Journal of Imaging Science and Technology® 54(2): 020508–020508-11, 2010.

Can a Corona Discharge Explain the Body Image of the Turin Shroud?

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Abstract. *The body image visible on the Turin Shroud (TS) has not yet been explained by science; this article proposes a hypothesis of image formation based on corona discharge (CD). Even if the environmental hypotheses relative to CD can be refined, many facts detected on the TS body image seem in agreement with the characteristics of an energy connected to CD and related to the human body enveloped in it. After a synthesis of the proposed imaging mechanisms and a presentation of the main characteristics of CD, the results, both at macroscopic and microscopic levels, of some experiments are presented and discussed also in light of some comments coming from scholars of Shroud Science Group. The results support the hypothesized mechanism of image formation and they show no appreciable chemical-physical differences from the image features of the TS. Therefore they confirm that the proposed CD mechanism could have been involved in the TS body image formation. © 2010 Society for Imaging Science and Technology.*
[DOI: 10.2352/J.ImagingSci.Technol.2010.54.2.020508]

INTRODUCTION

The Turin Shroud (TS) is a 4.4-m-long and 1.1-m-wide linen cloth that appears to have enveloped the corpse of a scourged thorn-crowned man who was stabbed in the side with a lance and crucified.[1,2] There are also many marks caused by blood, fire, water and folding apparent on the cloth that partially obscure the indelible double body image (front and back). The wounds are what interest forensic pathologists most because they would be 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.[3] This means that, considering the thickness of the fabric where the image of the face is, see Figure 1, 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. Corona discharge (CD) images have this characteristic.

The TS is believed by many to be the burial cloth Jesus Christ was enveloped in when 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 relic.

Scientific interest in the TS started in 1898 when Pia, who photographed it, noticed that the negative image on the TS looked like a photographic positive. The luminance levels of the body image can be related to the three-dimensional (3D) image of a human body.[4,5]

The most important scientific analysis of the TS performed in 1978 by Shroud of Turin Research Project (STURP)[1,2,6] found no explanations for the body image impressed on it. The characteristics of the TS body image are very unique and impossible for now to be reproduced all together[7,8] even if many different hypotheses, frequently supported by experimental results, have been formulated.[7,9] Some examples of proposed hypotheses are listed below.

1. The image, which originated from the direct contact of a body with the cloth, is due to a natural chemical reaction, perhaps similar to the effect of herbaria leaves.[10]
2. The image was the result of the emanation of ammonia vapor[11] or the interaction of gases produced by the corpse with substances derived from retting of the linen.[12]
3. The image is a painting: many techniques have been proposed, but the best results have been obtained using a modified carbon dust drawing technique.[13]
4. It was obtained from a warmed bas-relief.[14,15]
5. It was obtained by rubbing a bas-relief with pigments or acids.[16]
6. It was obtained by exposing linen in a darkened room using chemical agents available in the middle ages.[17]

Although good experimental results have been obtained on the basis of hypotheses 1–6, these proposals are unable to describe all of the characteristics of the body image listed.[8] The hypothesis of a source of radiation from inside the enveloped body has instead a larger consensus even if some points must be still be demonstrated: it may be synthesized as follows.

7. The body image was caused by an energy source coming from the enveloped man, perhaps during a particular natural phenomenon such as lightning or earthquake, or during the Resurrection[18] in which is supposed a short-lived but intense source of energy. The source of energy may be of protonic,[19] electric,[20]

Received Jan. 16, 2009; accepted for publication Nov. 11, 2009; published online Feb. 26, 2010.
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Figure 1. Processed TS face to better show the body features. Having the body image tonalities reversed, the negative of the original image is here reproduced, but the blood traces that were impressed as positive have been left unchanged.

ultraviolet (UV) (Ref. 21) type or it may be due to a CD.[22–26]

The hypothesis 7 seems very probable, although, due to the need to manage relatively high sources of directional energy, no complete experiments have been done.

The characteristic of corona or electrostatic imaging on the TS was first noted by Mills[27] and by Adler in 1982.[28] In 1983, Scheuermann[29,30] proposed a possible body image formation mechanism based on CD and obtained some interesting experimental results. Whanger[28,31,32] also found evidence of images of other objects on the TS, formed with CD.

In 1984, Bensen[33] considered ball lightning as the source of energy for experiments on small samples to reproduce the body image. In 1985, Morgan[34] reported a hypothesis of image formation by means of CD made by Coote who proposed the piezoelectric effect of quartziferous rock subjected to an earthquake as the source of an electrostatic field. In 1986, Judica Cordiglia[35] obtained some images on linen samples using an electrostatic technique. In 1990 Tyrer[36] proposed a necrotic radiation connected with CD for the TS body image explanation. In 1997, Lindner[37] proposed an electron source as the cause of the body image formation. In 1998, Lattarulo[23] theoretically proposed a hypothesis of image formation based on CD generated by an external source and in 2000, De Liso[24] obtained some images on linen cloths during earthquakes. In 2005, Scheuermann improved his studies with F. Lattarulo and the author[25] showing that electron CD radiation is a very good candidate to explain the TS body image formation. Some peculiar characteristics of images obtained with CD have been discussed at the Columbus Shroud Science Group (SSG that discusses on "YAHOO!" scientific aspects about the TS) Conference on the TS in 2008.[26]

This article, after recalling some theoretical aspects of the CD in the view of the TS body image formation and after the formulation of some hypothesis regarding the conditions in which the body image formed on the TS, compares some experimental results with the detected characteristics of the TS.

