BODY IMAGE FORMATION HYPOTHESES BASED ON CORONA DISCHARGE

Giulio Fanti[1], Francesco Lattarulo[2], Oswald Scheuermann[3]

[1]Department of Mechanical Engineering, University of Padua,
Via Venezia 1, 35137 Padua - Italy, e-mail: <giulio.fanti@unipd.it>
[2]Department of Electrical and Electronic Engineering, Polytechnic of Bari
via Orabona, 4 - 70125 Bari – Italy, e-mail <lattarulo@deemail.poliba.it>
[3] Am Neubruch 25, 90571 Schwaig-Behringersdorf, Germany

SUMMARY

The present paper proposes two possible hypotheses of the body image formation of the Turin Shroud (TS) based on corona discharge (CD). An impression mechanism based on CD proves to be the most credible one after verifying that some characteristics of the TS image are not in full agreement with the hypothesis of a simple burst of light proposed by K. Moran and G. Fanti in 2002.

Theoretical and experimental results relative to plasma in the air are presented and discussed on the basis of a comparison with data relative to the TS both at macroscopic and microscopic levels. Even if the environmental hypotheses relative to CD can be refined, the experimental results obtained show no appreciable chemical-physical differences from the image features of the TS.

1) INTRODUCTION

The Turin Shroud (TS) is a 4.4 m long and 1.1 m wide linen sheet that wrapped the corpse of a scourged, thorn-crowned man who was stabbed in the side with a lance and crucified (Jumper 1984, Adler 1996). There are also many marks caused by blood, fire, water and folding impressed on the sheet that partially cancel the double body image (front and back) indelibly impressed. The wounds are what interest forensic pathologists most because they would be very difficult to produce.

The body image is extremely superficial, but in some areas of the frontal image, such as those of the face and perhaps the hands, it is superficial on both sides (Fanti 2004). This means that, considering the thickness of the fabric where the image of the face is, there is a very superficial image on the top and one on the bottom, but nothing in the middle; the top and bottom images correspond in both shape and position.

The TS is believed by many to be the burial cloth Jesus Christ was wrapped in before being placed in a tomb in Palestine about 2000 years ago. It is the most important relic of Christianity and has generated more controversy than any other religious relic.

Scientific interest in the TS developed after 1898, when S. Pia, who photographed it, noticed that the negative image on the TS looked like a photographic positive. In 1931, G. Enrie photographed the TS at high resolution using an orthochromatic plate. In this photograph, the TS body image looks like a photographic negative, and its luminance levels can be related to the 3D image of a human body. The bloodstains are of human blood, transposed to the linen fabric by fibrinolysis (Adler 1996).

A scientific analysis of the TS in 1978 by the STURP (Shroud of TUrin Research Project) (Jackson 1984, Jumper et al. 1984, Adler 1996), found no scientific explanations for the body image on the TS. One attempt at explanation states that the image formed as if it were caused by exposure to a short-lived but intense source of energy coming from the body enveloped in the TS itself.

Many hypotheses and experimental tests have been carried out on linen fabrics to explain the formation of the body image, but for the moment no exhaustive solution has been found. The hypothesis of a source of radiation from inside the enveloped body has a large consensus even if some points must be still be demonstrated. Although good experimental results have been obtained on the basis of other hypotheses, all these proposals are unable to describe all of the characteristics of the body image listed (Fanti et al. 2005).

In 1983, O. Scheuermann proposed a possible body image formation mechanism based on CD and obtained some interesting experimental results, but his studies were interrupted because of the 1988 radiocarbon results. In 1984, I. Bensen proposed ball lightening as the source of energy for the body image formation. In 1985, R. Morgan reported a hypothesis of image formation by means of corona discharge made by G. Coote who proposed the piezoelectric effect of quartziferous rock subjected to earthquake as the source of an electrostatic field. In 1986, J.B. Judica Cordiglia obtained some images on linen samples using an electrostatic technique. In 1997, E. Lindner proposed an electron source as the cause of the body image formation. In 1998 F. Lattarulo theoretically proposed a hypothesis of image formation based on CD generated by an outer source and in 2000, G. De Liso obtained some images on linen cloths during earthquakes, but these works were not broadly considered.

A CD is an electrical discharge (Chen J., 2002) brought on by the ionization of a fluid surrounding a conductor, which occurs when the potential gradient exceeds a threshold, in situations where sparking is not favored. In a CD, a current develops between two high-voltage electrodes in a dielectric fluid, usually air, by ionizing the fluid so as to generate a plasma (which is the fourth state of matter beyond solid, liquid and gas) around one electrode. This leads to the collection of electrons and ions made by stripping the electrons from atoms and electronic emission from the negatively polarized electrode. The ions generated are used as the charge carriers to the other electrode. CD usually involves two asymmetric electrodes, one highly curved (emitter, injector or active conductor) and one of low curvature (collector). CD may be positive (if the emitter is positive) or negative, but the relative physics are different as a result of the difference in mass between electrons and positively charged ions. A neutral atom in a fluid, which is a region subject to a strong electric field, can be ionized by an exogenous environmental event, resulting from, for example, a photon interaction that generates a positive ion and an electron. The strong field then separates these charged particles and accelerates them. Additional electron and positive-ion pairs are then generated by collision causing a chain-reaction or electron avalanche. An ion species generated in this series of avalanches is attracted to the less curved electrode, completing the circuit, and maintaining the current flow. During a CD, blue/white glowing can often be seen because most of the emissions are in the UV (Ultra Violet) range. A negative CD happens in a non-uniform corona and generally has less energy than a positive CD, but the electron density is greater.

CD has applications, for example, in photocopying or ozone and NOx manufacturing and is generally avoided in electric power transmission, where it is sometimes called Partial Discharge, owing to the loss of power in corona processes audible noise and electromagnetic interference.

In the present paper first a brief discussion of the limits regarding different hypotheses on body image formation is discussed. Then the evidence that lead us to maintain that CD is a mechanism of image formation is described showing how CD satisfies all the facts listed in Fanti et al. (2005). The CD hypotheses are then supported with experimental, numerical and theoretical results. A description of the more favorable exogenous environmental factors that cause CD, in alternative to a supernatural inner source, is made with reference to the geological conditions in Palestine.

2) CRITICAL REVIEW OF PAST WORKS AND HYPOTHESES

Perhaps the greatest challenge for TS investigators is explaining how the body image was formed. Some researchers have hypothesized that an artist produced the image artificially by different means. However, G. Fanti et al. (2005) stated that, among other important facts, the image color resides only on the topmost fibers at the highest parts of the weave; this color resides on the thin impurity layer of the outer surfaces of the fibers while the medullas cellulose of the fibers in the image areas is colorless. Furthermore, the frontal image, at least the part corresponding to the head, is doubly superficial. Presently, no tested artists' works are able to show these peculiar characteristics.

A diffusion mechanism has been suggested by many researchers, such as R. Rogers (2002) who proposed that the body image is the result of a chemical reaction of the decomposition gases of the corpse with the linen cloth. However, this is inconsistent with some of the characteristics discussed by G. Fanti et al. (2005) who reported that the body image shows no evidence of putrefaction signs, in particular around the lips, and that there is no evidence of tissue breakdown (i.e. the formation of liquid decomposition products of a body). In addition, the resolution of the body image of 4.9±0.5 mm (G. Fanti, September 2005) has not yet been reached experimentally using a diffusion technique.

A direct contact has been proposed by many researchers, such as J. Volkringer (1991) and A. Mills (1995), but this hypothesis is inconsistent with some of the characteristics given by G. Fanti et al. (2005), such as the fact that a body image is visible even in the body-sheet non-contact zones such those between the nose and cheek.

Some researchers, such as J. De Salvo (1982), proposed the hypothesis that many mechanisms affect the body image formation. It has also been suggested that a diffusion mechanism can act in parallel with direct contact and perhaps also with radiation. In the experience of the authors, a solution to a problem that is not well understood can be reached assuming the presence of many different causes acting together, but frequently this solution hides the inability to reach the essence of the problem. Therefore, by applying the Occam's razor principle of minimum assumption, the situation both needs to be simplified and selected facts highlighted.

In order to explain all the characteristics discussed in G. Fanti et al. (2005) there would have to be a radiation source coming from the enveloped body, as previously proposed by many researchers. For example, a nuclear irradiation was proposed by J. B. Rinaudo (1998) and J. Jackson (1990) suggested the image was caused by soft UV radiation generated by a corpse that had become mechanically transparent. Nevertheless, these hypotheses are based on some facts that are not scientifically reproducible. G. Fanti with K. Moran (2002) as well were inclined to think that there was "*… radiation, perhaps of light, coming from the wrapped corpse*," also because this would account for "*… the fact that a body image is present where no body-cloth contact can be supposed*". However, later studies showed that the best way to agree with all the very particular characteristics of the body image is to consider not a common radiation source such as light, but a unidirectional radiation connected with the CD hypothesis. This conclusion was principally reached after the analysis of the following evidence in favor of a CD hypothesis.

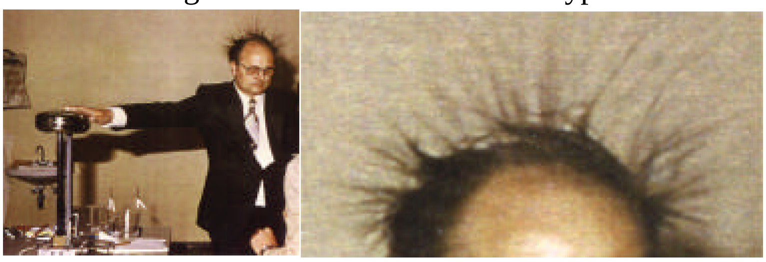

Figure 1. Hair disposition if a man (O. Scheuermann) is in contact with high-voltage electrostatic field produced by a Van de Graaff generator.

-1) The TS image of the hair (including the beard and moustache) is not simple to explain in a radiation hypothesis if no references are made to the electric field generated by the points and highly curved surfaces of the very thin cylindrical surfaces of hair, see Figure 1. This is because the TS hair is soft, as opposed to the supposed packing effects of anointing oils and body fluids such as blood and sweat. According to E. Lindner (1997), the hair image is an important sign of the presence of a radiation of electrons, but he hypothesizes that the protons disappeared and the bumping of the electrons against the neutrons lead the electrons to bounce against the TS causing the image.

