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Analysis of ancient fabrics, example of the Holy Shroud in Turin

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ABSTRACT

As it is not always simple to perform a systematic study on an ancient textile considering the complexity of the various techniques that can be applied, this paper considers as an example, the case of the HS (Holy Shroud), discussing the recent tests applied to it with relative results. After a brief presentation of the textile and an explanation of its complexity, the paper presents some tests and results obtained from 1978. The dark spots present in the fabric, attributable to the image of a man, add interesting information regarding its possible origin. The dating problem is discussed by comparing the information coming from the tradition with the contradictory result provided by the radiocarbon test performed in 1988 and other new dating results produced by innovative techniques. The dusts vacuumed from the HS, employed to perform a study of the human DNA coming from external contamination, provide an interesting hypothesis of the relic's origin; in addition, among these dusts, electrum micro-particles, provide an interesting hypothesis on Byzantine customs. Finally, the problems related to the conservation of the textile are also considered. This example shows how it is possible to obtain from a textile interesting scientific results and confirmations of previous historical hypotheses.

***Keywords*:** ancient textiles, Holy Shroud, DNA, body fluids, techniques, dating, historical information

1. INTRODUCTION

There are many historical and archaeological finds of fabrics in the world, with little known origins that could be subjected to detailed investigations. Among these there are not

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only relics such as the Holy Shroud (HS) or the Oviedo Sudarium, but also paintings such as the declared seventeenth-century copies of the HS, tapestries, frontals, carpets, clothes, textile fragments from excavations or burials, etc., many of which have little-known origins, history and characteristics.

For example, there are several scientific journals on the subject [1, 2] and an international conference on Egyptian archaeological textiles is held every two years at Antwerp in which scholars from all over the world participate to discuss their research and their latest discoveries.

Egypt in the first millennium A.D. was the fulcrum of an extraordinarily creative textile activity, in which the iconographic motifs derived from the various cultures with which Egypt came into contact, either through domination or through trade, have been reworked producing an unmistakable style, also thanks to a technical yield that only skilled and expert weavers could achieve. The favorable climatic conditions and the archaeological excavations allow us to still admire these precious finds: thousands of wonderful artifacts that enrich the collections of many museums around the world.

In some cases, the stratigraphy of the excavation area where the textiles were found provides some historical indication of the find under investigation but often these objects are known only summarily even though more detailed investigations could be carried out on them to better locate them in a certain historical period, to better understand the use for which they were produced and to identify perhaps even the person who used them.

Identifications of archaeological fibers and dyes in textiles [2] can be performed by fusing the results of different analytical techniques, such as, optical microscopy (OM), scanning electronic microscopy (SEM) or better Field Emission Gun-SEM (FEG-SEM), Transmission Electron Microscope (TEM), Energy Dispersive Microscopy (EDS), Raman spectroscopy (RS), Fourier transform infrared spectroscopy (FT-IR), Fiber Optics Reflectance Spectroscopy (FORS) and liquid chromatography (LC).

This paper takes into consideration the most important textile in the world for Christians, the HS, as an example to consider how many and which tests can be applied to an archaeological textile in order to obtain the maximum number of possible information of it thus collocating the relic in the right historical period with the identification of all the details still hidden in it.

2. THE EXAMPLE OF THE HOLY SHROUD

The case of the HS has been selected to present the various types of analyses that can be performed on a textile, because in addition to being the most important Christian relic in the world, it is also the most complex. In fact, it shows, among other signs, two darker spots attributable to body images of a man that are still today not yet scientifically explainable and bloodstains positioned in areas corresponding to the supposed tortures endured by that man.

The HS [3-5] is a linen fabric, 4.4 m long and 1.1 m wide, see Fig. 1. It is a hand-woven in 3:1 twill and each thread (non-constant diameter of about 0.25 mm) is composed of 80 to 200 linen fibers [6]. The word “shroud” corresponds to the Italian “Sindone” deriving from the Ancient Greek “sindòn”, meaning the burial cloth in which a corpse is wrapped.

According to the Catholic Christian tradition, the HS is the burial cloth in which Jesus Christ was wrapped before being placed in a tomb in Palestine about 2000 years ago. Science has not demonstrated the contrary, but the Catholic Christian Church does not impose on its adherents any veneration of the HS [7].

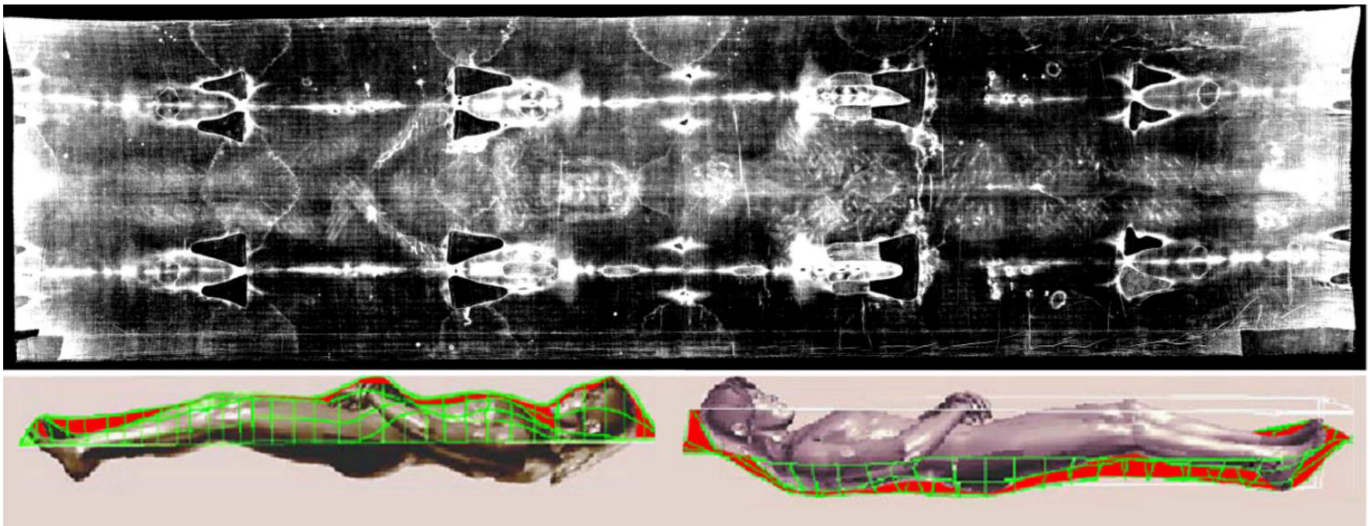

Figure 1. Front and back body images on the HS, negative image (top). Numerical reconstruction of the corpse wrapped in the HS (bottom).

There are some indications that the HS, probably spun and woven in India [8], was in Palestine in the first century A.D., and then taken to Edessa (present-day Sanliurfa in Turkey).

