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In this paper, we study the possible interactions between radiation and the Linen of Turin. The work is in line with the research focused, by scholars and scientists, on the detection mechanism of the Shroud body image formation. We have analysed the interactions between thermal, UV and particle radiation with the linen fabric. The performed analysis shows that any hypothesis of the Shroud body image formation by radiation must be rejected. Only the background was produced by the action of electromagnetic radiation.

Keywords: radiation–Shroud interaction; thermal, UV and particle radiation

PACS: 87.50.-a; 87.50.Eg; 87.50.Gi

1. Introduction

Among the archaeological findings that interest both scientists and non-scientists alike, the Shroud of Turin is certainly the most intriguing.

This cloth is an old rectangular piece of linen $\sim$4.36 m length $\times$ 1.10 m width. On it appears the image of a man (front and back), victim of a violent scourging and crucifixion. Moreover, on the linen are also visible burned and scorched areas (due to the 1532 Chambery fire), water marks and patches.

The Shroud has a history that can be traced back only to the year 1350, when it was in the possession of Count Geoffrey I de Charney in Lirey, France. In 1452, the cloth was ceded to Duke Ludwig I of Savoy. This last family protected it until 1983 when Humbert II gave it to the Roman Catholic Church. However, how it arrived in Lirey remains a mystery even today. In Figures 1 and 2, we show photographs of the Shroud of Turin.

Nowadays, many people think it is the burial cloth of Jesus of Nazareth; for others, it is a medieval forgery. Some believe absolutely that the body image is the result of a flash of light related to the resurrection. We do not agree with this picture of the body image formation and have decided to investigate the possible interactions between different kinds of radiation and the Shroud.

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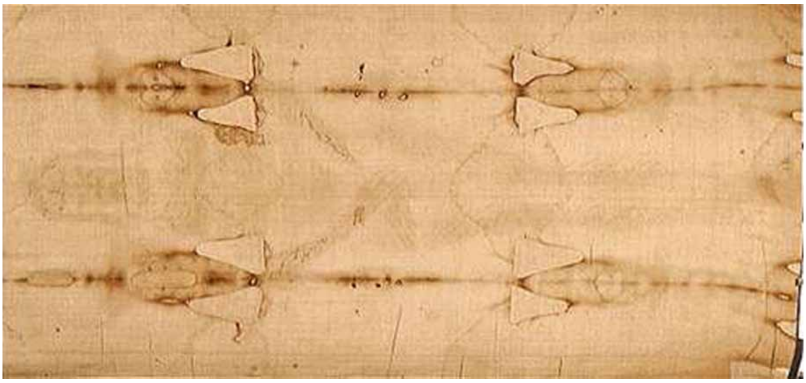

Figure 1. Photograph of the full frontal part of the Shroud body image.

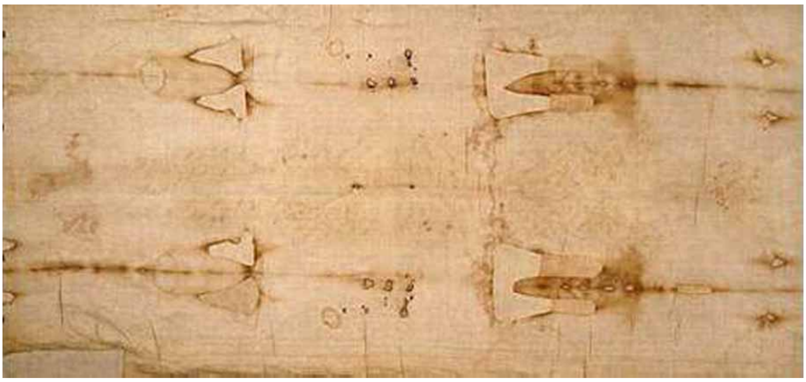

Figure 2. Photograph of the full dorsal part of the Shroud body image.

The chemical and physical characteristics deduced by the 1978 observations and experiments performed in Turin are great in number. Therefore, we refer the reader to (*1*), which is a complete synthesis of all these experiments and analyses.

Here, we wish to underline that on the Shroud of Turin, the linen fibrils (of about 10–15 μm thickness) are yellowed, with only two optical density values (*2*). They have almost the same value of optical density in the no-image area, which determines the background colour of the linen. In contrast, in the image area, there are fibrils with both optical density values: the background ones and others which are more yellowed, as Pellicori and Evans (*2*) have shown in their study. However, all of the fibrils have one of the two optical density values.

The ones with the background value delimit the regions (either in the large no-image area or within the image area with the fibril dimensions) where the linen is chemically modified within its whole thickness ($\sim$345 μm), and shows an almost constant optical density value. On the contrary, the more yellowed fibrils are modified almost only superficially, with a depth of a few tens of a μm only (the thickness of two or three fibrils) (*3*).