-2) According to G. Fanti et al. (2005), the body image on the Shroud is extremely superficial not only at a macroscopic level involving the fabric, but also at a microscopic level involving the single image-fibers. The medullas of each image-fiber of the Shroud are not colored; only a 100-300 nm-thick layer of polysaccharides around each linen fiber is colored. The cross-polarized photomicrographs of these image-fibers show the presence of very few defects related to proton, neutron or photon radiation. No defects are experimentally obtained in the case of a CD coloration.

-3) According to G. Fanti et al. (2005), "[i]*f a fiber is colored, it is uniformly colored around its cylindrical surface*". A radiative model that considers photons or other particles that strike against a limited surface of the linen fibers cannot easily explain the fact that the medullas are not colored. This would indicate that an electrostatic model must be hypothesized. In this model, variously energized geometry-dependent surface streamers impact the linen fibers according to a radial configuration.

-4) According to G. Fanti et al. (2005), "[t]*he color of the image-areas has a discontinuous distribution along the yarn of the cloth*" and "[t]*he absence of saturation implies that the image formation did not go to completion*". This is another fact that is not simple to explain if any radiation composed of uniformly distributed photons is hypothesized unless outwardly directed single streamers (making up the glow corona) impact the barrier under examination (TS) with a surface distribution law in function of the surface electrostatic stress (surface electric field intensity).

-5) A numerical simulation of hands (G. Fanti May 2005) radiating different types of energy showed that in order to obtain an image like that of the TS, it is necessary to hypothesize that there is not a radiation ruled by the emissivity of non-metallic surfaces, but a unidirectional radiation normal to the skin surface. This condition is typical of electrostatic fields.

-6) The three-dimensional information of the TS is not always consistent in the sense that, according to G. Fanti et al. (2005), image details corresponding to the Face grooves are more faintly represented (e.g. eye sockets and skin around the nose) while convex "hills" on the Face (e.g. eyeballs and nose tip) are more clearly represented. Therefore, the correlation between image luminance and body-sheet distance is not always verified. This can be explained by the fact that, with reference to a surface electrostatic field, the more stressed locations correspond to the protrusions.

-7) Two hypotheses have been proposed on how the TS was placed around the body (see Figure 2). Hypothesis 1 states that the Man was tightly wrapped in the TS by means of bandages. Hypothesis 2 states that the body was enveloped in the TS and put horizontally over the tomb stone but due to cadaveric stiffness, the head is still tilted forward and the knees partially bent in accordance to the position on the cross (Fanti 2001). Around the corpse there are plants that prevent body-sheet contact.

According to G. Fanti et al. (2005), the luminance level variation of the image sections of cylindrical elements such as legs approximates a cosinusoidal law (see Figure 3 A and B). This fact can be easily explained by means of an electrostatic model considering a circle, vertical cross section of a cylinder representing a leg, (see Figure 3 C) and a luminance vector L orthogonal to the circle. If the luminance level variation L along the circle is proportional to the electric field E of Eq. 4 in Hypothesis A (explained below in §3), L is:

$$L = k\, E(\theta) = 2k\, E_o \cos\theta \qquad (1)$$

where k is a constant and ϑ the angle between the horizontal radius of the circle and L vector. In reference to Hypothesis 2 and Figure 3 C, the vertical projection L' of L is:

$$L' = L \sin(1-\vartheta) = L \cos\vartheta = 2k\, E_o \cos^2\theta \qquad (2)$$

If the luminance level variation L along the circle is proportional to a constant electric field E, as stated in Hypothesis B (explained below in §3), L' is:

$$L' = E_o' \cos\theta \qquad (3)$$

Therefore, a vertical projection L' of the luminance vector on the TS surface follows a cosinusoidal (linear or quadratic) law in accordance to the TS body image.

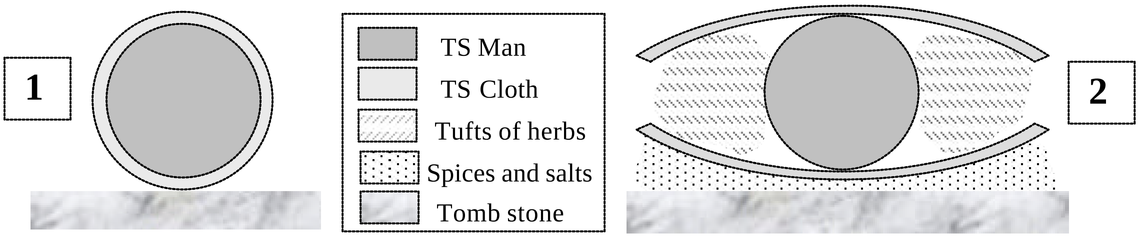

Figure 2. Two different hypotheses on how the TS was placed around the corpse: vertical cross section of the human body roughly schematized as a cylinder. -1) according to F. Lattarulo (1998), the Man was tightly wrapped; -2) According to G. Fanti (2001) the Man was enveloped.

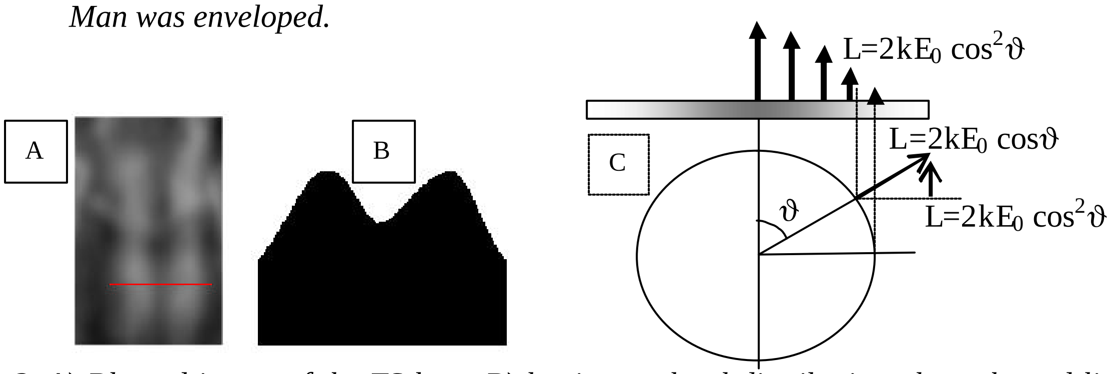

Figure 3. A) Blurred image of the TS legs; B) luminance level distribution along the red line of fig (A); C) schema of the distribution of luminance along a cross section of a cylindrical shape (leg).

-8) As will be shown in the section *5. Experiments and Results*, CD causes very a superficial and doubly-superficial, negative and undistorted 3-D body image, showing many details. On a chemical level, the color obtained by CD on linen cloth corresponds to a dehydratation of polysaccharides, as previously detected on the TS image.

Therefore, according to A. Adler (1999) "[s]*everal people have championed a coronal discharge mechanism ... and their experiments have provided samples … that come very close to meeting both the chemical and physical criteria*" of the TS characteristics.

3) HYPOTHESES INVOLVING CORONA DISCHARGE

Two different hypotheses involving CD can be proposed for discussing the body image formation process. These hypotheses, still in progress, are (see Figure 4):

- Hypothesis A) The Man was put in a tomb and subjected to an exogenous electrostatic field.
- Hypothesis B) The Man was put in a tomb and he directly generated an electrostatic field.

Hypotheses A and B can be combined with Hypotheses 1 and 2 of §2.7, but the combination B-1 does not seem to be directly related to the 3D features of the body image. With reference to the above hypotheses, the electric field is the result of a separation of electrical charges which can be assumed to be deposited in electrostatic equilibrium on the surfaces of three conducting objects (two flat electrodes simulating the tomb rock and a fluctuant electrode corresponding to the human body). In Hypothesis A, a virtual voltage is applied to the couple of flat electrodes, while in Hypothesis B, the voltage is applied between the body and the equipotential couple of flat electrodes.

In reference to Hypothesis A, the primary sources of the electrostatic field in the upper half-space are large (with respect to anthropometric magnitudes) quartziferous layers deposited in the lower half-space. However, for the sake of simplicity, the restricted electrostatic domain surrounding the human body can virtually be described by recurring to the currently adopted notion of a pair of indefinitely extended and parallel planar electrodes. The voids, filled by air, hold a floating and discharged (zero net-charge) conducting body. Therefore, the body can be seen as being located in a uniform electric field whose source is the pair of oppositely polarized boundary electrodes that emit opposite polarity stationary charges. The electrical field lines of the undisturbed electric field are vertical if the upper electrode system is made up of horizontal plates. The interposed floating conductor disturbs the surrounding electric field. Therefore, the overall electric field is characterized by equal inward and outward directed fluxes that are radially oriented around the body surface (see Figure 4 A). The local electric strength differs as a function of the body's geometry and orientation with respect to the undisturbed field.

In Hypothesis B the electrical field lines are radial as well, but the electric field pattern and local strengths differ significantly from Hypothesis A. This is because the electrode configuration in Hypothesis B (see Figure 4 B) is an energized (non-zero net charge) body located in the oppositely charged equipotential system (thus interconnected) made up of the pair of planar plates.

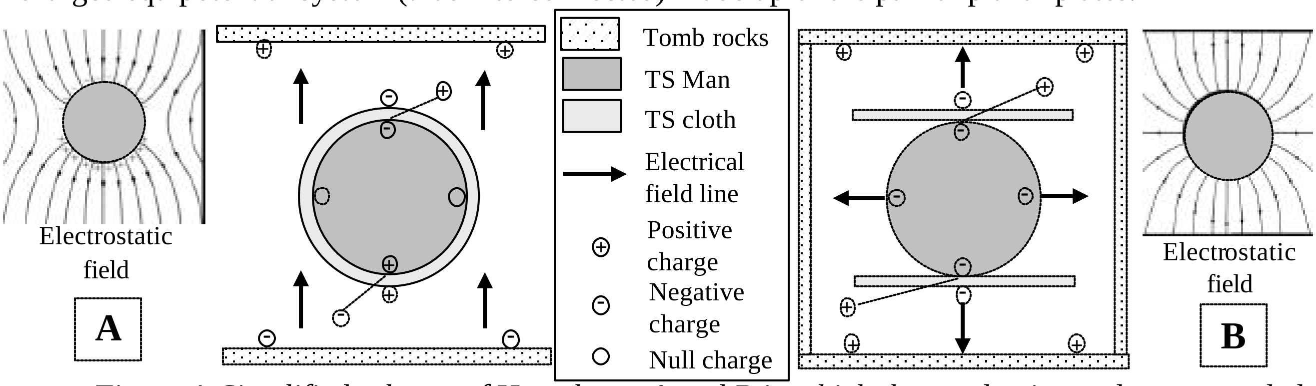

Figure 4. Simplified schema of Hypotheses A and B in which the conductive and not grounded or "floating" body is a cylinder (end fringing neglected).