CORONA DISCHARGE

A CD is an electrical discharge[38] brought on by the ionization of a fluid surrounding a conductor which occurs when the potential gradient exceeds a threshold *in situ* 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 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 is a partial discharge and differs from a total discharge, which is also sometimes visible in the plasma ball as a blue/white bolt of lightning.

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, guides and accelerates them along the field lines. 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 CD, blue/white glowing can often be seen because most of the emissions are in the UV range. A negative CD happens in a nonuniform corona and generally has less energy than a positive CD, but the electron density is greater.

CD has industrial applications, for example, in photocopying or ozone and NO_x manufacturing. Other examples of CD are described below.

St. Elmo's Fire

An example of CD is a phenomenon also known as St. Elmo's Fire.[27] During stormy weather, the normal "fine-weather" field of earth may be increased to such an extent that trees and other objects beneath the charged clouds emit a bluish electrical discharge reaching several centimeters in length and persisting for tens of seconds; if the potential

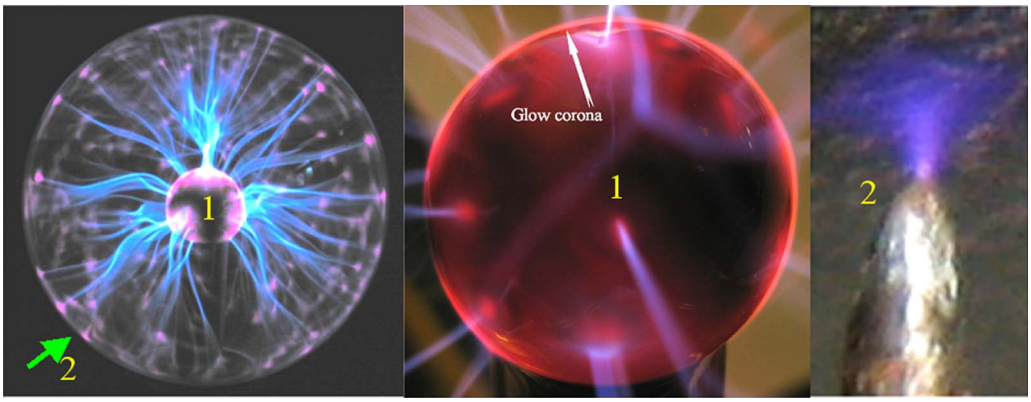

Figure 2. The plasma ball as an example of CD (on the left). (1) A detail of its inner sphere partially covered by pink CD. (2) CD in air at a conductive point. The point of a needle is placed near a plasma ball. The conical glow due to CD is evident in the air around the tip of the needle.

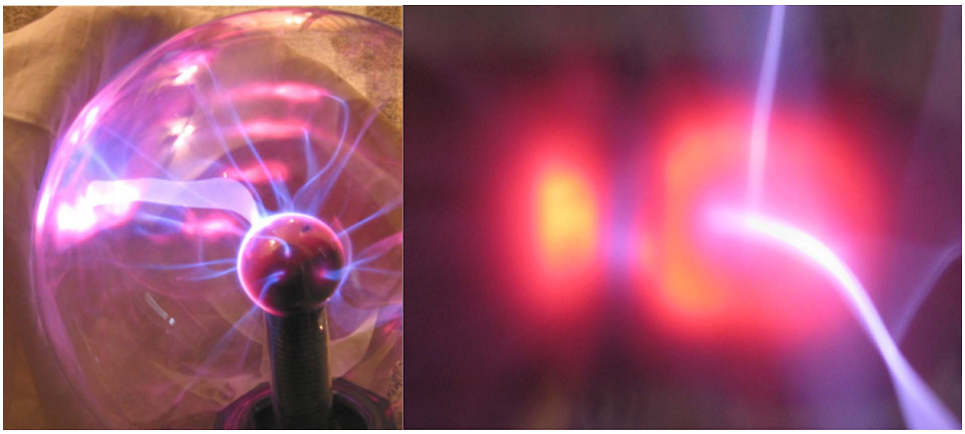

Figure 3. Hand image glow on a linen cloth. On the left, the hand touches a cloth put on a plasma ball. On the right, a detail of a finger image shows the intensity of the corona glow decreasing from the center to the edges, thus producing the 3D effect.

gradient continues to increase, then a dielectric breakdown can be reached and a lightning discharge results.

Plasma Ball

A typical example of CD can be found in a plasma ball (Figure 2); it is usually a transparent glass sphere filled with a mixture of various gases at low pressure and driven by a high frequency alternating current at high voltage (approx. 35 kHz, 2–5 kV), generated by a high voltage transformer. A smaller sphere in its center serves as an electrode. Plasma filaments extend from the inner electrode to the outer glass insulator, giving the appearance of constant multiple beams of colored light. A pink area around the inner sphere where CD is formed is visible.

Another example with a CD in correspondence of plasma ball can be detected if a conducting rod in unionized air is put close to the external glass sphere (see Fig. 2). Placing a conductive object near, or in contact with the glass alters the high-frequency electric field, causing a single beam to migrate from the glass sphere to the point of proximity or of contact. An electric current is produced as the glass does not block the electromagnetic field. The glass acts as a dielectric in a capacitor formed between the ionized gas and the conductive object.