The coincidence of the HS face with that of Christ on Byzantine icons and coins starting from the VII century A.D. is evidence that the HS was seen during the Byzantine empire. More than 100 congruence points with the HS were detected on the Byzantine images of Christ.

In 1203, a church in Constantinople exhibited every Friday a cloth, possibly the HS, in which Christ had been buried. After disappearing during the Sack of Constantinople in 1204, it appeared in Europe in 1353 at Lirey in France, during a dispute for its ownership between the owner Geoffry de Charny with the bishop of Troyes, Pierre d'Arcis, the king of France, Charles VI and the anti-pope, Clemens VII.

In 1532, a fire damaged the HS while it was conserved at Chambéry in France and in 1534 it was restored it by sewing some patches of cloth on the front and a second reinforcing tissue on the back. In 1578 it was taken to Turin where it remained until now, apart from some short periods of time when it was hidden, especially during wartime.

The HS was the property of Savoy from 1453 to 1983, the year in which Umberto II of Savoy donated it to the Pope St. John Paul II.

Until the XIX century, scientific interest in the HS was limited, because of the scarcity of direct analyses and the lack of photographs. Instead interest greatly developed after 1898, when S. Pia photographed it and sent copies to the scientific world for independent studies.

During the 2002 heavy intervention, all the patches and the old tissue were unstitched, thus revealing the holes in the fabric left by the 1532 fire. On that occasion, the length of the cloth was increased by some centimeters because it was stretched. Lastly, a reinforcing cloth, which no longer allows direct observation of the back of the HS, was again sewn onto the back.

There are also other traces such as water halos due to a probable accident that took place in the first centuries A.D. and some holes probably due to lit incense fallen on the HS. This is therefore a very complex textile and still little known in its details which among other things requires in-depth studies also on the era in which it was made, on its manufacture, on the darker unexplainable spots there impressed and on the blood impregnated therein as well.

3. INITIAL SCIENTIFIC APPROACH ON THE TEXTILE

Since the first photograph taken by Secondo Pia was disclosed to the scientific world from 1898, there were various scientific researches relating to the HS, and the first noteworthy work was that published in 1902 by Paul Vignon, but the scientific work more complete and interesting was the one carried out in 1978 by the American group STuRP (Shroud of Turin Research Project), made up of 33 scientists from various disciplines who carried out the following studies, example of how science can be interfaced on a fabric.

- Photography (frontal and backlit photographs);
- X-Ray Radiography and Fluorescence;
- Infra-Red reflectance photography and thermography;
- Spectroscopy (Spectra of UV [ultraviolet]-Visible Reflectance and UV Fluorescence);
- Collection of tape samples (special sticky tapes posed in contact with the fabric);
- Visual inspection with lenses.

Subsequent studies of the sticky tape samples were conducted using microscopy, pyrolysis-mass-spectrometry, laser-microbe Raman analysis and various methods of micro-chemical testing.

The principal results obtained from these studies are synthetized as reported in Ref. [Schwortz Barrie, A Summary of STURP's Conclusions, 1978, https://www.shroud.com/78conclu.htm] and many scientific publications followed on scientific journals.

"No pigments, paints, dyes or stains have been found on the fibrils. … Computer image enhancement … show that the image has unique, three-dimensional information encoded in it. … It is clear that there has been a direct contact of the Shroud with a body. ... The basic problem from a scientific point of view is that some explanations which might be tenable from a chemical point of view, are precluded by physics. Contrariwise, certain physical explanations which may be attractive are completely precluded by the chemistry. … experiments in physics and chemistry with old linen have failed to reproduce adequately the phenomenon presented by the Shroud of Turin. The scientific consensus is that the image was produced by something which resulted in oxidation, dehydration and conjugation of the polysaccharide structure of the microfibrils of the linen itself.

… We can conclude for now that the Shroud image is that of a real human form of a scourged, crucified man. It is not the product of an artist. The blood stains are composed of hemoglobin and also give a positive test for serum albumin. The image is an ongoing mystery… ."

The same STuRP group, after these inconclusive results, among others, suggested following scientific techniques of investigation for future testing:

- Fourier Transform Infrared Spectroscopy;
- Raman Spectroscopy;
- Energy Dispersive Spectroscopy;
- Atom probe tomography.

While the STuRP no longer had access to the HS, other scholars conducted experiments suggested by this American group and others as scientific development made available new and more sophisticated tools for investigation. Below are some of the most significant results grouped by argument: body image, body fluids, dating, information from dusts, conservation.

4. DARK SPOTS ON THE TEXTILE ATTRIBUTABLE TO BODY IMAGE

The study of the textile obviously becomes more complex if, as in the case of the HS, two big dark spots resembling the front and back images of a man are imprinted on it, moreover for the moment impossible to explain scientifically. Therefore, it is appropriate to go into detail about the body images represented by these spots. In this case, in fact, they are two very particular human figures, but also in other cases there may be more or less evident stains linked to particular events to which the textile has been subjected.

The HS images show an adult male, nude, well-proportioned and muscular, with beard, moustache and long hair posed on a horizontal plane, see Fig. 1. They are compatible with a man who had been scourged, crowned with thorns and crucified, who died on a cross, and who was stabbed in the side with a lance after his death. From specific studies it results that [9], due to rigor mortis, which began after his crucifixion, the Man is not supine; head is tilted forwards, knees are slightly bent and feet extended, as a result of being nailed to a cross.

In white light, the color of the body image is yellow/brown but, when viewed under b/w UV it is neutral gray or black [4]; in the 3-5 μm IR range the image disappears, but in the 8-14 μm IR range a white image is evident too [10].

The cause of the yellowing of the body image in visible light is due to chemical alteration of the polysaccharides in the linen fibers of the textile. This chemistry is similar to the characteristics of aging linen [4]. In 2004, the presence of a superficial body image on the back of the HS was detected in restricted areas [11].

In agreement with what was detected by STuRP Team, see Section 3, it is well known [12] that, up to now, science cannot explain or reproduce all together the very peculiar features of the body image. However, various hypotheses of image formation have been formulated.

Perhaps the most realistic hypotheses [13] refer to an intense radiation of various kinds (like visible light, X-rays and gamma-rays, protons and neutrons, excimer lasers) emitted by the corpse wrapped in the HS and for this reason most of them go beyond the purely scientific sphere because it does not appear that a corpse can emit radiation of such intensity. Consequently, many of these hypotheses refer to a phenomenon that comes out of traditional science, the Resurrection, which obviously cannot be reproduced in a laboratory.

A new hypothesis [14] seems to resolve this problem by hypothesizing the formation of the body image due to an energy similar to that which develops every year inside the Edicule of the Holy Sepulcher in Jerusalem: the Holy Fire (HF) [15].