3.1) Simplified electrostatic models

Hypothesis A (Lattarulo 1998)

A conductive and ungrounded cylinder (inner body) is inserted into a uniform electric field E_0. Accordingly,

$$E(\theta) = 2\, E_o \cos\theta \qquad (4)$$

represents the polar law for the surface field magnitude E(θ) (J.A Stratton 1941). Here E_o is the applied field and θ the angle that refers to the vertical direction.

The more stressed (at higher E(θ)) surface regions, namely those where the charge separation is characterized by larger densities, are in proximity of $\theta=0$ and $\theta=\pi$. E(θ) decays symmetrically, according to the above cosine law, up to zero for $\theta=\pm\pi/2$.

Hypothesis B

A surface deposit of charges (non-zero net charge) is present on a conductive and ungrounded cylinder (the human body) while the outer pair of boundary electrodes are grounded. If the latter electrode system is distanced enough from the inner body, the radial electric field E(θ) tends to be uniform as does the surface charge density. However, if the grounded electrode system comes closer, the non-negligible mutual electrostatic influence gives rise to a non-uniform E(θ)-distribution all around the inner body. This distribution cannot be represented by a formula similar to Eq. 4 since it is preferable to use numerical methods to study the field under examination.

Characteristics valid in both hypotheses

CD is present in the body surface where E(θ) exceeds the corona threshold, which is a function of the gas characteristics. The flux lines are orthogonal to the curve surface of the cylinder and, therefore, agree with the assumed direction of "radiation", which is orthogonal with respect to the skin as evidenced in (G. Fanti, May 2005). However, while in Hypothesis A the density charge is variable with angle θ, in Hypothesis B this density is almost constant.

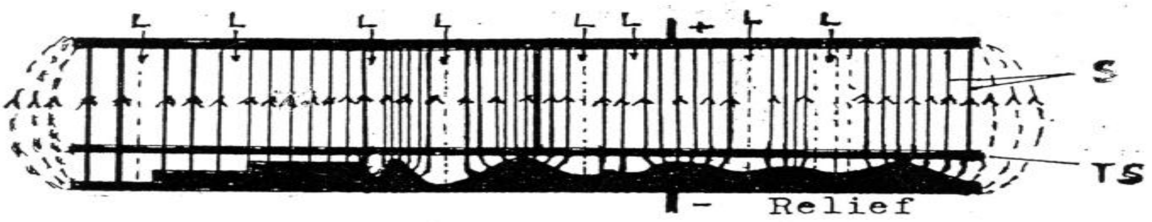

Figure 5. Schema of charge concentration at protrusions under a linen cloth (TS) and corresponding strength lines S; L=low density of the electrical field.

If the inner object (the human body) has an irregular configuration presenting protrusions and valleys, the local electric field strength changes significantly, becoming larger at the outer locations of the protrusions (see Figure 5).

-3.2) Body and environmental hypotheses

- *Hypothesis A)* The body was tightly wrapped in the TS by means of bandages and placed horizontally on the tomb stone. No other hypotheses on the configuration of the corpse, such as those described in Hypothesis B are necessary in this case.
- *Hypothesis B)* The body was enveloped in the TS and placed horizontally on the tomb stone, but due to cadaveric stiffness, the head was still tilted forward and the knees partially bent in accordance to the position on the cross (Fanti 2001). Around the corpse there are plants that prevent body-sheet contact; due to this configuration, no lateral images were impressed on the TS and some geometrical distortions (e.g. torso and calves) are explained.

Characteristics valid in both hypotheses

- The body covered by the TS was placed on a dry (thus insulating) stone covered by spices and salts. The field perturbation related to the different dielectric constants of the insulating components, air included, are assumed to be negligible in comparison to the perturbation caused by the conducting body.
- At the moment of the image formation, the TS (whose basic constituents are cellulose and air) had been anointed with oil, which is dielectric, and other similar substances or it was dry. Therefore, the fabric is assumed to be a dielectric posed around the body.
- There were air-filled interstices in the dielectric compartments between the stone and body.
- The air was ionized by radon so that the CD threshold significantly decreased.

-3.3) Bloodstain formation hypotheses

- The human blood clots were wetted with a cloth, redissolved and transposed onto the TS by means of a fibrinolysis process.
- After the bloodstains were transposed onto the cloth, a CD began and a body image formed on the TS yarns, but blood on the fibers act as a local barrier to corona bombardment, thus preventing the shielded fibers from undergoing any corona aging.
- In reference to Hypothesis 1, the lack of flagrum signs in zones where there is lateral contact, for example the legs, lead us to assume that there were objects, such as bandages, placed between the lateral part of the legs and the TS.

-3.4) Corona discharge hypotheses

It is known that CD occurs in nature as an electrostatic discharge (S. Elmo's fire, according to an old-fashioned terminology) during thunderstorms. Furthermore, if a conducting rod in non-ionized air is put close to, but non in contact with, an opposite conductor (for example, a plane collector), CD will occur, especially concentrated around the tip, if a suitable voltage is applied to the electrode system (see Figure 6).

It is also known that an earthquake can cause a large electric field surrounding compressed rock layers of quartz (quartz crystals are present for example in granite or gneiss layers). The possible presence of large amounts of radon, frequently detected before and during earthquakes, makes the environmental air a highly ionized medium. In this environment, CD effects have been detected on and above the earth surface. An earthquake is mentioned in the New Testament, a circumstance leading to make the following suppositions.

Figure 6. Positive CD in non-ionized air at a conductive point. The experiment involved a conductive point (left) in proximity to a plasma ball covered by a sheet of paper (right).

-*Hypothesis A)* A surface corona process in the tomb formed a complete image as a result of an exogenous electric field produced by the piezoelectric effect of quartziferous layers. The triggering mechanical cause was an earthquake, which also caused a significant pre-ionization by radon efflux and concentration. It is worth considering that earthquake-originated electric fields are generally not strong enough to produce CD on smooth conductive surfaces unless the corona inception level is lowered by environmental pre-ionization.

- *Hypothesis B)* CD over the body could have been a by-product of a particular phenomenon, such as the Resurrection (a phenomenon that cannot be discussed on a scientific level). Perhaps the corpse emitted electrons as a form of radiation (β-rays are electron rays). In this case, any reference to pre-ionization becomes an insignificant detail.
- *Hypothesis A)* The presence of radon (common when there are earthquakes) in the environment drastically promoted the corona activity even in the realistic presence of an electric field that was not exceptionally strong.
- *Hypothesis B)* The not necessary presence of radon reduced the ESD threshold.

Characteristics valid in both hypotheses

- During a CD, air produces free electrons and positively-charged ions.
- The energy associated with the corona streamers is not enough to directly impress any scorch-like image.
- The electrostatic field was not intense enough to oxidize a significant amount of the TS apart from the very superficial body image.
- It is possible to have a corona between two surfaces in contact, such as the tip of the nose and the linen cloth, if one of the two is not a conductor (i.e. the linen cloth). This is true unless the TS is wet (water or other conductive fluid that completely permeates the air filled interstices); in other words, if the two surfaces become conductors, the system becomes equipotential making the local electric field strength tend to zero.

-3.5) Hypotheses on CD effects for body image formation on the TS

-*Hypothesis A)* There is a relationship between the 3-D information of the body image on the TS and Eqs. 1, 2 and 3. Similar laws are expected if the smooth cylinder is replaced by an unevenly shaped conductor with an irregular surface.

-*Hypothesis B)* In addition to Eqs. 1, 2 and 3, the CD effect also depends on the distance between the corpse and the TS, which also produces some 3D information (see Figure 7). The 3D effects of the body image are caused both by the electrostatic field variation along the body surface and by the body-cloth distance.

Characteristics valid in both hypotheses:

- Although electrons are the medium that triggers the process, it is the ions (ionized air and vapor surrounding the streamers) ozone (O_3) and acids, photons, UV light and heating up to 50-150 °C that produce the image: they react with the polysaccharides of the linen fibers, and break their chemical compounds.

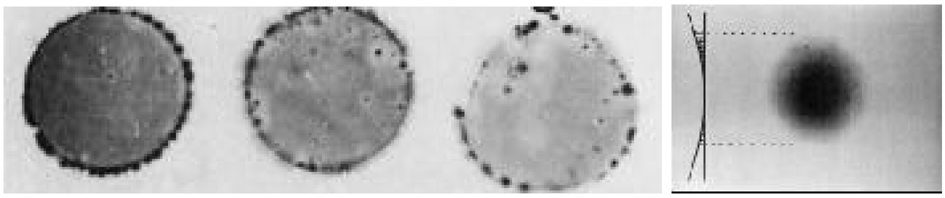

Figure 7. 3-D effect of coin images formed on photographic paper by means of CD. On the left, 3 coins were exposed to CD; the darker image corresponds to the coin closer to the condenser. On the right, a spherical object near a flat condenser generates an image darker in the middle showing 3-D effects.

- The glow often accompanying CD appears as a bluish glow, essentially UV light.
- CD produces energy-free zones in impurities around the linen fiber surface. CD acts at a chemical level with the linen fibers in such a way that color was produced as the fibers aged.
- Relatively long exposure to CD produces surface erosion of the linen fibers, but this is not the case of the TS image.
- When the filamentary streamers that generate the glow strike the linen, some catalysts due to the presence of iron, calcium and strontium or oils in the TS can act on the fabric.
- The image produced by CD is probably at first latent or weakly visible. Further heating lower than 200° C, exposition to sunlight or aging that dehydrates the polysaccharide layer, turns the image into a yellow to light brown color. Heating must not be higher than 200° C because, if it is, it singes the linen fibers and generates UV fluorescence, but the TS image does not fluoresce.
- In order to have a CD-originated imaging effect, the TS must be inside the glow-CD layer, i.e. the length of the single emitted streamers is greater than the body-cloth distance.
- The glow-CD layer is interrupted by the presence of the TS and re-starts on the outer surface of the TS. The outer streamers are energetically less severe, so that the intensity of the image impressed on the outer surface of the linen is reduced. This explains the double superficiality of the image.
- The pre-ionizing rate of radon is responsible for the elongation and energy of the single streamers.