If a hand touches a linen cloth that is in contact with the plasma ball (see Figure 3), the same CD effect is evident and the hand image glows on the cloth. This effect can be compared in some ways with the TS body image formation because the glow on the cloth shows that there is an energy distribution along the surface of the cloth itself, strictly connected with the image that could be produced; in fact this energy could be responsible for the chemical interactions at the linen fiber level that caused both the dehydration and the oxidation typical of the TS body image. It can be observed that the finger image shows an intensity decreasing from the center (contact point) to the edges (increased body-cloth distance), thus producing the 3D effect typical of the TS body image.[4,5]

Earthquake

It is also known that an earthquake can cause a large electric field surrounding compressed rock layers containing quartz (granite or gneiss layers). The possible presence of large amounts of radon, frequently detected before and during earthquakes, makes the environmental air an ionized medium. In this environment, CD effects have been detected.[23,24]

CD Imaging on Linen Fabric

In light of the discussion about imaging on a linen fabric similar to the TS, CD results in: UV luminescence, heating, ozone (O_3) and other reactive substances, acoustic effect, and electromagnetic interference.

Heating (from 40°C to 150°C) and UV luminescence are probably the two most important effects for the body image formation because they could be responsible for the dehydration of the polysaccharides linen cloth. Although electrons are the medium that triggers the process, it is the UV radiation and heating that produce the image; they react with the linen fibers, and break their C═C chemical bonds. CD produces energy-free zones in the linen fiber surface; it acts at a chemical level producing color on the fibers similar to aging.

Ozone and other very reactive substances such as nitric acid (NHO_3), together with hydrated ions and proton clusters $(H_2O)_nH^+$ (if water vapor is present), must not be neglected in the CD process even if, according to the author, they do not seem to be the direct cause of image formation. Experimental results obtained from long-time exposure to the CD show that the reactive gases cause ablation that cancels image traces, but this is not the case of the TS image that was apparently formed in a relatively short time period. Other researchers[23,27] instead think that the reactive gases can also play an important role in the image formation. The contribution of these reactive gases should be more thoroughly studied in the near future.

The acoustic effect and electromagnetic interference produced by CD are not relevant to the image formation.

FACTS IN FAVOR OF CORONA DISCHARGE IMAGING

Perhaps the greatest challenge for TS investigators is explaining how the body image was formed. Recent studies[7,9] 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 consistent with the CD hypothesis. This conclusion was principally reached after analysis of the following evidence in favor of a CD hypothesis related to an intense electric field.

(1) CD causes a doubly superficial[3] negative[1] and 3D[4,5] body image like that of the TS.
(2) Also on a chemical level, the color obtained by CD on a linen cloth corresponds to a dehydration of polysaccharides, as detected on the TS image.[39]
(3) The 3D information of the TS is not always consistent[8] because image details corresponding to protrusions are more clearly represented (e.g., eyeballs and nose tip). In a surface subjected to an electrostatic field, the more stressed locations correspond to the protrusions.
(4) According to many researchers,[8,40] the body image on the Shroud is extremely superficial also at a microscopic level involving the single image fibers. The medullas of each image-fiber of the TS are not colored; only the primary cell wall 0.2 μm thick[41] around each linen fiber is colored. CD coloration is similar.
(5) A numerical simulation of hands[42] 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 nonmetallic surfaces, but a unidirectional radiation normal to the skin surface. This condition is typical of electrostatic fields and CD.
(6) According to many researchers,[8] "*if a fiber is colored, it is uniformly colored around its cylindrical surface*". Linen fibers exposed to CD show this characteristic.
(7) The TS image of the hair appears soft, see Fig. 1, as opposed to the supposed packing effects of anointing oils and body fluids such as blood and sweat. In agreement with Lindner,[37] the hair image is an important sign of the presence of a radiation of electrons.

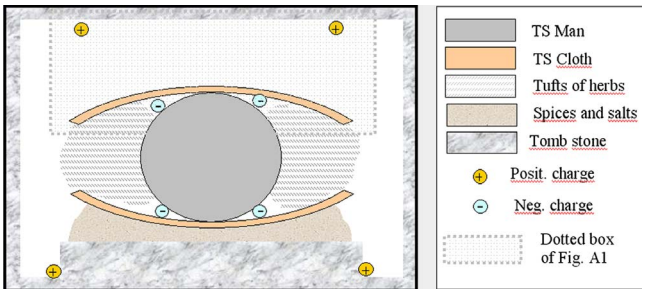

Figure 4. Hypothesized configuration of the TS body enveloped in the TS. The dotted box on the upper half of the scheme corresponds to the representation of Fig. A1.

Therefore, in agreement with Adler[43] "*several 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.

HYPOTHESES

To understand how probably the body image formed on the TS, it is necessary to point out some hypotheses relative to the environmental conditions in which CD developed.

Body and Environment

-The crucified human body, wet with corporal fluids, was conductive.

-The human body was enveloped in the TS and put horizontally over the tombstone (Figure 4). Due to cadaveric stiffness, the head was still tilted forward and the knees partially bent in accordance with the position on the cross. Around the corpse there were plants that prevented body-sheet contact. This configuration explains why no lateral images were formed on the TS and why some geometrical distortions (e.g., torso and calves) are present.[9,44]

