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PAPER

GENERAL

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A BPA Approach to the Shroud of Turin*

ABSTRACT: An investigation into the arm and body position required to obtain the blood pattern visible in the image of the Shroud of Turin was performed using a living volunteer. The two short rivulets on the back of the left hand of the Shroud are only consistent with a standing subject with arms at a ca 45° angle. This angle is different from that necessary for the forearm stains, which require nearly vertical arms for a standing subject. The BPA of blood visible on the frontal side of the chest (the lance wound) shows that the Shroud represents the bleeding in a realistic manner for a standing position while the stains at the back—of a supposed *postmortem* bleeding from the same wound for a supine corpse—are totally unrealistic. Simulation of bleeding from the nail wounds contacting wood surfaces yielded unclear results.

KEYWORDS: forensic science, BPA, Shroud, Turin, bloodstain pattern analysis, crucifixion

The Shroud of Turin is an ancient linen cloth measuring approximately 4.4 × 1.1 m, bearing on the one side the faint image of a crucified man showing all the marks of the Passion of Jesus. The Shroud has been subjected to intense examinations by many scientists, but their conclusions have not been unanimous, some pieces of evidence pointing to a genuine relic and others to a clever medieval artifact. The Shroud has been carbon-dated between 1260 and 1390 C.E. (1,2).

Recently the forensic scientific community demonstrated its current interest in the Shroud (3) and the potential for applying forensic science to the investigation of the controversial relic.

Following these discussions, the presumed bloodstains from the crucifixion wounds on the linen were approached using Bloodstains Pattern Analysis techniques (BPA), in order to reconstruct the most likely position of the arms and the body during the blood flow ([4,5] for preliminary tests). This might also help to understand how this ancient death penalty practice—of which almost nothing is known—was performed. Thus, the current authors are only dealing with the patterning rather than the controversy about the nature of the stains (blood or tempera painting?) (6–11).

Reddish stains are evident in the head area, in the wrist and forearm, on the chest and on the feet of the image on the Shroud, clearly representing the blood which oozed from the wounds caused by the crown of thorn, the nails, and the lance (Fig. 1*a,b*).

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Previous studies of the blood stains date back at least to the XIX century, when the French physician Pierre Barbet (12–14) examined the two short rivulets which are visible on the back of the left hand. Assuming that blood should drip vertically, he calculated that the nailed arms of the crucified man would have formed an angle of 35 degrees (assuming 0° for a horizontal and 90° for a vertical arm) and experimentally confirmed these figures by nailing human corpses to a homemade cross.

As there is two slightly divergent trickles on the back of the hand, he assumed that the crucified person had changed his position—and therefore the arms' angle—during the torture of the crucifixion.

Ricci (15) later speculated that the whole upper part of the body also had to vary its position to account for the blood flow on the forearms. Zugibe (16) suggested that the body was washed before being wrapped into the shroud, and that all blood rivulets come from *postmortem* oozing.

Bevilacqua et al. (17) proposed that the blood on the forearms originated not on the cross, but when the nails were pulled out, and the body was not washed. A number of papers have been published on the various issues of the crucifixion, such as the exact cause of death of a condemned person or the nailing position (18,19). In relation to the Shroud, Lavoie (20) experimentally demonstrated that a blood clot could leave a print on a cloth only if the contact takes place within 1–2.5 h, depending on the humidity. The same Author, tracing the Shrouds blood rivulets onto paper and wrapping it around a real body, was not able to find a natural explanation for their shape and position. Other experimental tests to clarify the formation of the peculiar ε-shaped blood flow on the forehead of the image have been performed by Svensson (21).

This study is partially inspired by these previous investigations; however, it is focused—by a more forensic and empirical approach—on the analysis of the left hand, of the forearms (where traces are visible from the wrist to the elbow), and of the "lance wound" and of the blood stains near the waist.

The alleged wounds from the crown of thorns on head and forehead, as well as those on the feet, were not investigated in the present study.