5) EXPERIMENTS AND RESULTS

Experiments were performed on linen samples and photographic paper to compare results with TS data. Some experiments were first done on photographic paper, since the image is easier to obtain, in order to better highlight some macroscopic characteristics of CD. Other experiments were then done on linen cloths in order to confirm the previous results and to highlight the microscopic effects of CD on linen fibers.

5.1) Experiments with a Van de Graaff ribbon generator

5.1.1) Experimental apparatus

A Van de Graaff ribbon generator was used to generate images of objects on photographic paper and linen cloth. The generator produces a DC (Direct Current) potential of 35000±5000 V with a current intensity less than 0.01 mA, see Figure 8.

Various objects were subjected to a series of discharges capable of producing a visible effect. A 4400V AC (Alternating Current) transformer at 0.0025 A (11 W) working at 50 Hz for 300 s was also used to obtain similar results. Both sets of experiments showed that a power increase causes a higher image intensity (see Figure 9). This increase is correlated to energy W, and thus the maximum depth for the image formation, according to the relation:

$$W = P\,t = U\,I\,t \qquad (5)$$

where P is electric power, t exposure time, U voltage and I current intensity.

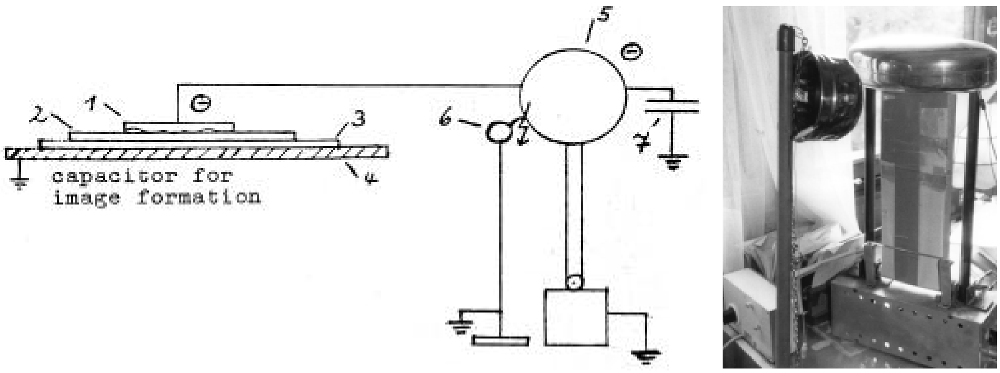

Figure 8. Schema of the experimental apparatus on the left: 1) metal relief about 3 mm thick; 2) photographic paper; 3) plastic foil as dielectric; 4) grounded metal plate; 5) Van de Graaff generator; 6) grounded sphere for spark discharges; 7) additional condenser to increase the capacitance. Photo of the experimental set-up on the right.

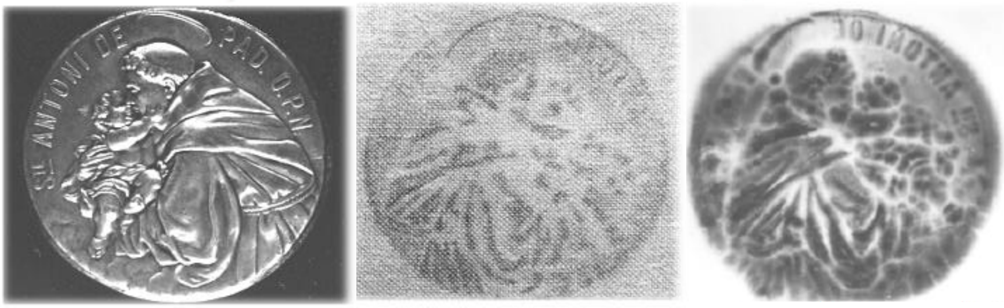

Figure 9. On the left, original St. Anthony medal (6 cm diameter and 3.5 mm relief depth) used for experiments; in the middle, result on linen cloth and on the right result on photographic paper.

<u>*5.1.2) Experimental results compared with those of the TS*</u>

- Double images without lateral information The TS image has a frontal image and a dorsal image, but no lateral body images are impressed on the cloth. Two reliefs of a medal were used in the experiment shown in Figure 10. Both frontal and dorsal images of the medal are represented simultaneously but no lateral images are visible, as is the case of the TS (this experimental set-up is in agreement with Hypothesis B).

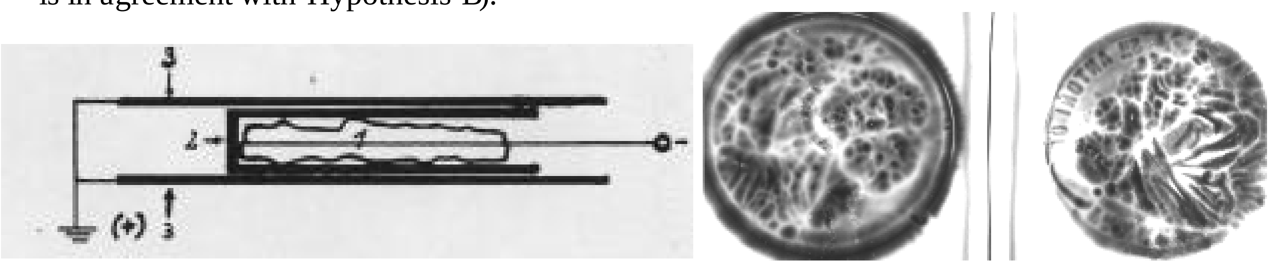

Figure 10. On the left, experimental apparatus: 1) double sided relief; 2) photographic paper; 3) plate in the electric circuit U form (+). On the right the results of the dorsal and frontal images on photographic paper.

- Effect of the distance The results of a coin placed at a distance varying from 0 to 3.5 mm from a sheet of photographic paper are shown in Figure 11. As expected, the image intensity decreases with the coin-paper distance, and at a distance greater than 3 mm the image disappears.

  In order to achieve a 3D distance of more than 40 mm in agreement with position of the TS in Hypothesis 2-B, a voltage much higher than the available experimental one is needed. Higher voltage means enhanced ion velocity and ion avalanche density, and ultimately, reduced scattering effect and improved image resolution. The distance of more than 40 mm of the TS image indicates that there must have been a discharge of a very high voltage which lasted for an extremely short time and thus avoided burning the cloth.

- Bandages CD experiments show that flat bandages are transparent on the impressed image whereas a piece of yarn that is round causes a mark on the image. In the TS body image, no bandage marks are clearly visible even if we can imagine that there were bandages (see Figure 12).

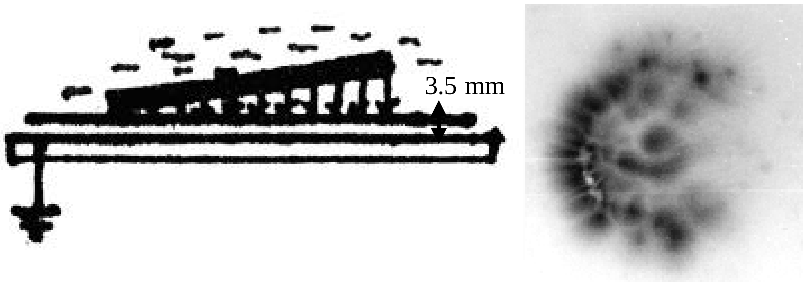

Figure 11. On the left, schema of the coin set-up with respect to the photographic paper; on the right, coin image impressed as a function of its distance from the paper.

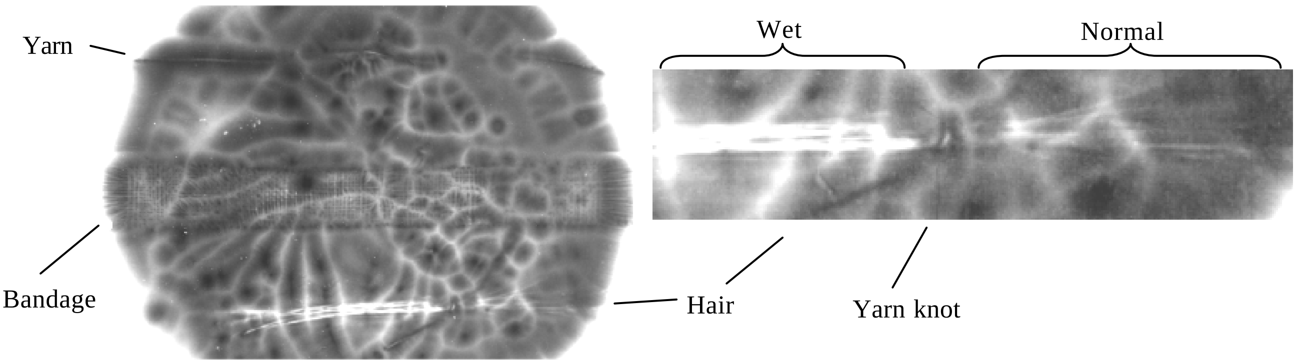

Figure 12. On the left, resulting image of a medal relief covered with yarn, bandage and hair. On the right detail of hair: clean hair is relatively transparent in the image but wet/moist hair causes a clear mark.

- Hair Experiments show that clear hair is barely represented in the image, but hair pre-treated with oil or a salt solution (sweat) is clearly represented as is the hair on the TS (see Figure 12).
- Blood Experiments show that moist blood prevents the generation of an image and in the TS there are no images where there are blood stains.
- Oil or salts It is easier to form an image of an oily or wet and salty object than if it is dry and it has been hypothesized that the TS was anointed with oils.
- Saliva and tears If cheeks are covered in saliva or tears, the respective area is not represented in the image as is the case of blood. In the TS, it is possible to detect a clearer area where there might have been saliva and tears or traces of water.