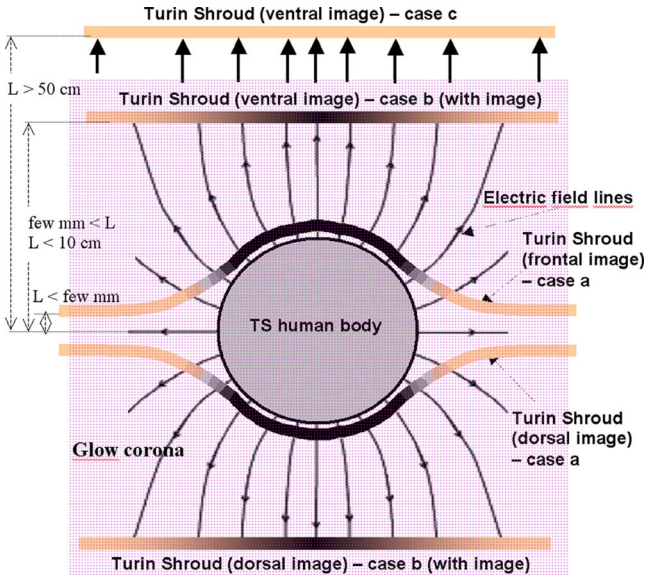

Figure 5. Scheme of a section of the TS human body enveloped in the TS and generating an electric field and glow corona. Three different positions of the TS (case a, b and c) show the corresponding configurations of the electric field lines. If the TS is close to the human body (case a), as it is in the image area, the electric field lines can be assumed orthogonal to the skin. In case b the TS is still in the glow corona but the field lines are almost parallel. In case c the TS is out of the glow corona so no image is formed.

-At the moment of the image formation, the TS (whose basic constituents are cellulose and air) had been anointed with oil, which is dielectric.

-The body, simplified as a cylinder, covered by the TS that acted as dielectric, was placed on an insulating dry stone covered with spices and salts.

Simplified Electric Model

-The crucified man in the tomb surrounded by a dielectric, the TS, was the direct or indirect source of an intense electric field (capacitor effect) (Fig. 4); in other words the corpse radially radiated electrons in agreement with the orthogonal direction with respect to the skin,[42] but the possible cause of this emission is beyond the scope of the present article.[†] Interestingly, ball lightning, which is a negatively charged sphere of ionized plasma that occurs during heavy thunderstorms, possesses some of the characteristics required for the TS image formation.

-A surface deposit of negative charges is present on a conductive and ungrounded human body (cylinder) while the outer positive boundary electrodes (rock) are grounded.

-CD, which is a function of the gas characteristics, is present around the body surface, where the electric field exceeds the corona threshold (see Figure 5).

[†]Some facts are considered and discussed in this paper trying only to find a scientific explanation for what can be detected; an energy capable of causing all the effects detected in the TS body image is here hypothesized, discussed and supported with experimental results. The eventual hypothesis of a particular event, perhaps related to a very rare natural phenomenon such as ball lightning, perhaps related to something such as a defibrillator, or perhaps connected to a supernatural energy is outside of the scope of the present discussion. This step-by-step procedure that for the moment only hypothesizes a possible energy responsible for the image formation, without detecting the phenomenon that caused it, seems to be necessary when scientific analysis is not able to completely explain and reproduce what is tested on the TS image.

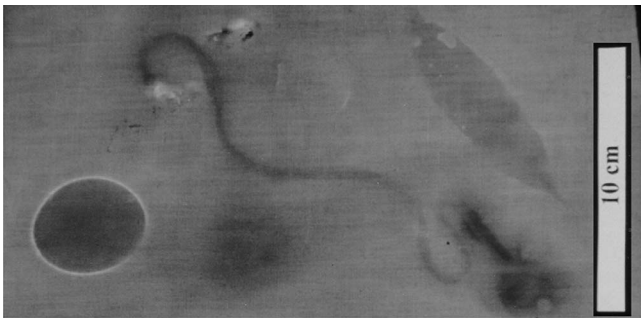

Figure 6. Linen sheet exposed to natural CD during an earthquake by DeLiso.[24] The images of a cartoon disk, a snake, a metal key and a leaf are shown from the left to the right. (Image courtesy of G. DeLiso.)

-The TS was inside the glow-CD layer, i.e., the length of the emitted streamers was greater than the body-cloth distance. The glow-CD layer was interrupted by the presence of the TS and it restarted, attenuated by the dielectric, on the outer surface of the TS. This explains why the superficiality of the TS body image is double in some image areas where there was a more intense electric field.[3]

CD and Imaging

-A negative CD was produced but the voltage was not high enough to cause arcing.

-It was possible to have a CD between two surfaces in contact, such as the tip of the nose and the linen cloth, because one of the two, the TS, was a dielectric.

-The image produced by CD was probably at first latent or weakly visible. Further aging turned the image into a yellow to light brown color.

-No references are made in this article about the effects of flowers, leaves and coins on a linen cloth, even if they also can cause an image if subjected to CD.

-A discharge of a very high voltage lasted for only a very short time and thus avoided burning the cloth;

-As shown in Fig. 5, the glow is more intense in the proximity of the human body, thus producing the 3D effect on the TS image.[4,5]

Mathematical Model Related to CD

-The electrical behavior of the upper half dotted box of the scheme in Fig. 4 can be modeled as a capacitor, separated by dielectrics such as TS and air.

-An electric field $E(t)$ is present between the conductive human body and the rock. If in a first approximation, the reference capacitor consists of two wide flat square parallel plates separated by a dielectric layer and if the plates size l, with area A, is much greater than their distance d and the instantaneous charge on a plate $-Q(t)$ is spread evenly, the instantaneous electric field between the plates $E(t)$, is

$$E(t) = -Q(t)/\varepsilon A, \tag{1}$$

where ε is the permittivity of the dielectric. In the case of the TS, the plates size l is not much greater than the distance d, so the electric field $E(t)$, and then the voltage $V(t)$, is a

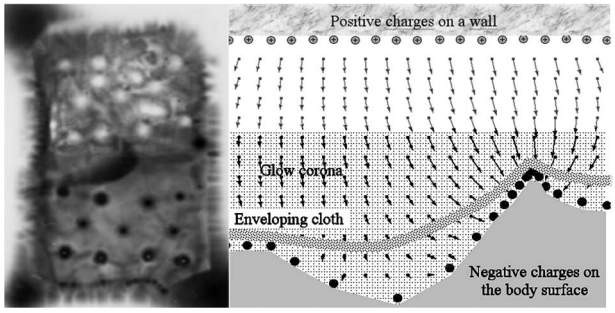

Figure 7. On the left, image of a 0.1-mm-thick sheet of copper in which some convex hills (darker) and concave hollows (lighter) were previously made by means of a pointed stick; the result was obtained using a Van de Graaff ribbon generator.[22] (Image courtesy of O. Scheuermann.) On the left, qualitative scheme of the voltage intensity corresponding to protuberances.

function of the position as shown in Fig. 5.