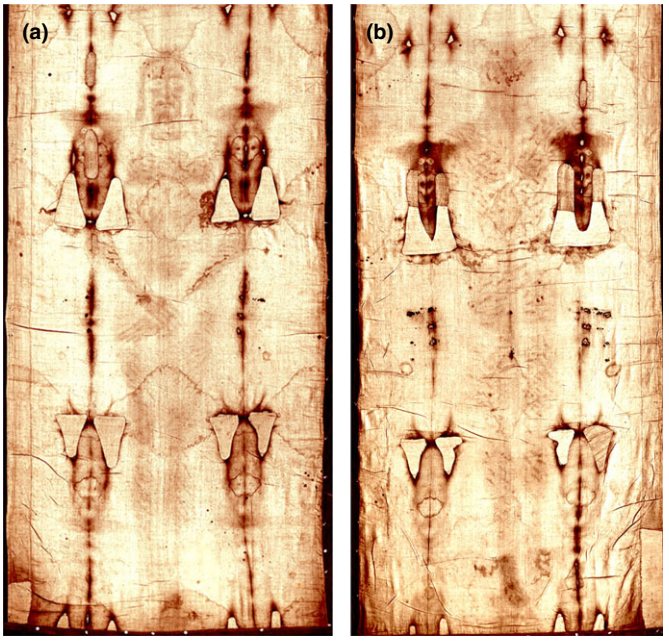

FIG. 1—*The Shroud of Turin before 2002 restauration. Frontal (a) and dorsal (b) images shown separately. (Modified by the authors from https://en.wikipedia.org/wiki/Shroud_of_Turin#/media/File:Shroudofturin.jpg).*

Various substrates (manmade or natural) as well as heat, humidity, and air circulation may come into play when attempting to recreate a scene or scenario. Obviously, one cannot know what the ambient temperature was at the time that the original Shroud had the pattern stain affixed to the cloth. Tests were performed at room temperature (ca. 22°C) and in the absence of air drafts. We deemed that such variables should not affect the positions and directions of the blood trickles.

It is also important to underline that the tests have been performed to understand the flowing of the blood on the body of a crucified man and its possible compatibility with the image on the Shroud rather than to evaluate the stain shape on the linen. This comparison has been possible due to the fact that the rivulets appear to be impressed clearly on the fabric.

Material and Methods

As the Shroud represents the print of a body on a cloth which was laid flat on it, the *left* hand of the body bore the above-mentioned short rivulets, while the left forearm showed a number of other ill-defined blood marks on its frontal part. The *right* hand is covered by the left one; therefore, no wound from the nail is visible. The frontal side of the right forearm, however, shows a better-defined blood flow from the wrist to the elbow (Fig. 1*a*). It is important to underline that on both arms the bloodstains are on the front side of the forearms.

In this study, the authors decided to focus only on the left arm of a volunteer to gain insight on the likelihood and mutual consistency of the stains on both the hand and the forearm of the image on the Shroud.

The reference images used to prepare the present experiments were from high-resolution published books (22).

We notice that the image on the Shroud is extremely faint and has a very low contrast. The best way to see the main features of the image—in our case the position and the directions of the assumed blood rivulets—is to watch it at higher contrast and at a medium resolution (even better its black-and-white negative).

The images that we show here are public domain photographs taken in 1931 by Giuseppe Enrie (23) and still shows the patches on the burn holes. For convenience, we have divided the image into the frontal and the dorsal part.

In these experiments, BPA was performed:

1 To simulate bleeding in contact with a wood surface, like the *patibulum*, in order to investigate the shape of the nail wound on the hand and the two short rivulets.
2 On a standing subject, with blood trickling down from the back of the left hand toward the forearm, in order to investigate the blood pattern at different arm-to-body angles in a crucified individual.
3 On a supine subject, with hands on the groin, to verify the likeliness of a *postmortem* flow.
4 On the short rivulets visible on the back of the left hand in the Shroud of Turin.
5 On the blood stain under the so-called spear wound, at the right side of the torso of the "Man of the Shroud."
6 On the blood stains present in the lumbar region of the Shroud (commonly called "belt of blood"), generally considered the result of a *postmortem* bleeding from the chest wound when the subject was laying horizontally after the removal from the cross. (Fig. 1*b*) (24)

In experiments 2, 3, and 4, whole human blood was used. According to the guidelines for human blood transfusion, the sample had been provided by a volunteer one week before the experiments; it had been stored—additioned with citrate phosphate dextrose (CPD) as an anticoagulant and saline-adenine-glucose-mannitol (SAGM) as preservative—at a medical laboratory at +5°C and brought to human body temperature just before use.