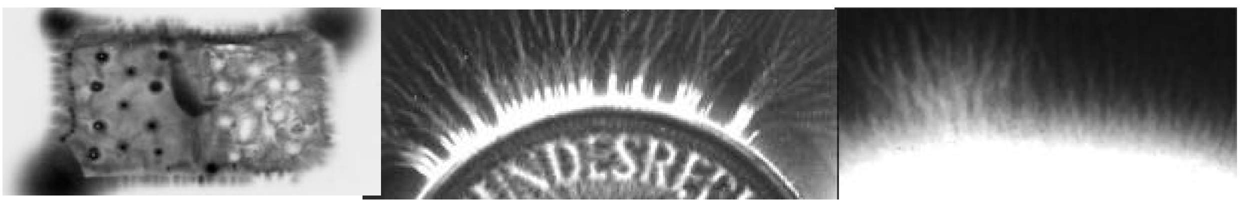

Figure 13. On the left, image of a 0.1 mm thick sheet of copper in which some convex hills (darker) and concave hollows (lighter) were previously made by means of a pointed stick. In the middle (positive CD) and on the right (negative CD), smear effects on coin images on photographic paper.

- Valleys and hills Concave valleys and convex hills respectively cause charge spacing out and concentration that generate lighter and darker images (see Figure 5). On the TS Face (positive) the eye sockets are lighter but the tip of the nose and the eye balls are darker than normal.
- Smears due to CD Smears generate an enlargement of the reproduced image. Perhaps this effect could be correlated to the TS fingers, which appear longer than normal (there could also be a charge concentration due to the point effect) (see Figure 13).
- Time effect Images experimentally produced on linen are consistent in color more than 20 years after their production, but images obtained with oily cloths can be less stable.

5.2) Experiments on linen cloth with a plasma ball

5.2.1) Experimental apparatus

A plasma ball was used to generate images of objects on linen cloth. In a plasma ball (Tipler 1998) voltages ranging from 3 to 8 kV, at frequencies between 20 and 50 kHz are applied between the sphere at the center and the glass shell which is grounded (Figure 14 A). The region in-between is filled with a mixture of inert gases such as nitrogen, argon and neon. The applied voltage partially ionizes the gas generating current-carrying plasma filaments. The colors displayed are paths along which ionization is occurring.

The generated electric field can cause avalanche re-starts and streamers in the air outside the ball and then CD as shown in Figure 6. The experimental apparatus used to form images on linen cloth was the following (see Figure 14).

- A commercial plasma ball having a diameter of 20 cm was used to generate an electric field.
- Some samples of new, but not bleached linen cloth (sizes of about 3 x 3 cm) were placed on the glass surface of the plasma ball.
- A metallic object having details less than 1 mm, in this case a bronze watch wheel (diameter of 15 mm), was placed on the linen sample.
- The metallic object was grounded by means of a copper wire connected to a metallic mass.
- A pressure of about 1000 Pa on the cloth was obtained by placing a non-conductive mass over the metallic object.

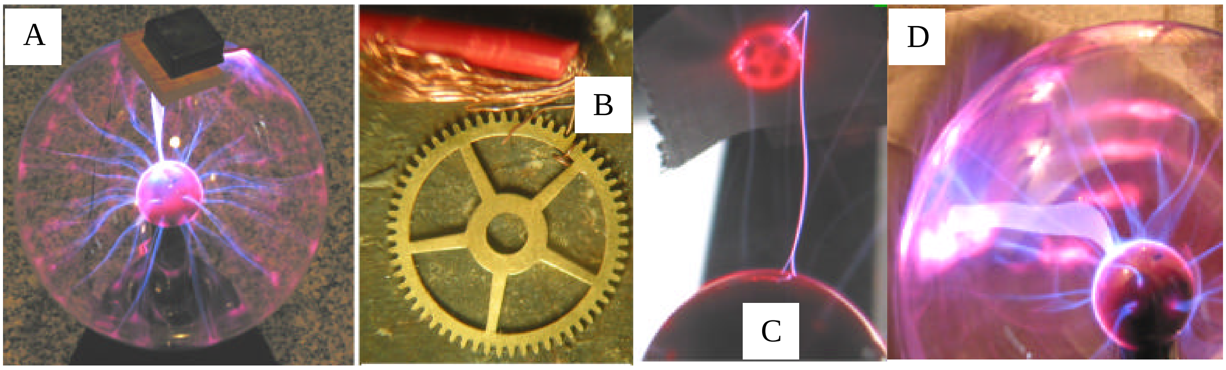

Figure 14. -A) Experimental apparatus used. B) Bronze watch wheel. C) Bolts of lightening in the plasma ball generates a CD in the air between the glass sphere, linen cloth and watch wheel. D) A human hand covered by a linen cloth placed over the plasma ball causes partial CD that are visible as the fingers shine due to the production of ions (condenser effect).

After an exposition of the linen cloth to the plasma ball varying from 300 s to 10,000 s, the samples were "aged" by heating them with an iron set at a temperature of 190±10°C. An optical pyrometer was used to measure the temperature of the linen cloth in an 8 mm spot in correspondence to the CD. The temperature was quite variable with a mean temperature on the cloth of 45 °C and a peak of 62 °C reached after 60 s of plasma exposition; the room temperature was 21 °C.

When a hand, covered by a linen sheet was placed on the external glass of a plasma ball, an image of the hand shone on the sheet, see Figure 14-D. An electrician's screwdriver, placed in the external electric field generated by the plasma ball, lit up showing that the electric field outside the plasma ball was strong enough to illuminate the screwdriver much more than when it comes into contact with a 220 V power mains.

5.2.2) Results on pure linen cloth

After an exposition of 300 s to the CD, the linen cloth showed an image that is only visible in UV light (see Figure 15 A). After heating this sample with an iron (additional thermal aging), the watch wheel image appeared even in visible light (see Figure 15 B). The resolution of the image is of the order of 1 mm, better than that of the TS, which is 4.9±0.5 mm (Fanti Sept. 2005).

If a linen cloth is covered with oil, after a similar exposition to CD, an image appears in visible light without ironing the sample. It is worth observing that, in accordance with the TS (Fanti 2004), the image on the linen cloth subject to CD is very superficial but double: it appears on both the front and back surfaces. Furthermore, as in the TS, the image on the back of the sample has a lower intensity.

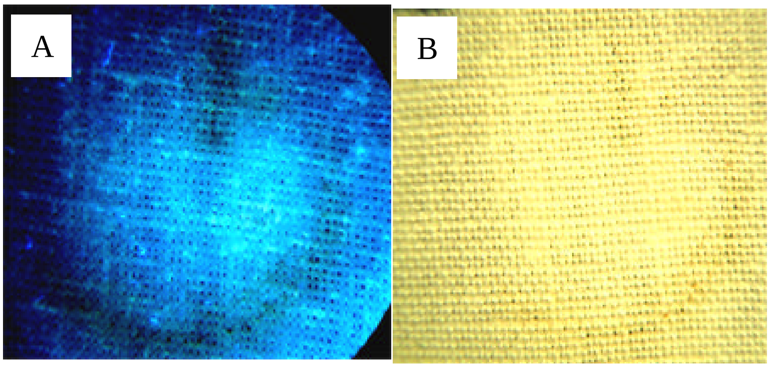

Figure 15. -A) Watch wheel image in UV light before heating (the vertical segment is the copper-wire image); -B) watch wheel image in visible light after heating the sample.

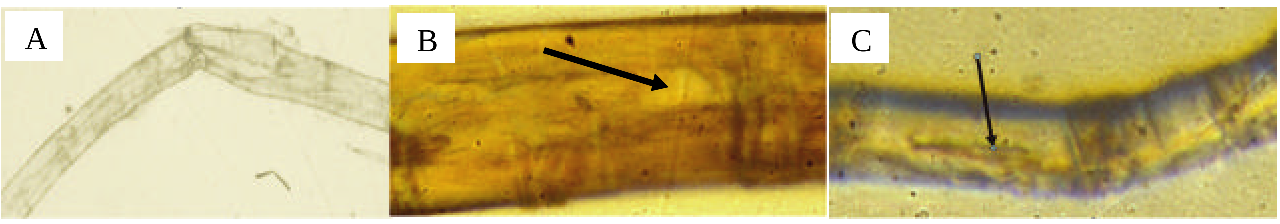

Figure 16. Photomicrographs of image fibers (diameter of about 10 micrometers) obtained by means of a plasma ball. –A) The medulla is not colored. –B) The arrow shows a non-color area corresponding to the fiber medulla because the color layer is absent there: this confirms that the color resides only on the outer layer as it has been detected on the TS. –C) In agreement with the TS, the image-fiber shows a "crackled" surface (arrow).

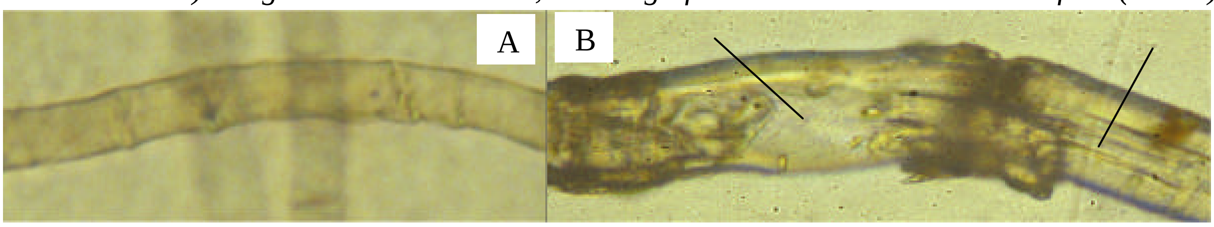

Figure 17. TS image-fibers (diameter of about 10 micrometers) coming from sample STURP-1EB (courtesy of Raymond Rogers, photomicrographs G. Fanti). –A) The medulla is not colored. –B) The left arrow shows a non-color area corresponding to the fiber medulla because the color layer is absent there; the right arrow shows a "crackled" surface.

The medullas of the resulting image-fibers are not colored and the fiber surface is "crackled" (see Figure 16 A-C) like those of the TS (see Figures 17). Furthermore, as can be seen in Figure 16 B, the image fibers obtained are circumferentially colored just as the TS image fibers are (in agreement with Fanti et al. 2005). This led us to assume that the image fibers can function as lightening conductors.

Figure 18: corrosion of a linen cloth exposed for 10,000 s to CD. –A) some voids in the yarns are evident. –B) photomicrograph of a linen fiber in which a diameter reduction is shown (diameter of about 10 micrometers).

