporating each of the organs, veins, arteries and skin in a precise manner, and increasing that athmosphere of amazing realism for the moment. This piece represents a clear example of the virtuosity of the "scientific wax modelling technique" by Juan Chaez, Luigi Franceschi and Ignacio Lacaba.

Therefore, and in order to dissect this extraordinary intrinsic collaboration between the anatomist and the sculptor by means of 3D technologies, the methodology was established in two distinct phases. A first phase of recording or data acquisition using a GO! SCAN50 laser scanner from CREAFORM (Fig. 2a). It is a high-performance portable laser scanner, an ergonomic device equipped with a white light projector, three cameras (two for data triangulation and one for colour capture) and a lighting system to eliminate shadows. With a recording resolution between 2 and 0.5 millimeters, it allows to obtain three-dimensional models at a scale of 1:1 and to acquire measurement data from the different parts of the piece and provide chromatic information of the surface. It is necessary to know the fundamental properties of the work (surface shine, translucency of the material, colour and shape, among others) in order to adequately take the maximum possible chromatic and topographical data. Scarcity of data causes the accumulation of errors that result in deformations, presence of noise, volumetric and chromatic deficiencies that impedes the correct reading of the 3D model (Graciano et al., 2017). In addition, the scanner software allows to view the data acquisition in real time and to observe the zones to be recorded at the same time (Fig. 2b). It is noteworthy that tracking key points by the software, called targets[1], represents a differentiating advance in this type of technology (Fig. 3a).

In the piece under study, the reflective effects due to the surface gloss and slight degree of translucency of the waxy material were mitigated by a gradual scan and controlling the inclination of the light projection on the largest possible surface. Despite this, the appearance of noise and small particles near the recorded surface was evident, as shown in Fig. 3b.

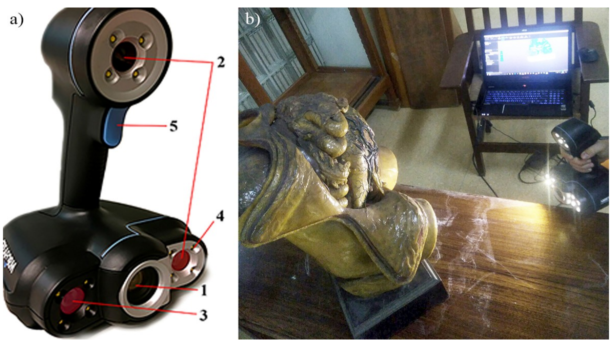

Fig 2. GO! SCAN50! scanner and 3D registration process. **a)** Parts of the scanner: 1. White light projector, 2. Triangulation chambers, 3. Colour camera, 4. Circular lights and 5. Trigger; **b)** 3D registration of a sculpture piece in wax at the Javier Puerta Museum of Anatomy of the Universidad Complutense of Madrid. Note how the data is collected and displayed in real time through the VXelements software.

The second phase of the process was the post-processing of the data obtained. This refers to the "cleaning" phase of the point cloud where trivial information is removed and possible errors are corrected. The software then calculates a mesh consisting of triangular polygons (Fig. 4a) and exports it to 3D model processing software. In the specific case of the anatomical wax model, a 3D model with a high level of detail was obtained for its diffusion (Fig. 4b) and high quality files for the analysis and breakdown of the different stages in which the work was supposedly created.

COMMENTS

The 3D model obtained from the work allows a rendering treatment with a multitude of possibilities in terms of the application of materials, lights and points of view. This fact makes it possible to obtain information at very high resolution and facilitate its analysis (for example, to observe alterations and fracture zones, the presence of polychromatic remains, layers or witnesses of the techniques and work tools used, among other aspects). A render of the recorded anatomical model is shown in Fig. 5, showing the high degree of accuracy of the model in relation to the wax part. This model can be animated in such a way that it is observed at 360º by means of interactive virtual musealization platforms[2].