This energy source consists of a fire produced by intense electromagnetic fields that maintains a cold plasma, around 40 °C, for several minutes. This phenomenon, which does not appear to be scientifically reproducible in the environmental conditions where it occurs, is repeated every year in the same place and is measurable with scientific means; it could be very similar to what could have occurred on Easter Sunday approximately 2000 years ago.

According to this new "photographic" hypothesis, described in [14], the electric energy closely connected with the HF produced a Corona Discharge and, would have interacted with the body fluids exuded by the wrapped corpse to form an image. Antiputrid substances, such as aloe and myrrh, would have interacted as in a photographic film where the image would have been formed through a Maillard chemical reaction (occurred between the reducing sugars of the flax and the amines of the urea exuded by the corpse).

Complete experiments have not yet been performed to test this hypothesis due to the ban by the Orthodox authorities on witnessing the phenomenon, but some experiments conducted at the University of Padua under the guidance of prof. Giancarlo Pesavento provided encouraging results see Fig. 2.

The author is therefore convinced that this hypothesis, also supported by some experimental results can be the right avenue to the explanation of the body image on the HS.

Also impressed on the HS are many other marks due to blood, fire, water and folding, which have greatly damaged the double body image. For the purpose of this paper, only body fluids are considered in the next section.

5. BODY FLUIDS ON THE TEXTILE

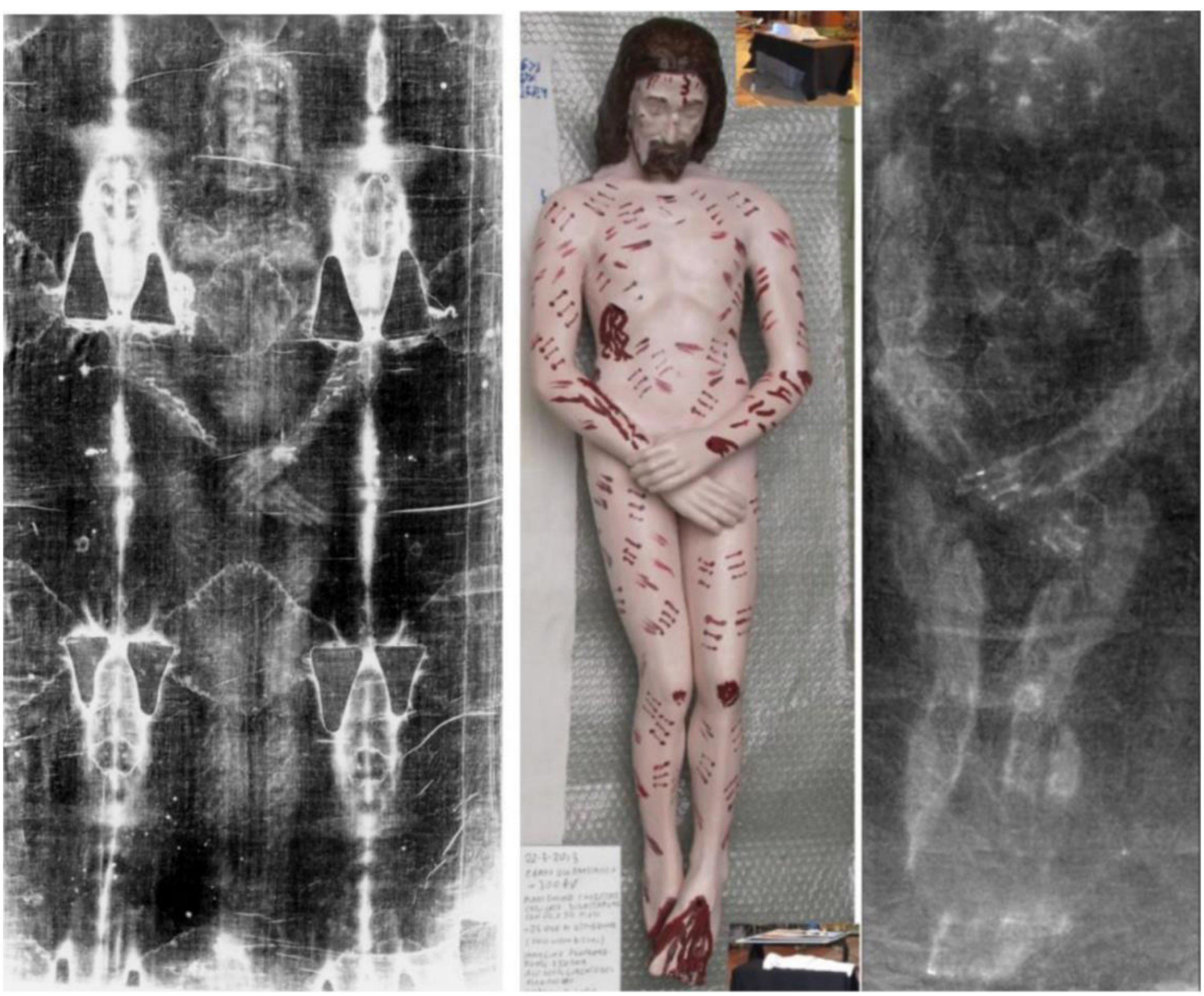

Figure 2. Negative frontal image of the HS (on the left), with a corresponding manikin built to produce an experimental image (on the right) by means of Corona Discharge.

Like various burial sheets of antiquity placed in contact with the corpse wrapped therein, the HS also highlights the presence of various kinds of body fluids and aromas which have impregnated the linen fibers. It does not appear that complete studies have yet been carried out on the textile in question, also due to the difficulty of having permission to acquire new samples to study, but some interesting results are reported below to indicate which types of studies can be performed on such an archaeological find.

The interest in these traces of bodily fluids and aromas imbibed in the textile is also relevant because it can help in the acquisition of historical information and can be related to its employment in the context of the uses and customs of the population of that time. For example, the possible discovery of anti-putrid substances such as natron, aloe and myrrh can demonstrate how corpses were once buried in a certain geographical region.

The specific characteristics of certain bodily fluids such as blood and serum can also provide interesting information on possible torture inflicted on the corpse wrapped in textile under examination.

In the case of objects also of a religious nature, the comparison between what is scientifically found on the textile and what is reported in the Sacred Texts may also be interesting, also for the purposes of authenticity of the artifact.

Various researchers examined the numerous red stains present on the HS by studying small crusts taken from either sticky tapes put in contact with the stains or from pieces of threads cut from these stains: they are W. McCrone [16], P.L. Baima Bollone and J. Heller and A. Adler of STuRP [17, 18].

J. Heller and A. Adler detected the presence of primate blood on the HS identifying hemoglobin and serum albumin in them, whereas, P.L. Baima Bollone, independently, detected the presence of human blood on the HS.