Corrosion, which is typical of exposition to CD, was found in a linen cloth after an exposition of 10,000 s to the plasma ball, but this was not the case in linen cloths exposed for 300 s. After such a prolonged period of CD exposition, no image is clearly visible because the corrosion most likely destroyed the image layer. Nonetheless, in the sample there are some voids without any sign of scorches: this means that the corrosion held at temperatures below 200 °C (see Figure 18 A). Furthermore, some fibers show a shortening of their diameter in correspondence of some zones exposed to corrosion (see Figure 18 B).

<u>*5.2.3) Results on coated linen cloth*</u>

In agreement with Fanti et al. (2005) "[b]*ody image color resides on the thin impurity layer of the outer surfaces of the fibers*" of the TS and this layer is made of polysaccharides. In order to reproduce this condition, samples of new unbleached linen sheets previously soaked in a saturated solution of sugar and air-dried for a few hours were subjected to CD for 300 s using a plasma ball.

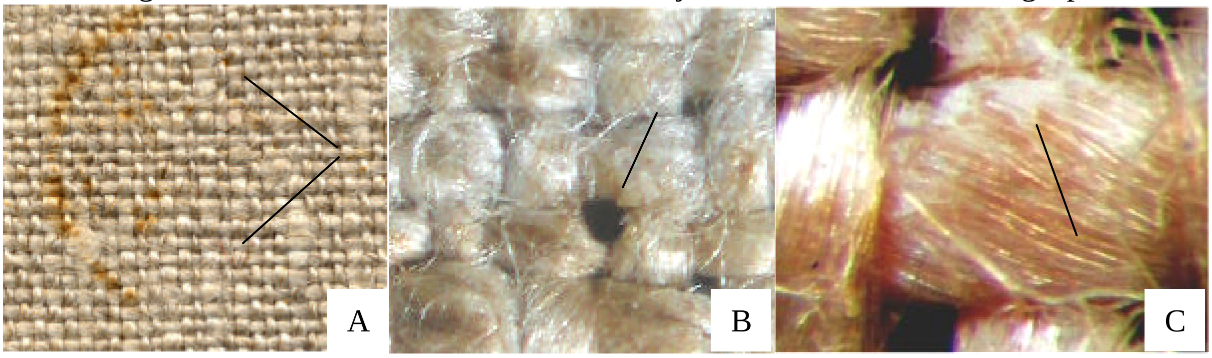

Figure 19. -A) image of watch wheel on a sugar coated linen cloth; -B) detail of the watch wheel image; the arrow indicates a burn caused by a series of lightening bolts that hit the same area; -C) detail showing the superficiality of the color on the yarns; the arrow indicates a bright area after the more brittle, superficial fibers were removed mechanically.

After heating the linen sheet, an image appeared in visible light (see Figures 19 and 20). Figure 21 shows a color fiber of the TS as a comparison: both uncolored medulla and color increment from the right to the left can be seen. In Figure 19 B a burn hole due to the effect of a continuous lightening acting on a specific point on the linen cloth can be seen. This was caused by pointing a conducting wire near the cloth. Obviously, these burn holes do not appear on the TS because no pointed conducting wires were presumed to be involved. The superficiality of the image and greater brittle behavior of the corresponding image fibers, which are typical of the TS, are verified with these corona experiments (see Figure 19 C).

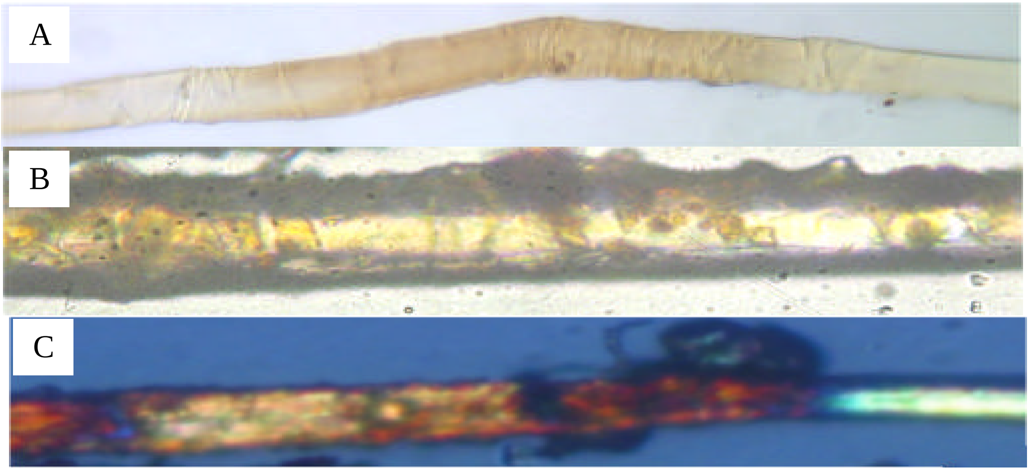

Figure 20. CD experiments on coated linen fibers (diameter of about 10 micrometers). -A) image-fiber colored in the middle: the medulla is not colored; -B) detail of another image fiber: the colored sugar-coating (yellow) can be seen; -C) color-fiber seen in cross-polarized light: the colored sugar-coating is darker on the left while the uncoated linen fiber on the right is white.

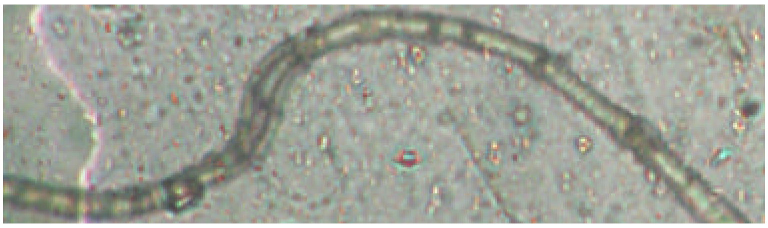

Figure 21. Uncolored medulla of an image-fiber (diameter of about 10 micrometers) coming from sample STURP-1EB (courtesy of R. Rogers, photomicrograph G. Fanti). The color increment along the fiber from the right to the left can also be seen.

It is interesting to observe that on a piece of yarn colored by the CD experiments, there are striations, i.e. colored linen fibers side by side with non-colored fibers, very similar to the TS image (see Figure 22).

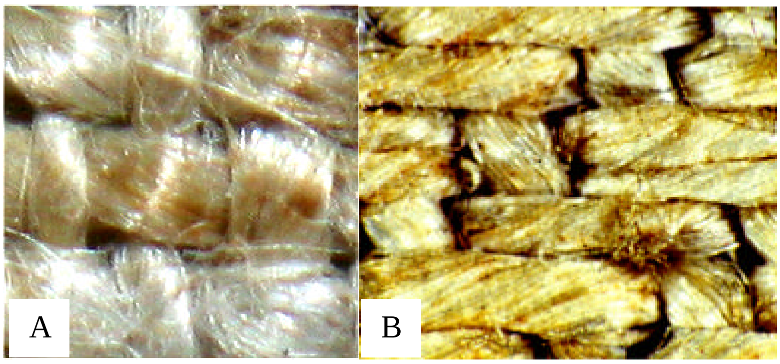

Figure 22. Contrast enhanced photographs of pieces of colored yarn in linen cloths: striations can be clearly seen. –A) CD experiment; -B) TS image (courtesy of Mark Evans ME-20 photomicrograph of the eye).

<u>*5.2.4) Microphotographs of image fibers in cross-polarized light*</u>

If a linen fiber is seen at extinction in cross-polarized light, some defects relative to the cellulose crystals in the fiber may be evidenced. The darker areas in the photomicrographs correspond to non-defects in the crystal structure of the cellulose while the lighter areas (at the growth nodes of the linen fibers) correspond to discontinuities or defects.

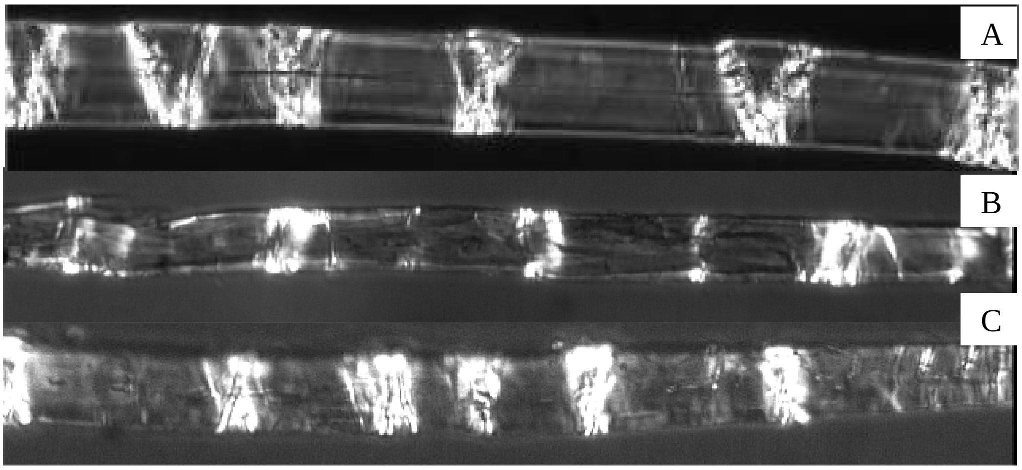

Figure 23. Photomicrographs of linen fibers (diameter of about 10 micrometers) in cross-polarized light (courtesy of J. Botella in 2005). –A) untreated fiber used as a control; -B) image fiber obtained by means of CD; -C) TS non-image fiber (courtesy of 3M Italia - G. Riggi di Numana in 2004).

Figure 23 A shows a typical photomicrograph of an untreated fiber used as a control. The presence of defects (clear areas) can clearly be seen at the growth nodes in the fiber, but the cellulose crystals outside the area of the nodes where the medulla are appear very dark and, therefore, without any appreciable defects. Figure 23 B shows an image fiber exposed to CD. Again there is no evidence of defects in the crystal structure of the cellulose in the medulla (dark area) showing that the CD does not act inside the fiber but only outside it. Figure 23 C shows a TS non-image fiber where some defects in the medulla can clearly be seen (mainly in the grey area on the left and on the right but also other lighter irregularities along the whole fiber). These defects have been caused by ageing. This result confirms the fact that the TS fibers are very old and that the CD cause effects in the crystal structure of the linen fibers one order of magnitude less than those present on the TS fibers.