This high-resolution 3D digital model allows a detailed organoleptic analysis to locate the signs and samples of the different stages of the sculptural work, being observable under multiple angles and textures, without the need to handle the original work. Fig. 6 shows several areas of the work where traces of the creation process can hardly be detected without precise observation and knowledge of the technique. These are internal joint lines that are chromatically perceptible by the translucency of the material; also, variations in the

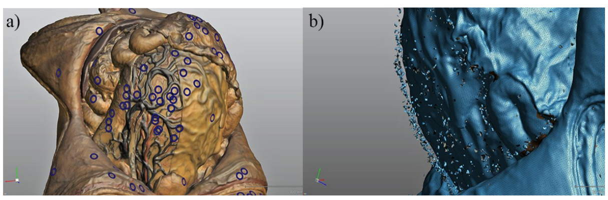

Fig 3. Data collection phase of the piece. **a)** Targets automatically captured by the laser scanner according to the colour variations acquired in real time; **b)** Presence of noise formed by the reverberence of laser light in contact with the smooth and shiny surface.

thickness of the layers due to their density, or volumetric modifications that indicate an overlapping element, even allow the use of parts of the work previously molded and, later adapted to the model, as a mean to advance in the manufacturing process of the final work, as will be explained later on (Fig. 8).

The analysis of these details of the realization process highlights the close relationship that was established between the doctor and the artist to achieve pieces with an extraordinary level of realism and perfection. This dissection process has made it possible to mark the different parts of the piece. Based on the information processed from the model by means of 3D treatment software (Zbrush, Pixologic), this model has been disassembled in the corresponding parts, as shown in Fig. 7. Colours were assigned to the different fragment groups in order to separate them and treat each of them independently (Scott-Spencer, 2017). Finally, the model was exported back to a visualization and rendering software, a neutral material was applied to each fragment, physical properties were assigned and colour information was projected.

Fig. 8 represents the superimposition of the different parts that, presented as hypotheses, seem to have been carried out by the artists during the process of making the wax model. First, and under the supervision of the anatomist, the artists performed a wax casting of the model previously molded in plaster. In this sense, and as a round hollow bulge, the artists cut the abdominal cavity by opening the loops that make up the anterior and lateral walls, adding the muscular fascia. At the same time, they added the epigastric vessels that run through the deep face of the anterior rectus muscles of the abdomen, and then the epigastric arteries and veins were covered with the peritoneal membrane. All in a row, the uterus was incorporated into the void of cavity and uterine vessels were added. Later, the intestinal loops were incorporated into the upper ridge of the uterus as well as the lower rim of the liver. Finally, the uterine vessels on the left side were covered with the peritoneum, and the extension of the major omentum that descends on the intestinal loops was widened, partially covering the uterus.

It is important to mention that this work required a great complicity between the artists and the anatomist. Conversations and explanations were constant with tireless hours of workshop. It required skillful hands and quick and controlled molding processes for faster handling and manipulation of the anatomical model. No less important was the task of selecting and collecting the waxes, preparing them, colouring them according to the desired shades following the indications of the anatomist, and finally producing the different pieces directly or by turning them into wax to be assembled in the final model.

Likewise, from the resulting 3D model, interactive images are obtained in a virtual way where the user interacts with previously registered and interpreted models, as shown in Fig. 9. This same process can be combined with other scanning methods (x-rays, computerized axial tomography, among others) to create models with more complex information adapted to the needs of users (Carrozzzino et al., 2008).

The 3D registration is a non-destructive and very graphical analysis tool that allows data collection, real-time monitoring, visualization without manipulation and dissemination and interaction through virtual platforms. Also, in the historical-artistic field,

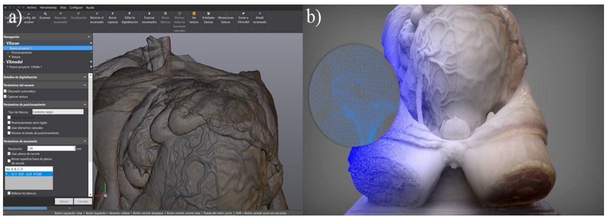

Fig 4. Stages of post-processing data. **a)** Mesh obtained from the point cloud corresponds to the piece under study; **b)** 3D model processed. From left to right: wireframe, neutral material, waxy material properties and colouring.