In sharp contrast, and with the same samples collected by STuRP, W. McCrone detected no blood whatsoever on the HS, but, instead, he identified very small-sized red pigments (like red ochre and vermillion) which he named "Sub-Micron Particles" (SMP) as being the source of the red images on the HS. A dispute arose concerning the identification of what constituted the redness that is visible on the HS, but there has been no meeting of the minds between these scholars.

Ref. [19] proposed a new interpretation of the data which reconciled the findings of W. McCrone with those of J. Heller, A. Adler and P. L. Baima Bollone regarding the source of the redness on the HS. This interpretation supposed that the bloodstains of real blood had been reinforced in the past with red pigments, but a second paper [20] updated these results on the basis of more recent studies and tests, reexamining the aforementioned interpretation of Ref. [19]. In particular, it showed the insufficiency of pigments that had been previously hypothesized to evidence a visible image of red stains on the HS, basing both on the X-Ray photos described in Ref. [21] and on experiments born from the results detected in Ref. [22]. Therefore, the SMPs should be excluded as the unique source of the red matter that is visible with the naked eye on the HS.

Nevertheless, it is interesting to know what is the origin of the SMPs found in correspondence with the HS's bloodstains. A hypothesis is based on the fact that the more than 50 painted copies of the relic made in past centuries may have transferred some pigment when they were pressed to the HS, making them higher order relics. In addition, a question still unresolved is that the bloodstains on the HS have retained a reddish color which is in contrast to the dark-brown to blackish color that is typical of aged blood.

To explain the redness of the HS's bloodstains, Ref. [23] adds a new hypothesis to those concerning (1) the effect of ultraviolet rays on the high-bilirubin content in the HS's bloodstains [24] and (2) the presence of carboxyhemoglobin in the aforementioned bloodstains. In parallel to an ongoing investigation on an alleged Eucharistic Miracle concerning a linen cloth with blood on it, Ref. [23] notes that this blood too has atypically retained its red color for years and therefore one can suppose that there may be a strict connection between the two types of blood [20].

Once the numerous wounds scattered throughout the HS were recognized as human blood [17, 18] we can understand that the textile shows the tortures suffered: signs of flagellation, crowning with thorns, nail driving in the limbs and a post-mortem wound in correspondence with the side, see Fig. 3.

6. TEXTILE DATING

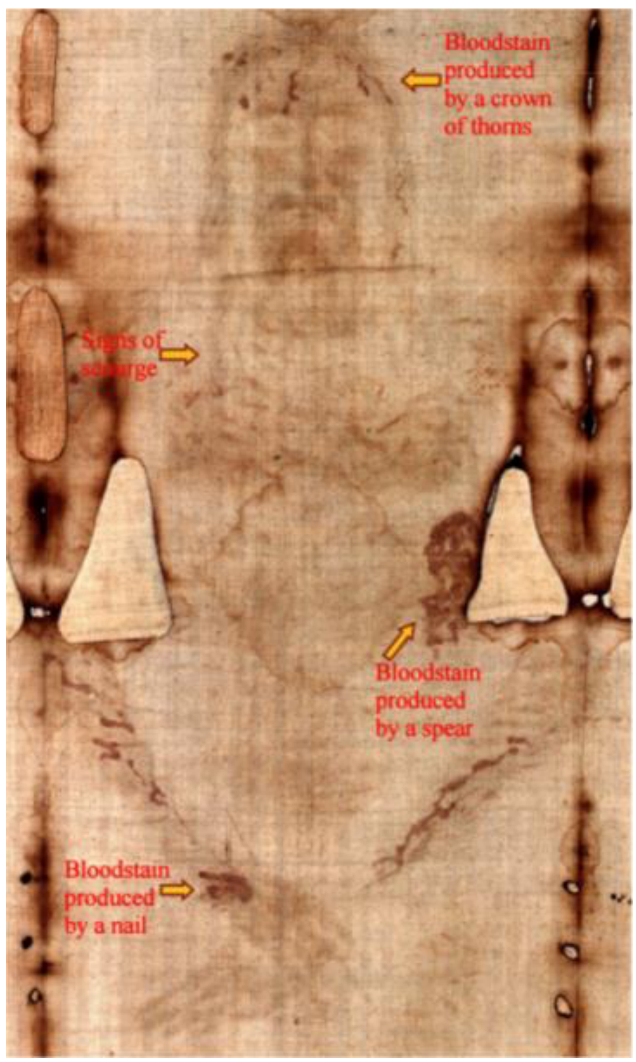

Figure 3. Signs of flagellation, crowning with thorns, nail driving and a post-mortem wound at the side on the body image of the HS.

Archaeological textiles are often found alongside objects of easier historical dating or from excavations whose stratigraphy leads to easy dating. However, in other cases, such as that of the HS, direct dating is not so simple because these textiles have been exhibited in museums or churches for centuries without having precise historical documentation. In these cases, it is therefore interesting to date the textile also to confirm or not the historical, artistic and religious information related to it.

However, this operation is not always simple and reliable because, especially in the case of fabrics, it is easy for these samples to be contaminated by various environmental factors and therefore an altered dating can result.

It is advisable to carry out a preventive study of the possible environmental factors that may have influenced the result and, moreover, to apply different dating techniques in order to try to arrive at some more reliable conclusion.

Things get even more complicated in the case of HS because, as we know, the first millennium of history is still obscure enough to clearly define the environmental conditions in which it was kept and to which external contaminations it was subjected (such as the transfer sweat from the hands of the faithful who venerated the Relic).

Furthermore, a very important fact, we have seen in Section 4 that the body image is not yet scientifically explainable but that the most plausible hypothesis is that of an energy related to it. An important problem then arises of defining whether this hypothesized energy for body image formation could also have somehow interfered in the dating techniques now being discussed.

In particular, more traditional datings such as that of the Carbon 14 (C14) will be compared with more innovative datings such as the mechanical one, those based on Raman and FT-IR spectrometry, the one based on the degree of depolymerization of cellulose based on X-Rays and the one based on historical information.

It should be added that the contamination of textiles by external environmental factors can be variable and that the subsequent cleaning does not always guarantee the removal of the filler material. It is for this reason that some specialized laboratories have recently refused to perform the C14 test for samples of textiles.

6. 1. Radiocarbon dating of the textile

In 1988, the HS was radiocarbon-dated to 1260–1390 A.D. [25]. A piece of linen (officially 7 cm long and 1 cm wide) was cut from the HS and given to Oxford, Zurich and Tucson (Arizona) laboratories, each of which independently measured the 14C/12C isotopic ratio to assign an age to the samples.

The Authors of Ref. [25] declared that "These results therefore provide conclusive evidence that the linen of the Shroud of Turin is mediaeval." but this "conclusive evidence" has since been questioned by many researchers, who identified both procedural and statistical problems [26-29] with this test.