6) DISCUSSION

A comparison of the results of these experiments involving CD with some characteristics of the TS leads to many interesting considerations. Some of the more noteworthy ones are listed here.

-1) According to J. Botella (2005), in reference to CD experiments, it "[…] *is easier to pull fibers from the image area of the cloth than from the non-image areas.*" This fact was also detected by L. Schwalbe (1982) and G. Fanti detected a more brittle behavior on a TS image fiber coming from STURP-1EB (courtesy of R. Rogers). This means that the linen fibers exposed to CD are more brittle than non-image fibers, as are those of the TS. Consequently, we can imagine that the TS fibers were exposed to CD.

-2) There is agreement between the images obtained by means of CD and the TS images with reference to the following points:

-a) linen bandages are transparent to CD effects (in reference to Hypothesis 1).

-b) clean, dry hair does not cause an image, but sweaty or oily hair generates an evident image;

-c) double superficial images appear on linen cloth pre-treated with sugar (Fanti 2004).

-3) The depth of penetration of the image in the TS is of the order of few tens of micrometers; experimental results indicate that to obtain such small depths, the exposure time to CD must have been less than a few milliseconds; this condition can be achieved by a series of short bolts of lightning (Scheuermann 1983).

-4) No references were made in this paper about the effects of flowers, leaves and coins on a linen cloth, even if also they can cause an image if subjected to CD, because their presence on the TS cloth is still not accepted by all researchers.

-5) The 3-D information of images obtained by means of CD is similar to that of the TS. There are differences in the image intensity in some areas where the TS probably touched the corpse: for example the tip of the nose generated the strongest image but also the hands were in contact with the TS. This fact can be simply explained using basic notions involving geometry-dependent electrostatic stress (point effect). Narrow concave areas of the corpse (e.g. eye sockets) and hills (e.g. eyeballs) seem to deviate from the normal 3-D information in their luminance: concave areas are clearer than normal, hills are darker. The difference in the luminance between the eyeballs and the eye sockets appears exaggerated in a 3-D relief because it displays an excessive distance. This can be explained by the fact that electric charge carriers (e.g. electrons) radiate preferably from points and protruding places.

-6) The voltage also determines the maximum body-cloth distance needed to form an image. In reference to Hypothesis B-2, according to J. Jackson, in the TS this distance is 4-6 cm if a uniform radiation is assumed. The experimental results also show that (Figure 11) the maximum depth capable of reproducing an image on photographic paper is 3.5 mm if a potential 35000±5000 V is used. A decrease in the current intensity (due to a change in the dielectric) did not seem to have an appreciable effect on the formed image, while the time and the potential, which could not be sufficiently varied in the experiments, had a greater effect both on the degree of scorching and the penetration depth on the fabric. On the other hand, the image contrast became lower when the current intensity was smaller. Dr. Igor Bensen of the Bensen Aircraft Corp. wrote that an energy level of 50 J/cm^2 applied for 0.1 s on a linen fabric produces an image. Assuming that half of the TS is involved in the image, it would require 1100 kW lasting for 0.1 s to produce an image. The most likely electro-potential would probably be at least 60 million V, more than 2000 times greater than the amount used in the experiments; such high potentials are not easy to achieve in the laboratory. Interestingly a Ball Lightening, which is a negatively charged sphere of ionized plasma that occurs during heavy thunderstorms, possesses some of these characteristics. Since it is negatively charged, it is attracted by positively conducting objects such as human bodies.

-7) R. Rogers (2004) commented that the UV of CD has to produce high energy-free defects in an impurity layer on the fibers' surfaces without affecting the cellulose, but if radiation is intense, defects also appear in the cellulose. He is right: radiation produced by means of CD must be not too intense. On the other hand experiments clearly show that it is relatively easy to reach this condition and no defects were detected in the medullas of the image fibers as it is shown in Figure 23.

-8) R. Rogers (2004) commented that any CD in the air produce atomic oxygen and excited oxygen molecules: both oxidize the material of the cloth. In agreement with him, given enough time or intensity, plasma in the air completely consumes a linen sample. According to the results shown in Figure 18, this fact was detected experimentally when the exposition to CD was sufficiently high. However, according to the results shown in Figures 15, 19 and 22 no erosion was detected when the exposition time was lower.

-9) R. Rogers (2004) commented that it is quite easy for sparks and arcs to form in the air, but no spark or arc damage is seen on the TS. Except the case shown in Figure 19 B, where damage was caused by a pointed conducting wire placed near the cloth, in the other experiments no damage was detected, in accordance with the characteristics of the TS.

-10) R. Rogers (2005) independently carried out some experiments on plasma effects, but at a very high rate of erosion: plasma was produced at 27 MHz in a 1% oxygen atmosphere having an energy of 220 W; the cloth was exposed for 30 s. In this case, the nap of the cloth was removed and the fibers were oxidized by the energetic oxygen atoms and molecules, even though the temperature was not high enough to dehydrate and color the cellulose. Rogers used these results to preliminarily reject the CD hypothesis and did not have the time to find out that CD applied at lower energy levels would have solved all these problems. He continued his studies on fibers excessively exposed to CD, observing them in cross-polarized light at extinction. He commented that the effects of plasma cause observable changes in linen samples looked at in cross-polarized light whereas no such effects can be observed in TS image fibers. On the other hand, the results reported in Figure 23 clearly show that these defects are not visible if the linen fibers are exposed to CD characterized by less intense energy levels.

-11) R. Rogers (2005) objected that two objects in contact with each other, such as the TS cloth and the tip of the nose, have the same electric potential and therefore no CD effects can be seen. According to §3.4, the local electric field strength is not negligible if the surfaces in contact are not conductors. O. Scheuermann (1984) experimentally detected that contacts of conductive objects with a linen cloth do not disturb the formation of an image because the resulting image is clearly visible without any discontinuity from the contact zone to the non-contact zone. In fact, the air located in the voids between the fibers makes CD possible.

-12) In reference to Hypothesis A, the electrical field lines were caused by the electrostatic field generated by quartziferous layers that were able to act in a volume having dimensions of hundreds of meters around the tomb. Furthermore, radon is presumed to have been present. In accordance with a lot of other data about the TS image, it is highly probable that the TS Man was Jesus Christ (Fanti 1998). If so, some research must address the geological conditions of tombs in Jerusalem. A preliminary analysis has showed that the presence of radon is possible even if there does not seem to be a very high concentration of radon. As far as the geological stratigraphy is concerned, it seems that no quartziferous layers are present under Jerusalem (1 km under ground). There are gravel (rock fragments and pebbles that are small smooth rounded rocks), chalk, phosphorite, limestone (a sedimentary rock consisting mainly of calcium) and thin layers (less than 80 m in total) of chert (variety of silica containing microcrystalline quartz). Nevertheless, these strata of chert do not generate piezoelectric effects because their quartz crystals are randomly disposed. Consequently, more detailed studies are needed with reference to Hypothesis A, with special attention paid to the presence of radon. Incidentally, an excess of ambient ionization can give rise to a self electric field.

-13) F. Zugibe (2005) considered the results obtained by R. Rogers and added some comments (numbered below as they appear in the original text).

- "*2. It is very unlikely that corona discharge would produce the kind of striations observed in the Shroud image*", but he did not observe the experimental results shown in Figure 22.
- "*6. When two surfaces touch (if they have any conductivity at all), they reach the same potential voltage; therefore, no electrons can be accelerated from one surface to the other and hence there can be no corona discharge*" and "[t]*he dark color at the end of the nose image could not be a result of a corona discharge since it is a contact point and should be white instead because there is no potential at a contact point*". As stated before, the TS anointed with oil is not a conductive material so the potential can be different. Perhaps the yarn striations typical of both the TS and the CD images, are due to this fact: if a group of conductive linen fibers is in direct contact with the charged body, their potential voltages are not so different so no image results; if an adjacent group of fibers of the same yarn is not in contact with the charged body, the interposed air acts as a dielectric and their potentials differ causing then an image. Therefore, the tip of the nose where there is a charge concentration must be assumed to be dark and not "*white*".
- "*8. Sufficient power delivered to a cloth can heat it to a high enough temperature for color formation, but it is doubtful that sufficient power can be delivered by a pure corona discharge to produce color, because the primary reaction in air will be oxidation of the organic phases.*" As stated before, the main cause of color formation is not the relatively low temperature of about 60 °C connected with corona activity but the presence of UV rays and aggressive

chemical by-products that generate high energy-free zones in impurities around the linen fibers surface.

- *"10. Corona discharge cannot be considered as an image mechanism because it requires high voltages arising from points or edges*." This statement is explained by Hypotheses A, and B.
- *"11. A plasma will burn away a surface layer of any organic material and char, burn the entire sample."* According to the results shown in Figures 16 and 20, this is not always true. A scientific statement like this should be made after having tested the effects of different plasma intensities and discharge modes.
- *"Effects noted included burning off of free flax fibers, removal of cementing substances, penetration through the porosity of the cloth, burning organic materials, etc."* Perhaps these effects can be observed if an excessively high energy source was applied, but, in agreement with data shown in Figures 15, 16, 17, 19, 20, 22 and 23, these characteristics were not detected when a proper energy source was used to obtain images.
- *"1. There was scorching in some of Scheuermann's fibers and they were nothing like Shroud image fibers, which are not scorched."* and *"2. In a photomicrograph in one of Scheuermann's samples […]. the medulla is darkened […]. proving that the temperature of the entire fiber had been raised above the level where dehydration reactions could occur[…] ."* Twenty years ago, Scheuermann ironed some samples at temperatures often higher than 200 °C to make the image more visible. G. Fanti sent some of these samples to R. Rogers to be tested. They had burn marks by ironing and showed a reddish UV fluorescence whereas regular samples did not fluoresce. This particular case must not be generalized without other analyses. No scorches were found in the samples shown in Figures 15, 16, 17, 19, 20, 22 and 23. Furthermore, A. Adler tested about 30 image samples, some of which were salt treated. In Adler's opinion, the salt treated images were very similar to the TS image (chemically and microscopically, also seen with UV light).
- *"3. Scheuermann used about 4,400 V at 0.0025 A (about 11 W) and some of Scheuermann's fibers showed color formation in the layer of sizing on the cloth; he did not use a pure, DC discharge; and he covered his cloth with a metal medallion*." O. Scheuermann connected a metallic wire from a Van de Graaff ribbon generator to an object to cause a DC current. Later on he exchanged the Van de Graaff with a transformer that produced better images (AC) because of its higher energy. The resulting image (AC) was similar to the one obtained from the experiments with a DC current because the low changing phase did not disturb the results.
- *"4. Scheuermann reported using 4,400 V …. to heat a small volume of linen to temperatures on the order of 300 degrees centigrade and that this temperature range would color both the sizing material and the linen (cellulose, hemicelluloses, and lignin)*." While O. Scheuermann tested a wide range of parameters to detect the most probable condition to which the TS was exposed, other researchers, such as R. Rogers, obtained their debatable conclusions from few data coming from very particular experimental cases.
- *"Although it has been reported that corona discharges affect only the outermost layer of fabrics, they in fact penetrate the entire porosity of a woven fabric. If they affected the very top surface and the opposite side, they would affect the core of the cloth*." Perhaps an excessive ironing at temperatures higher than 200 °C can cause an image to also affect the core of the cloth, but a statement like this must be supported both at theoretical and experimental levels. The data discussed in this paper shows that a double superficial image can be obtained (without affecting the core of the cloth) if the linen fabric is placed within the layer in which the corona discharge is acting.