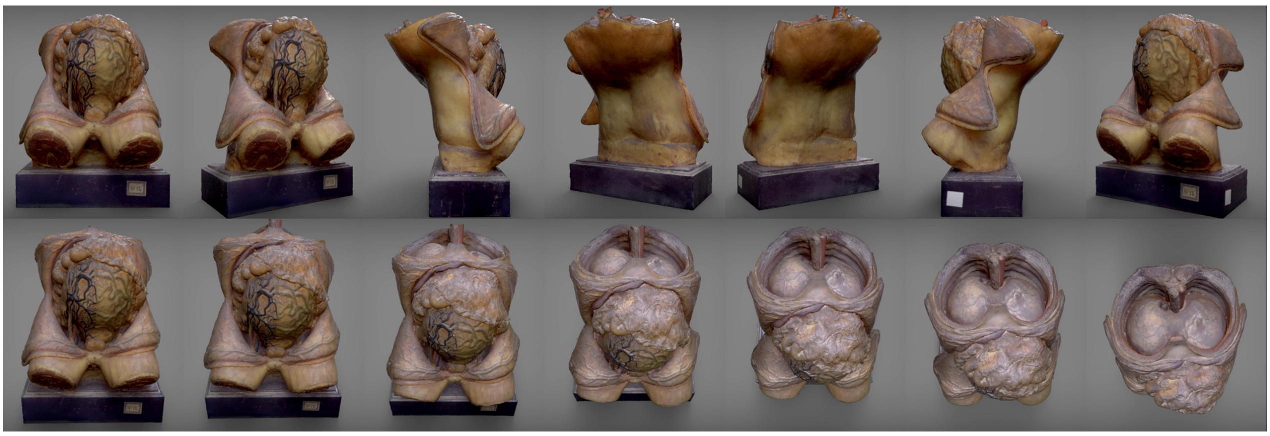

Fig 5. View of rotation sequences in vertical axis (upper row) and horizontal axis (lower row) of the 3D model.

this is an effective tool for recording an interactive documentation that provides a reliable visualization, localization and quantification of the different parts of the works and documentation of the creative process carried out by the artist. In the medical-anatomical field, it allows certain parts of the model to be documented and isolated, conferring the selection of information for students, researchers, professionals in anatomy or medicine.

In short, this study has incorporated the most advanced 3D technology to learn, document and disseminate a piece in wax of great importance from the collection of the Javier Puerta Museum of Anatomy of the Universidad Complutense of Madrid.

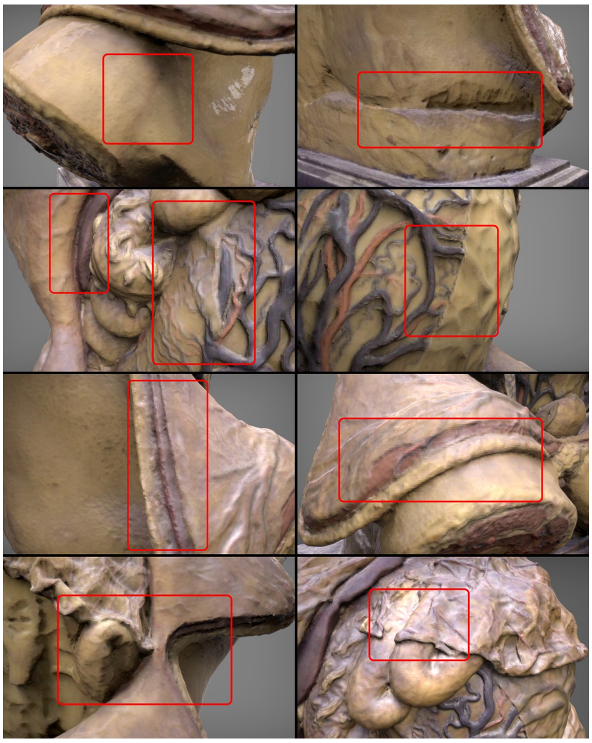

Fig 6. Cases where the detected signals are key elements that reveal the assembly and order of placement of the anatomical parts in the whole piece.