For example, in Ref. [27] a preliminary estimate of the kinetics constants for the loss of vanillin from lignin made by R. Rogers indicated an age of the TS "between 1300 and 3000 years old." A robust statistical analysis applied to the 12 sub-samples used for the 1988 radiocarbon dating showed that the Medieval result of the TS appears flawed by a significant systematic effect that makes unreliable the assigned age.

This supposed systematic effect might just be related to the hypothesized source of energy mentioned in Section 4 to explain body image formation. It is obvious, see Ref. [23] that dead bodies do not, typically, produce such a burst of energy and for this reason R.E.M. Hedges [30] wrote: “If a super natural explanation is to be proposed, it seems pointless to make any scientific measurement on the shroud at all.”

Of the opposite opinion was T.J. Phillips who wrote what follows [31].“If the shroud of Turin is in fact the burial cloth of Christ, … then according to the Bible it was present at … the resurrection of a dead body. …. the body [wrapped in the HS] … may also have radiated neutrons, which would have irradiated the shroud and changed some of the nuclei to different isotopes.” He suggested that “ … some 14C could have been generated from 13C.”

Ref. [23] too disagreed with Hedges’ statement because “… even though science is limited and unable to explain everything that can be observed and measured on the HS, we must not limit the application of science only to those things which are known in the natural world.”

R.E.M. Hedges [30] also proposed a second hypothesis: the “neutron capture by nitrogen in the cloth” of 14C atoms behave “in the same way as the original 14C” thus rejuvenating the radiocarbon age of textiles by centuries. The reaction in question, taken in consideration in Ref. [23] can be synthetically written as 14N(n,p)14C indicating that after an impact with a neutron n, nitrogen 14N transforms into 14C releasing a proton p. This reaction can be more explicitly expressed as:

$$14N + n \rightarrow 14C + p \quad (1)$$

According to Ref. [23], the phenomenon which created the image on the HS may also have altered the percentage of carbon isotopes, producing the non-negligible systematic effect detected by Ref. [26]. R.E.M. Hedges [30] in fact confirms that this textile sample “… had had an unknown but potentially contaminating history.”

Ref. [23], sustained the hypothesis, that neutrons possibly irradiated the HS and caused isotopic changes, by considering the recently discovered anomaly detected in the HS blood. Unlike common human blood which contains nitrogen (weight percentages of the order of 10%), the level of nitrogen in HS blood was negligible. This result was independently confirmed by the French Professor of Molecular Anthropology Gerard Lucotte.

Teruaki Enoto et al. [32], confirms that to the two known natural productions of carbon isotopes on Earth (primordial C13 originating from stellar nucleosynthesis, and C14 produced by atmospheric interactions with cosmic rays), we must add the production of carbon isotopes produced by lightning and storm clouds which are natural particle accelerators. These phenomena in accordance with Eq. 1, produce C14 atoms from nitrogen atoms.

Consequently, it easy to think that the source of energy hypothesized by some scholars for the formation of the body image of HS possibly contributed to varying the isotopic percentage of carbon contained in the linen of the fabric and then to altering the age of the HS.

6. 2. Mechanical dating of the textile

The mechanical dating of ancient flax fibers is based on the concept that the long cellulose chains in the ancient flax fibers break over time thus degrading the mechanical properties of the fibers themselves. From the analysis of some characteristic mechanical parameters it is therefore possible to obtain the assigned age of the sample in question.

Innovative dating methods based on the analysis of mechanical parameters (breaking strength, Young modulus and loss factor) and of opto-chemical ones (FT-IR and Raman) was presented in Ref. [Fanti Giulio, Pierandrea Malfi and Fabio Crosilla, Mechanical ond opto-chemical dating of the Turin Shroud, MATEC Web of Conferences, Volume 36, 2015, WOPSAS, 2015 Articlem01001, DOI: http://dx.doi.org/10.1051/matecconf/20153601001]. A particular cycling-loads machine able to measure the mechanical parameters of single flax fibers 1-3 mm long was there designed, built and calibrated, see Fig. 4.

The relationships between the mechanical parameter under examination and the age of the analyzed flax fibers were defined by calibration, measuring the respective mechanical parameters of flax fibers of known age, starting from 3000 B.C. up to the present day.

Ref. [33] proposed the following relationships between age and five mechanical properties of ancient flax textiles:

$$\sigma_r = 139.1\ e^{0.000968\ A},\ \pm 336 \text{ years, } P=0.94, \tag{2}$$

$$E_1 = 6.222\ e^{0.0007094\ A},\ \pm 418 \text{ years, } P=0.92, \tag{3}$$

$$E_2 = 8.176 e^{0.0006059\ A},\ \pm 537 \text{ years, } P=0.91, \tag{4}$$

$$\eta_1 = 7.538 - 0.001372\ A,\ \pm 193 \text{ years, } P=0.96, \tag{5}$$

$$\eta_2 = 4.260 - 0.001146\ A,\ \pm 385 \text{ years, } P=0.90, \tag{6}$$

where breaking strength σ_r, Young modulus E_1 of the last part of the increasing loading cycles, Young modulus E_2 of the first part of the decreasing loading cycles, loss factor η_1 of the last complete loading cycle representing the dissipated energy and loss factor η_2 of the inverse direction of the cycles are related to the age A of the sample. P is the Pearson's correlation coefficient. The loss factor is defined as:

$$\eta = D/2\pi U \tag{7}$$

where D is dissipated energy and U is stored energy during a whole cycle.

The mechanical response of both tensile strength and Young moduli confirmed the exponential law due to first-order reaction kinetics as supposed by the natural cellulose degradation. The loss factors instead, not being directly related to the strength of the cellulosic chains but to the energy dissipated during strain application, is correlated to a linear model.

The first mechanical dating of the HS was reported in an example of Ref. [33], where the method was applied to six fibers picked up from the relic. The resulting values, being A the evaluated age, are:

$$A_{\sigma r} = 577 \text{ AD};\ A_{E1} = 14 \text{ AD};\ A_{E2} = 456 \text{ AD};\ A_{\eta 1} = -510 \text{ AD};\ A_{\eta 2} = 564 \text{ AD},$$

which, using two different averaging methods give the following ages of the HS:

$$A_1 = 220 \text{ AD};\ A_2 = 372 \text{ AD}$$

with uncertainties of ±400 years.

A least squares multi linear regression was then applied to the measured mechanical data estimating an age of 260 A.D. with an uncertainty of ±274 years.