-The stored charge on each plate is the capacitance C:

$$C = Q/V = \varepsilon A/d \tag{2}$$

that decreases as the distance increases. An electric power increase related to CD causes a glow-CD layer increase that must be of the order of 5–10 cm to be able to reproduce the TS body image;[9,45] this fact leads to the necessity of having very high voltages.

EXPERIMENTAL RESULTS

CD Experiments with Various Systems

CD of very high intensity can be naturally obtained in concomitance with intense thunderstorms, but it is not simple to make experiments in these conditions also because it is not *a priori* known where it generates.

Low-intensity CD forms in concomitance with earthquakes if the subsoil is rich in quartziferous layers. Some layers in the subsoil are compressed before telluric shake and this compression causes a piezoelectric effect responsible for electrostatic field acting in the surrounding area. The primary threshold of CD can be lowered in the presence of radon that ionizes the ambience.

As theoretically described,[23] DeLiso[24] obtained interesting images on linen cloths, making experiments in caves rich in radon, made of quartziferous layers, in concomitance with earthquakes, see Figure 6. She covered different objects such as carton disks, leaves, metal keys and snakes with linen cloths put between two gneiss plates in a cave. The experiments with objects exposed to CD lasted for hours, before an earthquake; at the end, images appeared on the linen cloths.

The resulting images have many characteristics typical of the TS, but, probably due to the long exposure to a relatively low-intensity CD, these images are not as superficial as is the TS image. Future experiments under controlled conditions will be able to give better evidence for the superficiality of the obtained images.

A Van de Graaff ribbon generator can be used (Scheuermann[22,29,30]) to generate CD and images of objects on photographic paper and linen cloth see Figure 7. From

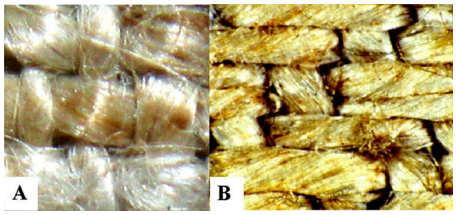

Figure 8. Contrast enhanced photographs of pieces of colored yarn in linen cloths: striations can be clearly seen. (A) CD experiment; (B) TS image of the eye (courtesy of Mark Evans ME-20 photomicrograph, © B. Schwortz).

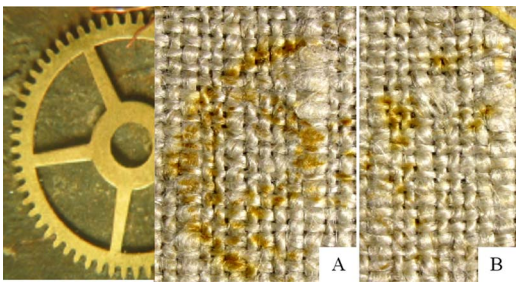

Figure 9. Resulting images on a linen cloth of a watch wheel (on the left) obtained by means of CD produced by a plasma ball. When the exposure of the linen cloth to CD causes more evident effects, the resulting image is superficial but double. In the figure it appears on both the surfaces, front (A) and back (B) and there is no image in the middle.

the experiments done the following can be noted: image intensity increases with power and distance between charged body and linen cloth thus producing some 3D information. Clean hair is barely represented in the CD image, but hair pre-treated with oil is clearly represented as it is on the TS. Saliva or tears prevent image formation.

CD Experiments with Plasma Ball

The experimental apparatus used to form images of objects on linen cloths using a plasma ball is the following:

-A commercial plasma ball having a diameter of 20 cm.
-Some samples of new linen fabrics, manufactured like old linen (about 3×3 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 the ground.
-A pressure of about 1000 Pa on the cloth was applied by placing a nonconductive mass over the metallic object.

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 peaks of 62 ± 1°C reached after 60 s of plasma exposure; the room temperature was 21°C.

After exposing the linen cloths to CD in air generated

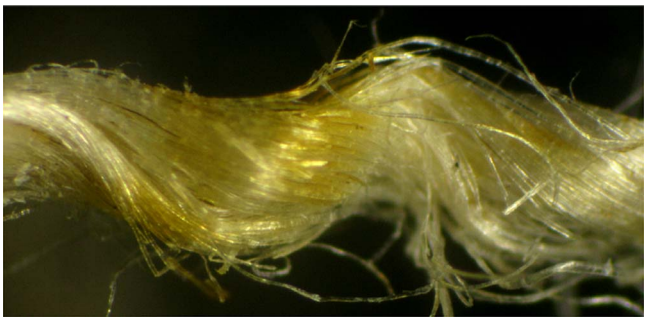

Figure 10. Linen yarn colored with CD: the color intensity varies along the fibers and only the topmost fibers are yellowed.