The latter yield a measurable intensity of the body image (*4*, *5*):

$$I(z) = I_b + I_M\left(1 - \frac{z}{R_0}\right), \tag{1}$$

where z is the estimated cloth–body distance, I_{b} the intensity of the background colour, $I_{\mathrm{b}} + I_{\mathrm{M}}$ the colour intensity in the contact areas (the regions with $z = 0$), and R_0 is the cloth–body distance which gives $I(z) = I_b$. However, underneath the 20–30 μm thickness of the yellowed fibrils, there are always fibrils with the background colour.

In contrast to the optical density, the image intensity I shows continuity in its trend because it represents the density of the more yellowed fibrils. In fact, in the contact areas, where the image appears to be darker, the intensity assumes the maximum value of the yellowed fibril density. It changes its value, as the analytic expression of the above parameter (Equation (1)) shows.

In this paper, we discuss a linen that enveloped a human body for the characteristics of the image that is made of blood. In fact, in the central part of any bloodstain, there are proteins (haemoglobin and albumin), whilst all around there is only serum (*6–9*). Therefore, the formation of the blood image is due to a contact mechanism between the linen and the human body enveloped in it (*6–8*). Additionally, biliary pigments are present in the blood (*6*).

The formation of the body image is unknown. We think there are at least two mechanisms: one of contact (as the single mechanism that has acted in the Shroud blood image formation), which explains the high resolution of the image, and the other, that, acting at a distance, explains the existence of the correlation $I(z)$ well represented by Equation (1) (*5*).

2. The radiation–fabric interactions

The background colour, due to the oxidation and dehydration of the cellulose present in the fabric (*10–12*), has a yellowing that is almost constant throughout the linen cloth.

A comparison with other linen fabrics shows that this is the result of the interaction with electromagnetic radiation, because it occurs to any linen fabric exposed to light and/or heat, with an optical density that is related to the received energy (which also depends on the exposure time).

For the most interesting body image area, it is necessary to justify the chemical cellulose modifications of the fibrils with the optical density value as observed by Pellicori and Evans. In this context, we have studied thermal emission, ultraviolet and particle radiation.

2.1. *Thermal radiation*

When analysing a possible emission of thermal energy from the human body, it is important to underline that dehydrative and oxidative processes only lead to a shallow yellowing of the linen's cellulose structure (*3*).

In this picture, we consider the known expression

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = -cA\frac{\mathrm{d}T}{\mathrm{d}x}, \tag{2}$$

where $\mathrm{d}Q/\mathrm{d}x$ represents the speed of heat transfer through the surface A, c is the linen's thermal conductivity ($5 \cdot 10^{-4}$ cal/cm s K) and $\mathrm{d}T/\mathrm{d}x$ is the temperature gradient.

Equation (2) is in line with the few tens of a micrometre thickness because the low value of c makes the temperature gradient very high. Consequently, the thermal state of the linen changes rapidly with the depth and the transfer of energy of interest affects only the first two or three superficial fibrils (20–30 μm).

Unfortunately, for this hypothesis, the energy emitted for unity of surface and time,

$$R = e \cdot \sigma \cdot T^4, \tag{3}$$

is very low, taking into account the e value of the body emissivity, the Stefan–Boltzmann constant ($\sigma = 5.67 \cdot 10^{-8}$ w/m^2 K^4), and the temperature T of the emitting body (*12*, *13*). Therefore, this energy is not sufficient to oxidise and dehydrate the cellulose in the fabric as it appears on the Turin Linen.

2.2. *UV radiation*

For the ultraviolet radiation, it is difficult to hypothesise that a human body is a source of photons with λ values of some hundred nanometres. Their energy would, however, be sufficient to cause photochemical reactions with the cellulose within the linen. Consequently, the deduced discolourations of the linen should take the characteristics of the Shroud body image into account.

We have calculated the average penetration depth and later deduced how the chemistry of the linen should be modified by the action of the UV radiation.