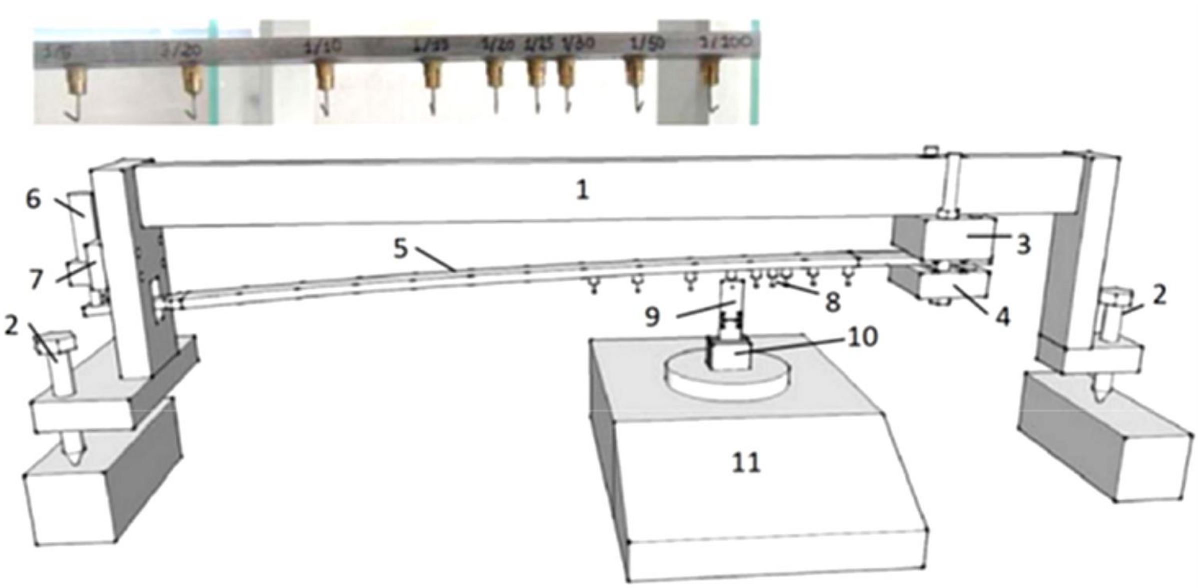

Figure 4. Sketch of the micro-cycling machine built from Ref. [60]. 1 frame is horizontally regulated by screws 2;3,4 clamping blocks for the displacement-reducer cantilever beam 5; 6 micrometric screw gauge (mounted on coupling plate 7), that moves beam 5. To one of the hooks 8 (on the top left a detail of the hooks having reduction factors from 1/5 to 1/100) is hanged a proper sheet 9 tabbing the fiber under test. The lower part of 9 is glued with two iron blocks 10 that lay on the plate of the analytical balance 11.

6. 3. Chemical dating of the textile

The chemical dating, Raman and FT-IR (Fourier Transform – Infra Red), of ancient flax fibers is based on the concept that the cellulose of the flax fibers degrade over time thus changing its chemical composition. From the concentration of some specific chemical bonds, it is therefore possible to obtain the assigned age of the sample in question.

For the FT-IR dating, the already cited Ref. [Fanti, Malfi & Crosilla] indicates that the band integrals more sensible to age resulted those located in the 2600-3080 cm^{-1} and 3070-3600 cm^{-1} ranges, whereas those in the 800-1180 cm^{-1} and in the 1500-1760 cm^{-1} ranges had an opposite tendency. Two ratios R1 and R2 (see Eq. 8) of the amplitude peaks integrals of each sample have been evaluated in the corresponding spectra as a function of the wavenumber n expressed in cm^{-1}:

$$R_1 = \frac{INT(2600{,}3080)}{INT(1500{,}1760)}; \qquad R_2 = \sqrt{\frac{INT(2600{,}3080)}{INT(800{,}1180)} \frac{INT(3070{,}3600)}{INT(1500{,}1760)}} \tag{8}$$

where:

$$INT(a,b) = \int_a^b I \, dn \tag{9}$$

and I is the measured intensity subtracted to its corresponding baseline.

R_1 expresses the ratio between CH_{1-2} stretching and OH bending while R_2 depends on the product of CH_{1-2} and OH stretching divided by the product of OH bending and other groups contained in the 800-1180 cm^{-1} range.

Eight reference flax samples have been used for calibration evidencing a systematic effect due to heat produced by fire that was therefore properly corrected on the basis of experimental results. The relation between the FT-IR ratios R1 and R2 and the corresponding age A of the linen sample is:

$$A = 1730+1809 \ln R_1 \text{ ; } P=0.90 \tag{10}$$

$$A = 1706+2379 \ln R_2 \text{ ; } P=0.95 \tag{11}$$

After correction for the systematic effect of the fire, the age of the HS respectively resulted of 200 B.C. and 297 B.C. when calculated with R_1 and R_2.

For the Raman dating, the same Ref. indicates that the ratio $R_{COC/OH}$ of the amplitude peaks in the spectra are very sensible to the flax textile age and the following R_R ratio was calculated:

$$R_R = \frac{I_{1097}}{I_{3251}} \tag{12}$$

The relation between the Raman ratio R_R and the corresponding age A of the linen sample resulted influenced by the fluorescence level of the sample therefore the following equations were determined as a function of the fluorescence F.

$$A = 2451 + 2299 \, ln \, R_R \quad \text{(with F=0.79); P=0.91} \tag{13}$$

$$A = 7498 + 4871 \, ln \, R_R \quad \text{(with F=1.82); P=0.95} \tag{14}$$

$$A = 6041 + 4129 \, ln \, R_R \quad \text{(with F=1.55)} \tag{15}$$

As flax textiles exposed to heat sources seem to show a negligible bias, no correction was applied and the Raman age of the HS sample resulted of 32 A.D. Table 1 synthetizes the results of chemical dating after having averaged the two results obtained by FT-IR analysis.

Table 1. Age of the HS resulting from chemical analysis.

Chemical dating	**FT-IR**	**Raman**
Age	250 B.C.	30 A.D.
Standard uncertainty	200	250

6. 4. X-Ray dating of the textile (depolymerization of the cellulose)

A new method for dating flax textiles consists in determining the degree of depolymerization of the cellulose contained in the flax fibers and their structural degradation can be analyzed by means of X-Rays inspection.

Ref. [34] demonstrated that this method can be successfully applied by means of a Wide-Angle X-ray Scattering (WAXS) that verified a biunivocal relation between the degree of polymerization of ancient fibers and their historical age.

The X-ray dating method was then applied in Ref. [35] to a sample of the HS consisting of a thread taken in proximity of the 1988/radiocarbon area.

In particular, one-dimensional integrated WAXS data profiles for a HS sample, about 0.5 mm × 1 mm in size, were obtained, which were fully compatible with the analogous measurements obtained on a linen sample whose dating, according to historical records, is 55–74 AD, Siege of Masada (Israel).