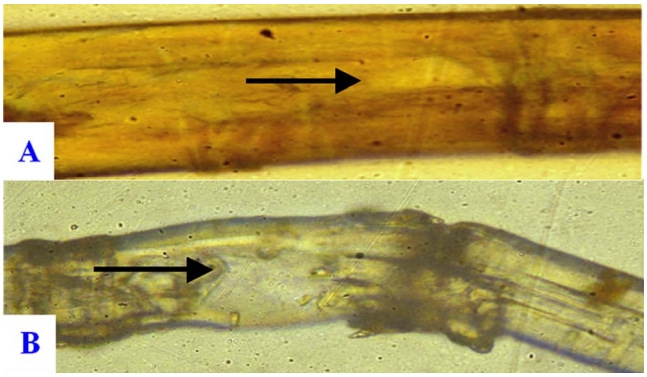

Figure 11. Image fibers (diameter of about 10 μm) obtained with (A) CD and (B) from TS sample STURP-1EB. The medullas of the image fibers are not colored. All the image fibers are circumferentially colored but after the application of a mechanical stress, the lack of the external colored layer is visible. The arrows show the noncolor area corresponding to the fiber medulla where the color layer is absent.

by the plasma ball, varying the time 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.

Some experimental results similar to the TS image are reported below.

1. After exposure to CD for 300 s, an image on the linen cloth is visible if the sample is illuminated with UV light. After heating the same sample with an iron (thermal aging), the image also appears in visible light.[26]
2. If a linen cloth is covered with oil, after a similar exposure to CD, an image also appears in visible light without ironing the sample.[26]
3. There are striations on threads, colored by CD, i.e., colored linen fibers are placed side by side with noncolored fibers (see Figure 8).
4. The image produced by CD is very superficial (Figure 9) and it is also double in some cases: it appears on both the front and back surfaces of the linen cloth but no image is visible in the middle.
5. The image color resides on the 200 nm thick primary cell wall[41] of the TS fibers. The medullas of the image fibers are not colored.[26]
6. A color variation can be observed along the fibers' length due to their position in the fabric, see Figure 10.
7. The image fibers obtained from CD are circumferentially colored, see Figure 11.

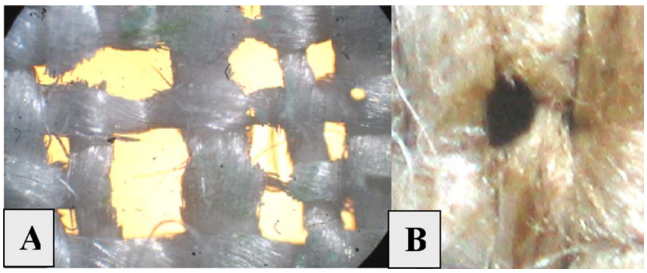

Figure 12. Effects of prolonged exposures of linen sheets to CD (for more then half an hour). (A) Ablation. (B) A hole appears without burnings or image traces.

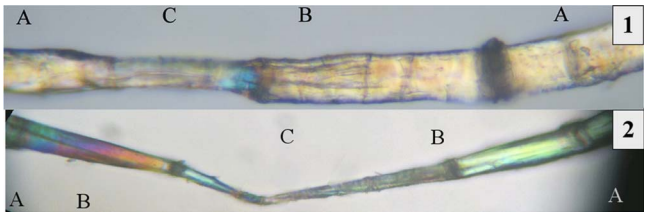

Figure 13. (1) TS linen fiber coming from Filter "*h*" corresponding to the buttocks area in polarized light. The shape of the fiber, 14 μm thick, can be subdivided into four areas. (A) The typical linen fiber. (B) Some longitudinal crevices lead to the assumption that shrinking was probably caused by exsiccation caused by a CD source. (C) The reduction in diameter to 8 μm was probably caused by a local ablation following an exposure to CD. (2) Linen fiber in polarized light, taken from the fabric shown in Fig. 12(A) in which a reduction in diameter is detected after exposure to CD. The same areas A-B-C are evident.

8. Burn holes due to the effect of a continuous spark acting on a specific point on the linen cloth can be obtained in some case of long exposure, see Figure 12(B). Ablation was also found in linen cloth after an exposure of more than half an hour to CD, see Figures 12(A) and 13.
9. The crystal structure of image linen fibers exposed to CD does not exhibit appreciable effects.[26]

DISCUSSION

The characteristics of the images obtained on linen cloths after exposure to CD correspond to those of the TS as reported.[8] As SSG researchers made some comments,[25] the most important ones are discussed here.

Radiation as the Probable Cause of the TS Body Image

Radiation is the probable cause of image formation[7] because (a) the 3D effect shows that there is a continuous relation between luminance and body-cloth distance, explainable with a source of energy acting at a distance; (b) there is also an image in the cloth's areas where contact is very dubious.

A new preliminary result based on the analysis of some TS fibers coming from the TS buttocks area can be added: some fibers have limited segments of about 40 μm, showing signs of apparent localized ablation which can be perhaps explained by a source of concentrated energy like a small arcing. Figure 13(1) shows a TS linen fiber from the buttocks area having the same characteristics of experimen-

Figure 14. (A) TS negative image of hands. (B) CD experiments (Ref. 35) resulting in producing an image of hands obtained from a live body (negative image—courtesy of Judica Cordiglia) showing many similarities such as elongation due to distortion, negativity and 3D characteristics. (C) corresponding 3D processing of image B.

tal fibers exposed to prolonged CD [Fig. 13(2)]. The "C" area is very limited (few tens of micrometers) and it is not easy to obtain such a result if localized electrical discharges are not used.

Mathematical Approximation of the 3D Effect

In the case of TS, the 3D effect[26,47] is better approximated with a negative exponential law. The exponential best fittings relative to the frontal, dorsal and face images[45] are the following:

-Frontal image (not including the face): $L=125\ e^{-0.246D}$; correlation=0.946.
-Face image: $L=215\ e^{-0.311D}$; correlation=0.933.
-Dorsal image: $L=147\ e^{-0.309D}$; correlation=0.979.