-14) J. Jackson (1982) made some experiments on CD using a reference face. He observed the associated heating with AGA-780 thermo-vision and concluded, perhaps in an excessively simplistic way, that "*… electrostatic imaging does not appear to be a viable way of producing an image like the one on the Shroud."* This is mainly because he rightly found *"… that not only is distance a factor in field strength but probably even more important is the local curvature of* *the body shape since electric field tend to accumulate around regions of curvature. Such effects seem to be a potential problem ….*". First of all, the direct correlation between corona effects and temperature must be demonstrated because the image in CD experiments does not seem to be directly generated by temperature. Secondly, the dependence of the electric field on the surface curvature seems to be detectable, for example, where the eyes in the TS image are (see § 2-6 and §5.1.2).

-15) J. Jackson (1990) hypothesized a mechanism of image formation resulting from a burst of energy from inside the body, which had become mechanically transparent. He also hypothesized that the source of energy responsible for the body image formation was radiation mainly composed of soft UV rays. Is this hypothesis compatible with Hypothesis 2-B? Apart from some details that can be discussed elsewhere, the soft UV rays assumed to exist by J. Jackson may be due to CD. Furthermore, the double superficiality of the frontal body image he postulated (1990), which was verified by Fanti (2004), is compatible with Hypothesis 2-B. A thorough study and comparison between Jackson's hypothesis and Hypothesis 2-B would perhaps lead to a common one where it is not necessary to make the special assumption that the enveloped corpse became mechanically transparent.

7) CONCLUSIONS

On the basis of some proposals that have not widely publicized and on works limited to specific arguments, this paper presented different hypotheses of an image formation mechanism involving CD relative to the TS body image. This mechanism was proposed because many other hypotheses have failed some verification in reference to the very peculiar characteristics of the TS body image. Even the most credible hypothesis related to radiation still has some unanswered questions.

The CD hypothesis explains many facts, some of the most interesting of which are: the need to assume the soft hair; that there was a radiation source normal to the skin; the absence of detectable defects on the cellulose crystals after the energy application; the uniform color of the thin layer of polysaccharides around the linen fiber; the discontinuous color along the yarn; the 3-D information, which does not always agree with a simple body-cloth distance relation; the sinusoidal-law relative to the luminance where the legs were; and, finally, the double superficiality of the image.

The paper presented a theoretical background for the work, followed by a discussion of many experimental results in comparison with the corresponding data obtained from the TS. The results proved that many peculiar characteristics of the TS body image can be experimentally reproduced using CD. A final discussion evidenced that many aspects that other research studies have found difficult to explain with reference to CD effects can be explained if the involved energies are not too high. This must be kept in mind when considering the environmental conditions needed to have produced the TS image.

The aim of this paper was not to completely explain how the TS body image was formed, but rather to propose an energy source based on CD and its collateral effects, such as the generation of UV rays and aggressive chemical by-products, both of which could be considered as probable body image formation agents for the TS. Future detailed analyses considering all the peculiar aspects of the TS image will perhaps clarify the choice of Hypotheses 1 or 2, A or B, and shed some more light on the open questions regarding the most important relic of Christianity.

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REFERENCES

- Adler A. D.: Updating recent studies on the Shroud of Turin, Archaeological Chemistry 625, 223-228, (1996).
- Adler A.: "The nature of the Body Image on the Shroud of Turin", 1999, http://www.shroud.com/pdfs/adler.pdf.
- Bensen I. : Shroud News, Australia, June 1984
- Botella J.: private communication, 2005, Dr. José Botella, Univ. Regensburg, Lehrstuhl für Entwicklungsbiologie. Universitätstrasse 31, D-93040, Regensburg, Deutschland, Tel: 0941-9433088, e-mail: jose.botella-munoz@biologie.uni-regensburg.de.
- Chen J., "Direct-Current Corona Enhanced Chemical Reactions", Phd Thesis, University of Minnesota, USA. August 2002. http://www.menet.umn.edu/~jhchen/Junhong_dissertation_final.pdf
- De Liso G.: "Verifica sperimentale della formazione di immagini su teli di lino trattati con aloe e mirra in concomitanza di terremoti", "Sindon Nuova Serie", Quad. n. 14, dicembre 2000, pp. 125-130
- De Salvo J. A., "The image formation process of the Shroud of Turin and its similarities to Volckringer patterns", *Sindon* n. 31, dicembre 1982, pp. 43-50.
- Fanti G., Marinelli E.: "Probabilistic Model Applied to the Research carried out on the Turin Shroud" III Congresso Internazionale di Studi sulla Sindone, Torino, 5-7 Giugno 1998, http://www.shroud.com/fanti3en.pdf.
- Fanti G., Marinelli E.: "A study of the front and back body enveloping based on 3D information", Dallas International Conference on the Shroud of Turin, Dallas, Texas, U.S.A., 25-28 October 2001.
- Fanti G., Maggiolo R.: The double superficiality of the frontal image of the Turin Shroud, accepted for publication in Journal of Optics A: Pure and Applied Optics as a paper, 12 March 2004.
- Fanti G. et al: "Evidences for Testing Hypotheses about The Body Image Formation of the Turin Shroud" Third Dallas International Conference on the Shroud of Turin: Dallas, Texas, September 8-11, 2005
- Fanti G.: "Valutazione della risoluzione di immagini mediante analisi del modulo della funzione di trasferimento", Congresso Nazionale di Misure Meccaniche e Termiche, Desenzano, 12-14 Settembre, 2005.
- Jackson J.P., Jumper E.J., Ercoline W.R., "Three dimensional characteristic of the Shroud Image", IEEE 1982 Proceedings of the International Conference on Cybernetics and Society, October 1982, pp. 559-575.
- Jackson J.P., Jumper E.J., Ercoline W.R., Correlation of image intensity on the Turin Shroud with the 3-D structure of a human body shape, Applied Optics, 23-14, pp. 2244-2270 (1984).
- Fanti G. : "Numerical analysis of mutual radiation effects of complex surfaces" to be presented at 2nd Italy Canada Workshop on: Applications of 3D Digital Imaging and Modelling - Padova, May 17-18 2005.
- Jackson John P.: "Is the image on the Shroud due to a process heretofore unknown to modern science?", Shroud Spectrum International No. 34, March 1990, pp. 3-29.
- Jumper E. J. et al., A comprehensive examination of the various stains and images on the Shroud of Turin," ACS Advances in Chemistry, Archaeological Chemistry III: 205, 447-476 (1984).
- Lattarulo F.: L'immagine sindonica spiegata attraverso un processo sismoelettrico, III Congresso internazionale di studi sulla Sindone, Torino, 5-7 Giugno 1998.
- Lindner E., La Santa Sindone e la Risurrezione, M. Lindner Verlag, Karlsrue, Germany, 1997.
- Mills A.A.: "Image formation on the Shroud of Turin", Interdisciplinary Science Reviews, 1995, Vol. 20, No. 4, pp. 319-327.
- Moran K., Fanti G.: "Does the Shroud body image show any physical evidence of Resurrection?", 4th International Scientific Symposium, Centre International d'Études sur le Linceul de Turin, Paris, April 25-26, 2002.
- Morgan R., Shroud News, Australia, June 1985.
- Riggi di Numana G. - Rapporto Sindone I - 1978-1982, Il piccolo Editore, Torino, 1982.
- Riggi di Numana G. - Rapporto Sindone II - 1978-1987 - 3M Edizioni, Milano 1988.
- Rinaudo J. B.: "Image formation on the Shroud of Turin explained by a protonic model affecting radiocarbon dating", III Congresso internazionale di studi sulla Sindone, Torino, 5-7 Giugno 1998.
- Rogers R.: "Scientific method applied to the Shroud of Turin, a review", http://shroud.com/pdfs/rogers2.pdf, 2002
- Rogers R.: both private and on ShroudScience-Yahoo!-Group discussion on corona discharge effects, 2004 and 2005.
- Scheuermann O.: "Hypothesis: Electron emission or absorption as the mechanism that created the image on the Shroud of Turin - Proof by experiment" first edition September 1983, Fondazione 3M, Segrate, Milano, Italy 2003.
- Scheuermann O.: "Appendix I to Hypothesis: Electron emission or absorption as the mechanism that created the image on the Shroud of Turin - Proof by experiment", 1984, private communication to G. Fanti in 2003.
- Schwalbe L. A. and R. N. Rogers, "Physics and Chemistry of the Shroud of Turin, a Summary of the 1978 Investigations," Analytica Chimica Acta 135 (1982), pp.3-49.
- Stratton J.A., "Electromagnetic Theory", Mc Graw-Hill, New York, 1941, pp. 201-207.
- Tipler P.A.: "Physics for scientists and engineers" IV ed., W.H. Freeman and Company, 1998.
- Volckringer J., "The Holy Shroud: science confronts the imprints", The Runciman Press, Manly, Australia 1991.
- Zugibe F. : "The Crucifixion of Jesus: A Forensic Inquiry", M. Evans and Company Inc. New York, II Edition, 2005.