It resulted that the HS textile is much older than the seven centuries proposed by the 1988 radiocarbon dating reported in Section 6.1 and the results are compatible with the hypothesis that the HS is a 2000-year-old Relic, under the condition that it was kept at suitable levels of average secular temperature in the range between 20.0 °C and 22.5 °C and relative humidity in the range between 55% and 75% during the first 13 centuries of unknown history, in addition to the seven centuries of known history in Europe.

Ref. [36] considered the effects of temperature and humidity on the aging of the flax textile under examination during first 13 centuries of not well-defined history, comparing the environmental conditions of different alleged historical and geographical paths of the HS.

It resulted by Monte–Carlo simulations that the Jerusalem–Beirut–Constantinople–Lirey–Chambéry–Turin historical path is more probable for the HS sample by WAXS than the more commonly proposed Jerusalem–Edessa–Constantinople–Lirey–Chambéry–Turin path. Nevertheless, a possible sojourn of the HS at Edessa for some centuries cannot be excluded.

Again Ref. [36] concludes that the WAXS evaluation of the natural aging of the HS is compatible with a 2000-year history.

6. 5. Historical confirmation (of numismatic and iconographic type)

The dating or the historical path of a textile can be confirmed or at least suggested by the comparison with pictorial, iconographic and numismatic representations that indicate the possible passage of the textile in question through a particular place.

In the case of the HS, for example, the remarkable similarity of the innumerable Byzantine depictions of the image of the peculiar face of Jesus of the HS helps the reconstruction of the historical path of the Relic.

The first example of this kind of iconographic analysis is the Pantocrator, conserved in Saint Caterina's Monastery, at the foot of Mount Sinai in Egypt, which was painted in the sixth century by order of Emperor Justinian I, see Fig. 5. The Ref. [Whanger, A. D., Whanger, M.,

The Shroud of Turin, an Adventure of Discovery Technique: A New Image Comparison Method and Its Applications, Providence House, Franklin, 1998, USA] found many points of congruence between the Pantocrator icon and the HS face, demonstrating that whoever painted the icon saw either the HS or a good copy of it.

Another example is the Cross of Justin II also known as "Crux Vaticana" ("Vatican Cross") dated around 568–569. It is kept in the Treasury of St. Peter's Basilica, in Vatican City and itis perhaps the oldest staurotheke (reliquary of the Christ's Cross). It is a jeweled cross in gilded silver 35 cm (13.8 in.) tall, given to the Roman people by the Emperor.

Figure 5. Christ Pantocrator of St. Catherine's Monastery at Sinai.

From a numismatic point of view, it is evident a close correlation between the images of Christ on the Byzantine coins and the image of face on the HS. Ref. [Fanti Giulio, Byzantine Coins Influenced by the Shroud of Christ, Jenny Stanford, 2022, Singapore] reports, among others, the following information.

1) The first indirect numismatic reference to the HS appears around 420 when the Byzantine emperors minted mensural crosses showing the sizes of the body of Jesus Christ that should have measured from the relic.

2) The first official image of Jesus Christ on a coin is the one produced under Emperor Justinian II in 692 A.D. The probability that the engraver, in making the mold for the coin, was inspired directly by the image on the HS is calculated to be more than 99%.
3) An aesthetic investigation shows that the hypothesis that the image on the HS was copied from a Byzantine coin is to be rejected.

7. INFORMATION FROM VACUUMED DUSTS

7. 1. DNA analysis of contamination

It is very easy for an ancient textile to come into contact with various persons over the centuries and therefore to keep in its fibers precious information about who have somehow contaminated it.

Just touching a textile with your hands involves a transfer from the skin of sweat and other particles into the fibers of the fabric which therefore also retain genetic information about the person who came into contact with it over time.

A DNA analysis of vacuumed textile particles can therefore indirectly provide valuable historical information about the possible textile exposition in various places.

For example, some dusts from the HS were vacuumed and subjected to DNA analysis. Ref. [8] reports the main findings from the analysis of genomic DNA.

Several plant taxa native to the Mediterranean area were identified; regarding human mitogenome lineages, sequences from multiple subjects of different ethnic origins were detected, which clustered into a number of Western Eurasian haplogroups, including some known to be typical of Western Europe, the Near East, the Arabian Peninsula and the Indian sub-continent.

The results regarding Human mtDNA haplogroups found on the HS (38.7% from India, 55.7% from Middle East and only 5.6% from Europe) indicated a probable Indian manufacture of the textile.

7. 2. Electrum particles

In addition to the genetic analysis, the dust aspirated from the textile can provide interesting additional information. For example, if the textile was used for burial purposes as in the case of the HS, traces of essences and anti-putrid substances such as aloe and myrrh can be found, as well as traces of blood.

Of particular interest, the analysis of HS aspirated dusts also led to another finding. Ref. [37] reports that micro-particles of electrum were detected via Energy Dispersive X-ray Fluorescence analysis. Electrum is an alloy of gold and silver with traces of copper, typical of coins minted in the Byzantine Empire around the tenth-eleventh century A.D.

It is well known that the Electrum gold-silver alloy is not frequent in the gold coinage of ancient time. The presence of this alloy can be considered typical of the Byzantine Empire, if we exclude the Lydian coins of 6th century B.C. and few other rare cases not applicable for possible correlation with the HS. This result, therefore, is an additional clue of the HS presence in the Byzantine Empire in the period up to 1204 A.D.

After the publication of this study the first author was contacted by his American friend Russ Breault, president of the Shroud of Turin Education Project Inc., who proposed the following explanation for the presence of these electrum micro-particles. As indicated by a micro-particle found inside a longitudinally cut linen fiber, R. Breault hypothesized that this result was due to the sliding of electrum coins (showing on one side the image of Jesus Christ) for the realization of contact relics.

8. CONSERVATION OF THE TEXTILE

A very important point that cannot be exhausted in these few lines concerns the study of the most suitable conservation of the textile, in fact the conservation methods of textiles are various and also depend on the type of specimen under examination.

For example, if the textile is linked to religious factors such as the HS or the tunic of some saint, the factor linked to "objects of awe" must also be kept in mind, which complicates even more and considerably limits the choice of type of conservative intervention. Ref. [38] reports the following.

"Awe severely limits a conservator's options; it is the greatest inhibitor of choice. …. In such cases, all concerned instinctively recoil from intrusive treatment because they understand that any action may negatively affect the future significance of the object. ... Most textile conservators now consider only preventive conservation in the form of passive mounts .... Invasive treatment is no longer considered appropriate for textiles of unique significance. ... It is universally acknowledged that over-ambitious treatment may prejudice artistic or cultural significance. ... The race to distance conservation from restoration became a strong characteristic of our field from the 1960s to the mid-1990s."

In the case of HS, things get even more complicated because the body image, produced not by pigments but by a chemical reaction of linen which is analogous to aging, tends to disappear over time because the background tends to reach the same color of the body image. To avoid this, it is necessary to reduce as much as possible the environmental factors linked to the aging of the linen, first of all the lighting.