D being the body-cloth distance in centimeters and L the luminance in the range 0–255 relative to the negative TS body image. The curve relative to the dorsal body image is slightly different from the one of the frontal image but both differ from the curve of the Face image.

This fact is in favor of the hypothesis that there were some asymmetries in the ambient where the CD acted showing the limits of the simplified model hypothesized. The fact that the face image is characterized by a more intense luminance level must be more thoroughly studied in the future, but we can suppose that the head emitted a greater level of radiation or another cloth acting as an additional dielectric was put over the head thus amplifying the CD effect.

Contacts with Surfaces Having Different Potentials

Rogers[12] and Zugibe[46] 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. Nevertheless, the local electric field strength is not negligible if the surfaces in contact are not conductors. Scheuermann[30] 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 to the noncontact zone.

3D and Resolution

Schneider[26,47] supposes that there is an imaging problem in obtaining 3D features[4,5] together with a good resolution. The relatively high resolution of 4.9 ± 0.5 mm[48] of the TS image and the higher resolution of experimental results can be explained by the fact that the electric field lines do not cross each other and the radiation is very directional. Furthermore, higher resolution in the TS body image is found in correspondence to "almost-contact" areas such as the face and hands. On the contrary, the 3D effect is more evident where the distance of the human body from the TS is greater.

Judica Cordiglia[35] used a live human body to form an image of hands on a linen sheet by means of CD [Figure 14(B)]. The resolution of this experimental test appears to be of the same order of the TS hands shown in Fig. 14(A). The 3D characteristic of this result is evident in Fig. 14(C).

Brittleness of Image Fibers

Schwalbe[39] observed that it is easier to pull fibers from the TS image area than from the non-image areas. Also, the author detected a more brittle behavior on a TS image fiber coming from tape STURP-1EB; the same brittle characteristic was detected in the linen fibers previously exposed to CD.

Comparison with Other Experiments

Jackson et al.[5] made some experiments on CD using a reference face. They observed the associated heating with AGA-780 thermovision and concluded, perhaps in a simplistic way, that electrostatic imaging does not seem the best way to reproduce the TS image, also because with respect to field strength the local body curvature must be considered, which seems a potential problem.

First of all, the direct correlation between temperature and imaging must be demonstrated because the image seems also generated by UV involved in the CD process. Second, the dependence of the electric field on the surface curvature seems to be detectable, for example, where the eyes in the TS image are.

Perhaps Jackson's hypothesis,[18] which proposes a soft UV radiation as being responsible for the body image formation, can be in some way compatible with CD hypothesis; the soft UV rays may just be due to CD. A thorough study and comparison between Jackson's and the CD hypotheses will perhaps lead to an improved one where it is not necessary to make Jackson's special assumption that the enveloped corpse became mechanically transparent.

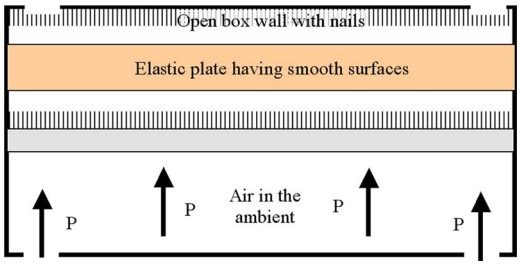

Figure A1. Stiff open box representing the ambience in which the CD happens. The TS human body or the ionized gas inside the plasma ball are represented by the lower air in the ambience of the box in which there are high voltages V and then high mechanical pressures P (force per unit area). The "elastic plate having nails on one surface" represents the TS human skin or the glass sphere which does not allow the electric current to pass (flow of velocity v) but they allow the action of the voltage V (velocity v); the nails correspond to the chemical energy capable of breaking the polysaccharides $C{=}C$ bonds of the linen fibers. The elastic plate having smooth surfaces corresponds to the TS or to the linen fabric used in the experiments. The "box wall with nails" represents the CD in ambience external to the TS or external to the experiments in which still there is a voltage which causes a smaller force acting between the wall and the elastic plate (not represented in the scheme).

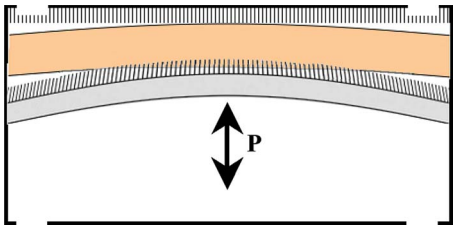

Figure A2. Open stiff box subjected to the influence of the pressure P and of CD: the "elastic plate having nails on one surface" vibrates under the action of the pressure P corresponding to the voltage V oscillating at high frequency (in the plasma ball case) or corresponding to the impulsive voltage (in the TS case). As a consequence, an image forms on the elastic plate having smooth surfaces which in turn is excited; therefore it hits the box wall with nails forming a second image on its back surface. As in the TS case, both the external surfaces are damaged ($C{=}C$ bonds broken) but there is no damage along the plate thickness.

Difficulties in CD Hypothesis

Even if the hypothesis based on CD seems the most probable one, there are some aspects that must be still clarified. The TS body image can be explained by an intense source of energy, such as ball lightning, but the experimental conditions are not easy to reproduce. The problem is related to the explanation of how the human body, which was a corpse, enveloped in an insulating cloth wetted with oils, could have generated such intense energy. This problem goes beyond the scope of the present article. For the moment, the following causes can be considered: a possible electric contact across the TS, between the human body and an electric source such as a lightning, a ball lightning that wrapped the corpse, or a supernatural phenomenon.