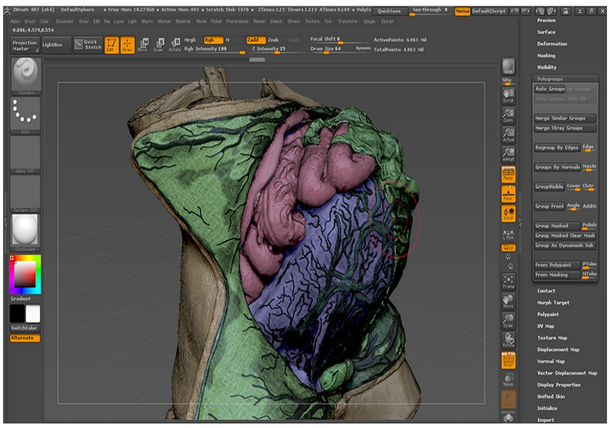

Fig 7. Screenshot of the Zbrush software where the different groups of fragments can be observed by different colours.

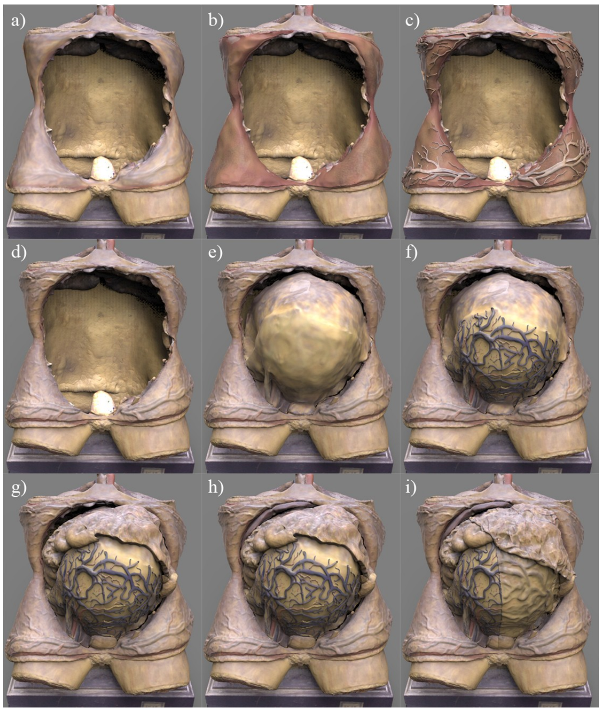

Fig 8. a) The posterior wall of the empty abdominal cavity is observed as well as loops from anterior and lateral walls covered by muscular fascia. **b)** Deep side of abdominal muscles are shown. **c)** The epigastric vessels run along the deep side of the anterior rectum abdominis muscles. **d)** Epigastric arteries and veins are covered by the peritoneal membrane. **e)** The gravid uterus has been located in the abdominal cavity. **f)** Uterine vessels are added. **g-h)** Instestinal loops and the inferior edge of the liver are incorporated over the uterus upper edge. **i)** Greater omentum is increased in size descending over the intestinal loops covering the uterus partially. The left uterine vessels are hidden behind peritoneum although they could be observed through it.

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Fig 9. Interactive simulation showing the different parts of the anatomical model.

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Notes

[1] Reference points, around the surface to be recorded, which serve to correct the triagualization of the data taken. These can be points present in the environment of the object (parts of the landscape, objects, or newspaper used as the basis of the recorded work) in the case of photogrammetry, or by the recognition of chromatic or superficial variables in the case of laser scanners.

[2] http://www.teseratik.com/portfolio/esculturas-anatomicas-en-cera