In experiments 1, 5, and 6, synthetic blood (25) was used for convenience. Preliminary tests confirmed that the behavior of whole human blood and synthetic blood were identical, and that the results of the experiments were super imposable. (26)

Experimental Results

Test 1—Back of the Hand

To investigate the shape of the nail wound on the hand and the two short rivulets, a preliminary test was set up to simulate bleeding in contact with a wood surface. A circular stain of 0.3 mL of synthetic blood was applied onto the back of the hand of a living volunteer to simulate a puncture-type injury; pieces of wood with different textures (from bark to smooth finish) were pressed on the hand for 10 sec and the resulting pattern observed (Figs. 2a and 2b). The results were not conclusive, as the wound is not clearly decipherable. In some cases, the texture of the wood also left its own imprint on the volunteer's skin. This result underlines how difficult it is to speculate on the real location of the nail's exit-wound based on the imprint on the Turin Shroud.

Test 2—Forearm

A ballistic angle finder was used, measuring the arm-body (or forearm-body) angle of a standing subject from 0° (arm parallel to the ground and perpendicular to the body) to 90° (vertical arm).

Two series of measurements were carried out, one with the elbow bent (armpit angle always at 90°) and the other with

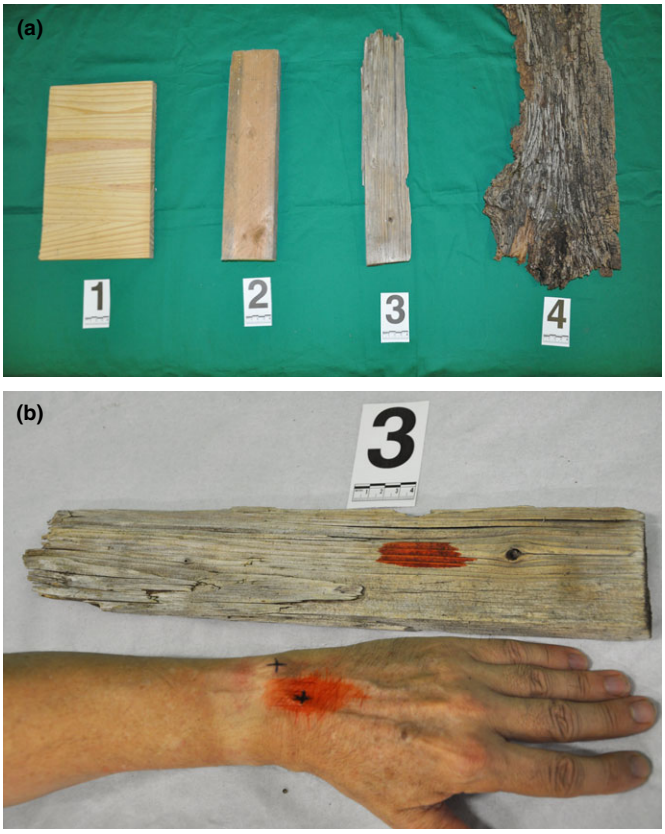

FIG. 2—*(a) Wood surfaces used in test N. 1. (b) Example of the alteration of the stain on the hand of the volunteer due to a contact with wood surfaces.*

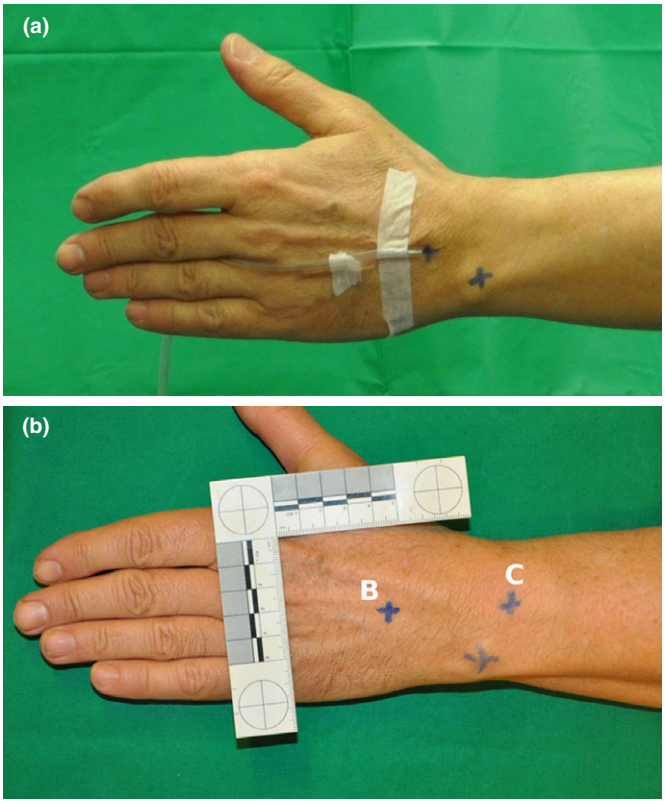

FIG. 3—*(a) The cannula is fixed at Destot's space (point A). (b) The picture shows the location of point B, corresponding to the cannula location closest to the knuckles, and point C, corresponding to the cannula location closest to the wrist.*

straight upper limb. No differences between the two series were noted: the blood flow results relate only to the position of the forearm in respect of the ground.