In addition to the presence of these elements, we must also consider that it is very important to avoid possible deterioration of the blood and the DNA contained in the body fluids.

Unfortunately, a heavy intervention was carried out in 2002 on the HS and this is the comment of an expert archaeologist, W. Meacham of Ref. [Meacham William, Comments on the Shroud "Restoration", www.shroud.com/restored.htm]. "The "restoration" of the Shroud was thus clearly in opposition to modern conservation practice. I insist on putting the word restoration in quotation marks because it was not a true restoration either, but a series of radical, invasive alterations and cleaning operations for either cosmetic purposes or grossly misinformed conservation purposes. The precious relic was handled for almost a month in bare hands without gloves, often with unnecessary lighting directed on it, and subjected to considerable stresses in the removal of patches and backing cloth, and addition of a new backing cloth."

The HS is now conserved laid flat, see Ref. [5], in the Cathedral of Turin in a dark container at uniform temperature. Many studies involving direct analyses will be necessary to solve the many open scientific questions especially addressed to the unknown image formation, but, from a conservation point of view, it is necessary to perform the smallest number of tests, especially avoiding those which require high-power light sources, in order to minimize the aging process.

In the last few decades, much has been done to improve the conservation status of the HS, especially when it was decided to keep it in a controlled environment, no longer rolled up on itself. But can it be stated that all the conservation problems have been solved? We should not forget some problems reported in Ref. [3] related to prolonged deterioration, because our care in conserving the HS will make us responsible for ensuring that future generations can see the body image as we admire it today.

9. COMMENTS AND PROPOSALS FOR FUTURE STUDIES

As is the case with many textile archaeological finds, even for the HS, there are many questions that are still unanswered. However, if some fabric of secondary importance does not require that all the information it hides be discovered, in the case of fabrics of primary importance as in the case of some relics, it would be important to deepen the studies with modern investigation techniques.

In the case of HS, we have seen that much was done by the STuRP American group in 1978, but since then only isolated and limited research has been done by smaller and less equipped groups.

In 2002, as we saw in Section 8, a questionable intervention was carried out, during which textile samples of various kind were collected, but which have not yet been given to scholars capable of examining them and obtaining useful scientific and historical information.

Instead, it would be important to apply innovative techniques including those described in Section 1 such as OM, SEM, FEG-SEM, TEM, EDS, RS, FT-IR, FORS and LC which are mainly non-destructive and non-invasive. However, the sizes of the HS in many cases do not allow the entire fabric to be subjected to the tests mentioned and it is therefore necessary to carry out the analyses on appropriate samples taken from the relic for the purpose.

Obviously in this case there is the sampling problem which should be as least invasive as possible, but in most cases, it is sufficient to take samples on a micrometric scale which practically do not degrade the integrity of the relic in any way.

However, in order to carry out these samplings with the subsequent tests, it is necessary that a large commission of worldwide experts be appointed who, following the example of the STuRP, carry out preliminary analyses on dummy samples suitably prepared to simulate the type of information obtainable and the possible invasiveness of the test.

It is then necessary for this commission to include a very large number of experts, each one both for the discipline that interests the analysis and for the disciplines with which each analysis can interfere.

For example, in the 2002 intervention, two textile experts were called who, even excellent in their field, probably knew little of the fact that light accelerates the process of reducing the contrast between body image and background. As a result, they worked for several days with intense lighting aimed directly at the fabric. So, if they did an acceptable job from a textile point of view, they accelerated the process of image deterioration that any chemical expert would have tried to avoid.

And if the STuRP was made up of 33 experts in various disciplines, today's commission should not be less numerous because, since then, new fields of investigation have opened up that should not be overlooked.

Among other, it should not be forgotten that various scientific hypotheses of image formation regarding HS have been proposed, based on disciplines ranging from chemistry to biology, from physics to forensic medicine and optical image analysis. Furthermore, the scientific approaches to the study of tissue fall into the following groups: chemical, physical and historical material analysis, biology of both the body fluids of the wrapped Man and of the vegetal material, medical examiner, engineering of the materials and image analysis.

The group of experts should also not forget to:

- search for an explanation regarding the formation of the body image also using innovative microscopes such those already mentioned above,
- analyze and classify different types of blood impregnated in the HS: pre- and post-mortal, venous and arterial, mixed or not with other body fluids,
- analyze the possible environmental factors that can have interfered in the past with the linen fabric and those that can interfere in the next future as a function of the conservation choices and therefore minimize them.

10. CONCLUSIONS

It is not simple to perform a systematic study on an ancient textile because there are many topics to be explored and very different techniques can be used depending on the type of specimen in question. For this reason, the paper considered as an example the most important textile in the world for Christians, the HS, presenting and discussing the techniques that have recently been applied to it.

After a brief presentation of the artifact and an explanation of its complexity from various points of view, to understand how many and which types of studies can be performed on a textile to increase information on it, a mention has been made to some tests with the respective results obtained by the group of American scientists named STuRP which in 1978 carried out very sophisticated scientific analyses.

The particular characteristics of the textile were then summarily described both from the point of view of the unexplainable double body image there visible and the bloodstains present on the textile, which have raised some controversies.

We then addressed the complex problem of dating the textile, which in the case of HS provided conflicting results, some of which were widely criticized for the lack of evaluation of possible environmental effects that may have altered the results. In the case of fabrics, in fact, it is very easy for some types of contamination to seriously affect the results. To confirm the result suggested by tradition, other new dating techniques of the HS were presented and discussed, thus confirming the dating to the first century AD. In addition, a possible explanation was here discussed for the fact that the 1988 radiocarbon dating provided a result incompatible with many others.

Alternative dating methods were described, such those based on the mechanical parameters of the flax fibers, the chemical characterization of the flax by Raman and FT-IR spectroscopic analysis and the X-rays analysis, which analyzed the degree of depolymerization of cellulose; a numismatic and iconographic analysis was added too.

The statistical analysis of the human DNA vacuumed from the textile, produced by the contact of people that over the centuries touched and kissed the relic, allowed to provide an interesting hypothesis of the origin of the textile. In fact, the resulting Human mtDNA haplogroups (38.7% from India, 55.7% from Middle East and only 5.6% from Europe) suggest an Indian manufacture of the textile.

The analysis of the metallic particles vacuumed from the HS allowed to recognize the high percentage of electrum micro-particles, a gold and silver alloy frequently used in Byzantine coinage in the first millennium A.D.

Finally, the problems related to the conservation of the textile are also discussed, also considering the possible factor linked to "objects of awe", which complicates the choice of type of conservative intervention. After some critical comments on what has been done so far, some proposals for future analyses are finally formulated.

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