Owing to the energy of the photons mentioned above, the interaction with the fabric occurs mainly because of a photoelectric effect. In such a case, the attenuation coefficient is $\tau = \sigma N$, where N is the number of atoms per cm^3 and σ the atomic cross section in cm^2 per atom. An estimation of τ can be obtained (knowing the attenuation coefficient of another substance) using the standard relationship (*14, 15*):

$$\tau_1 = \tau_2 \cdot \frac{\rho_1}{\rho_2}\frac{A_2}{A_1}\left(\frac{Z_1}{Z_2}\right)^n. \tag{4}$$

In the above relation, the numbers 1 and 2 are used for the linen and water, respectively, because we know the attenuation coefficient values versus λ for the latter substance (*16*). A is the atomic weight, ρ the density, Z the atomic number and n a function of the photon energy. Starting from the value of the attenuation coefficient for UV radiation of $\lambda = 250\,\text{nm}$ in water ($\tau = 3.76 \cdot 10^{-4}\,\text{cm}^{-1}$ (*16*)), we have calculated, using Equation (4), the same coefficient for the linen, which results in about $10^{-4}\,\text{cm}^{-1}$.

In our case, we compared the cellulose structure ($(C_6H_{10}O_5)_n$) with water (H_2O), deducing the Z values by the ratio $\Sigma n_i Z_i^2 / \Sigma n_i Z_i$. In this last expression, n_i and Z_i are the atomic fraction and the atomic number of the ith element, respectively, for the calculations in the cellulose and the water structures (*17*).

The corresponding average penetration depth is in the order of of many tens of a centimetre. Consequently, it is not in line with the depth of the yellowing characteristic of the Shroud body image. Besides, this radiation does not reproduce the chemistry of the above image. In fact, it does not distinguish the fibrils that should be yellowed to reproduce the chemical of the Shroud body image.

2.3. *Particle radiation*

This mechanism of body image formation is related to emission particles, such as protons, from the human body. For us, this hypothesis is very unlikely. However, we also investigated this mechanism using the SRIM program (*18*), a collection of software packages which calculate many features of the transport of ions in matter. With this program, we deduced the penetration depth of a beam of protons that impact, with perpendicular direction, the fabric. We furnished to the above program the incident energy of the protons and the density of the cellulose structure ($(C_6H_{10}O_5)_n$), 1100 keV and 1.017 g/cm^3, respectively. As a result, these particles would penetrate into the linen by about 30 μm, which corresponds to the thickness of two or three linen fibrils.

With this state of affairs, the emitted protons could reach the fabric with an energy that decreases when the cloth–body z distance increases. The result would be a uniform yellowing with a constant optical density for all the fibrils that are at the same distance. Consequently, the above density will change with continuity.

In other words, the particles (we can also use d, t, τ, α of suitable energy) would guarantee the characteristic body image depth but do not fit to the observation of Pellicori and Evans. In fact, these authors showed that in the Shroud body image region, the optical density does not change with a constant trend: it assumes two values only. Therefore, we exclude the above mechanism. The same is true for the flash of light, because there are no tracks on the linen (*7*).

2.4. *Other radiation*

Recently, starting from the Pellicori and Evans observation (*2*), we have shown that the Shroud, during the body image formation, has absorbed energy with discrete values (*19*). In fact, in the image region, there are fibrils with only two optical density values.

This means that the fibrils which are more yellowed have received the same quantity of energy necessary to change the optical density from the background value to the one observed by Pellicori and Evans (*2*). Therefore, in this paper we do not consider the corona discharge (*20*) and the excimer laser irradiation that could simulate the Shroud body image by colouring the linen (*21*). In fact, these mechanisms do not yield the discrete distribution of the yellowed fibrils that was found in the image.

Among all the characteristics of the Shroud body image, this is the one which is most difficult to satisfy. In fact, we cannot write an expression like Equation (1) for the optical density; only for the density of the yellowed fibrils or, which is the same, the intensity of the image.

3. Conclusion

In this paper, we have considered the possible interactions between radiation and the Turin Shroud. At first, we made energetic calculations comparing the obtained results with the depth of the yellowing that yielded the body image. Later, a comparison was made with the chemistry of the linen cloth.

Unfortunately, the thermal hypothesis is not a suitable formation mechanism because the energy is not sufficient to modify the chemistry as it is in the Shroud's body image region. Besides, this mechanism does not agree with the observations of Pellicori and Evans (*2*).

Subsequently, we have analysed the possible interaction with UV radiation, although we are not able to imagine a human body that emits the above radiation. We have calculated the average penetration depth, comparing it with the thickness of the linen. However, a mechanism that has its origin in UV radiation does not correspond to the discrete distribution of the optical density.

Finally, we had the same difficulty when we considered a human body emitting particles. In such a case, the calculations satisfied the thickness of the yellowed fibrils that yielded the Shroud body image. However, such particle irradiation cannot explain the linen's chemistry, because we have deduced a continuous distribution of the optical density in the fabric.

In conclusion, all radiative hypotheses related to the formation mechanism of the Shroud body image must be rejected, as they do not satisfy the known characteristics of the above image. Only the background colour was produced by the action of electromagnetic radiation, in the same way as it acts on any linen fabric.

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