CONCLUSION

The aim of this article is not to completely explain how the TS body image was formed but rather to discuss an energy source, CD, and its collateral effects such as temperature and generation of UV rays, which could be considered as the probable body image formation agent for the TS. Future analyses will perhaps shed some more light on the open questions regarding the most important Relic of Christianity. In the details of the hypotheses regarding the TS image formation, some aspects of the interpretative model are considered and discussed. Experimental results with CD show similarities with the TS body image, and discussion is based on notes posted by SSG researchers.

Not all aspects of the image have been fully explained, but the CD hypothesis is perhaps the only one able to explain many facts detectable on the TS body image, some of which are: the soft hair; the double superficiality of the image; the uniform color of the thin primary cell wall all around the linen fiber; the discontinuous color along the yarn; the 3D information, which both agrees with a simple body-cloth distance and with the surface curvature. These and other results proved that many peculiar characteristics of the TS body image can be experimentally reproduced using CD.

The problem related to the explanation of how the human body could have generated the intense energy related to CD goes beyond the scope of the present article, but for the moment, we can refer to an electric contact across the TS, between the human body and an electric source such as lightning or ball lightning that wrapped the corpse or to a supernatural phenomenon. Up to now no sure conclusion can be reached about the mechanism that really formed the body image because it is not possible to experimentally reproduce the source of energy necessary to obtain an experimental copy of the TS image.

ACKNOWLEDGMENTS

The author thanks the Shroud Science Group on YAHOO! (especially G. Ballabio, F. Lattarulo, A. Whanger and B. Wiech) and in particular R. Schneider who, through discussion, allowed the author to clarify some details. Thanks also to R. Rogers for the TS samples furnished and to O. Scheuermann, who furnished photographs and interesting information. Finally particular thanks to A. Whanger and M. Whanger who kindly edited the article.

APPENDIX: ELECTRO-CHEMICAL-MECHANICAL ANALOGY

Sometimes a complex problem can be easily solved using a proper analogy; here it is considered the electrical-mechanical analogy that poses the following correspondences:

-Strength variable: to voltage V corresponds force F or pressure P.
-Flow variable: to electrical current I corresponds velocity v.

A chemical-mechanical analogy is added to represent the effect of the chemical energy due to CD acting on the polysaccharides of the linen fibers: the rupture of the $C{=}C$ double bond is here represented by nails that damage a smooth surface when hitting on it.

Table A1. Correspondences of the proposed analogy.

Dotted box of the scheme represented in Fig. 4	Plasma-ball experiment	Analog system proposed
Human body (I)	Ionized gases in the glass sphere of the plasma-ball (I)	Air in the ambience (P)
Human skin with CD (V)	Glass sphere with CD (V)	Elastic plate having nails on one surface (v)
Turin Shroud (V')	Linen fabric (V')	Elastic plate having smooth surfaces (v')
CD in external ambient (air)	CD in external ambient (air)	Box wall with nails
CD energy capable to break the C═C bonds	CD energy capable to break the C═C bonds	Nails

The dotted box of the scheme represented in Fig. 4 can therefore be transformed in the scheme of Figure A1. Table A1 shows the correspondences of the proposed analogy.

The stiff open box of Fig. A1 represents a capacitor modeled as a chamber with flexible plates in it separating the input on the bottom from the output on the top.

The following characteristics are evidenced.

-The input pressure P corresponds to the capacitor's voltage V.

-A constant gas flow (having velocity v, corresponding to current I) does not have great effect because it does not pass through the elastic wall; the flow only deflects it.

-A transient pulse or alternating gas flow can transmit the elastic energy (and then the electric one) necessary to make the wall vibrate.

-An overpressure results in the wall bursting, analogous to dielectric breakdown.

-The typical characteristic of a capacitor to have relatively high electric voltages V without transmitting high currents I corresponds to the box characteristics having the possibility of furnishing relatively high velocities v of the walls due to their flexion, without the possibility of transmitting gas pressure P.

After the definition of the electro-chemical-mechanical model we can discuss the corresponding effects of CD on the TS imaging, see Figure A2. For example in reference to the plasma-ball experiments, we have a high-frequency current I corresponding to a high-frequency vibration v of the "elastic plate having nails on one surface" that touches in some points the "elastic plate having smooth surfaces" which in turn vibrates at a lower velocity v'. This motion causes the hitting of this last plate against the box wall. Therefore, both the sides of the elastic plate having smooth surfaces are damaged by the nails that form an "image" on both the surfaces, one more evident on the lower side and one less evident on the opposite side, also in agreement with Ref. 3.

This analog model has shown how it is possible to obtain images on a linen sheet using a simple plasma ball, but in the case of the TS, things are a little different. From the CD experiments it has been shown that some image can be obtained on the linen sheet if it is in the proximity of the glass sphere (not distant more than few millimeters). Instead, in the case of the TS we have images on the linen fabric corresponding to anatomical parts distant up to about 100 mm.

To simulate this characteristic in the analog model, we must increase both the distance between the elastic plates in the box and their distance from the upper wall. To obtain images on the elastic plate having smooth surfaces it is now necessary to drastically increase the wall flexion and then the relative pressure P acting on the wall that corresponds to very high electric voltage V (of the order of many millions of volts[29,31–33]). This can be achieved by using a very high-frequency vibration or more simply by an impulsive loading (corresponding to a burst of electric energy like lightning) that deforms the elastic plate having smooth surfaces in such a way that the nails of both the two adjacent plates are able to damage the smooth surfaces.

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