The volunteer was standing in front of a green background, his back facing the camera used to record the results. The end of a transfusion cannula was fixed at the wrist at Destot's space (point A), to simulate the dripping from a puncture-type injury where it is usually believed that the nail for the crucifixion was positioned (Fig. 3).

According to the results of experiment number 1, the exact location of the nail exit-wound is not distinguishable; consequently, two other series of experiments were performed with the aperture of the cannula a little closer to the knuckles (point B) or to the wrist (point C; Fig. 3a).

Whole human blood with anticoagulant was used. A transfusion bag was attached to the cannula and placed above the aperture; a rolling clip on the tubing allowed control of the blood flow rate (Fig. 4).

A small amount of blood was allowed to drip down from the cannula. Pictures were taken during the procedure; subsequently, the arm was outstretched horizontally in two orientations for additional documentation. At the end, the volunteer turned 180° facing the camera, and pictures were taken while he was crossing his hands in front of his groin in a Shroud-like position to allow for a comparison with the image on the Shroud.

The authors want to restate that the Shroud represent the imprint of a body; therefore, by a mirror effect, the right arm will be, looking at the cloth, on the right side of the viewer, and the left arm on the left side. The authors chose to perform the tests on the left arm of the volunteer to allow a more intuitive comparison with the Shroud pictures; this choice does not affect the direction of the blood flow according to the human limbs anatomical symmetry.

To investigate the possibility that the victim was crucified to a single vertical pole without the horizontal crossbeam, forearm-body angles of 110° and 130° were also tested, when the hands are directly above the head.

All the experiments performed clearly demonstrate that the angle between the arm and the body must be greater than 80° and smaller than 100° in order for the rivulets to flow from the wrist toward the elbow on the outer part of the forearm, as it appears on the Shroud.

In addition, when the forearm-body angles were 110° and 130,° the blood always trickles down on the radial part of the forearm, opposite to what is observed on the Shroud.

Similar results are obtained for all the different locations of the nail exit point (A,B,C).

The results of this part of the study also preclude the use of any kind of ligature to tie the arm or the forearm horizontally to the crossbeam (*patibulum*) for the "Man of the Shroud." Considering these results, the imprint on the Shroud does not correspond with the traditional artistic image of a crucifix with his arms stretched out on the crossbeam. A position with the arms folded backwards at the elbow and bent around the crossbeam—as in the painting of Mantegna (*Crocifissione*, 1457-1459)—is also not supported by this interpretation.

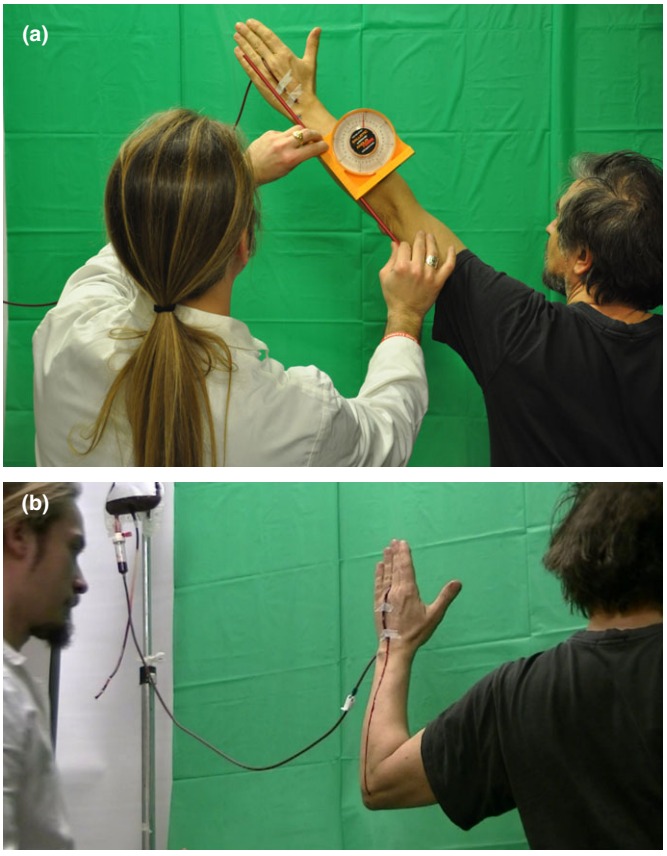

FIG. 4—*(a) A ballistic angle finder has been used to place the volunteer's arm in different positions before allowing the blood to flow. (b) The cannula attached to the transfusion bag allows the blood to flow while the volunteer is standing in the different possible positions of a man affixed to a cross.*

Test 3—Forearm in Supine Position

The volunteer was lying in a supine position on a horizontal surface, his hands overlapping his groin (left hand on top). The end of the cannula was again attached to the back of his left hand, and a small amount of blood was let drip from the transfusion bag.

The blood rivulet was then photographed as soon as it had dried enough to allow for movements of the subject's arm. The experiment was repeated after the surface on which the volunteer was lying had been tilted 5° both clockwise and counterclockwise. For each inclination, two sets of tests have been performed: one with the volunteer completely supine, and one in a flexed position with the head partially raised and his knees bent. This flexed position was chosen according to the recent reconstruction of the possible position of "The Man of the Shroud" (Fig. 5).

When the volunteer was in these positions, the blood movement never matched the Shroud. Instead the flow was parallel to the forearm for a few centimeters before dripping toward the lateral or medial side of the forearm. The rivulets also never ran at an angle comparable with the two shorter stains located on the back of the left hand of the Shroud.

Test 4—Rivulets on the Dorsal Surface of the Hand

The previous test number 2 was focused on the flowing of the blood along the forearm; for this new test, the frontal pictures of the volunteer's forearm obtained in the aforementioned experiment have also been used for a comparison with the stains on the back of the left hand of the Shroud. Using a protractor, the authors measured the angle between the blood rivulets and the middle line of the forearm (Table 1). For a reliable comparison, only the first 4 centimeters of the rivulets from the exit point have been examined. As in the previous experiment, the different locations of the exit point (A, B, C) seem not to interfere with the results.

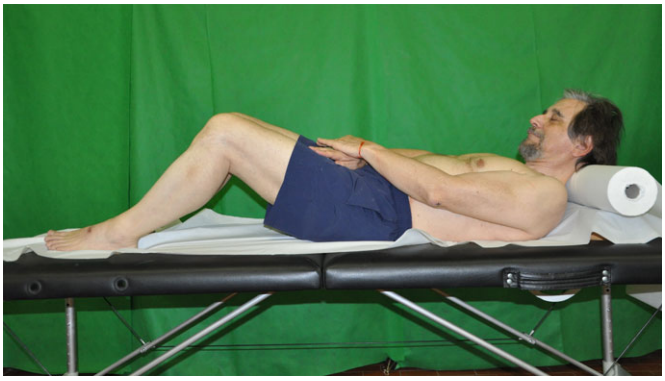

FIG. 5—*The volunteer is shown supine in a flexed position.*

Although it is difficult is to analyze the stain close to the nail's exit-wound as previously mentioned, the angles of the two short rivulets visible on the Shroud have been measured on a photograph, referring to the line connecting the elbow and the ulnar styloid process. The anatomical points have been identified on the Shroud image as well as on the volunteer; on the volunteers skin, the points have been marked to ensure consistency in the analysis. The distal rivulet on the Shroud appears to flow with an angle of 40°, while the proximal runs at 50°.

It was noted initially that the rivulets obtained during the experiments appear longer than the ones recorded on the Shroud, as they extend to the elbow of the volunteer and also generally change direction near the ulnar epiphysis.

Thus, as shown in Table 1, to obtain a rivulet/forearm mid-line angle of 40° as on the Shroud, forearm/body angle of the crucified man should be approximately 50°. To observe a rivulet/forearm mid-line angle of 50°, as for the proximal rivulet on the Shroud, the forearm/body angle should be approximately 45°, as can be deduced from the two experiments at 40° and 50° (that, respectively, created a rivulet angle of 63° and 39°: Figs. 6a and 6b).

In addition, the data in Table 1 closely resemble the findings of the French physician Barbet (12–14), who calculated on a real corpse a forearm slant of ca 35°. For his experiments, he nailed a corpse, with the arms in a horizontal position (0°), to a cross, which was resting flat on the floor. The cross was raised vertically before he measured the angles formed by the arms when they were supporting the weight of the body. However, from this

TABLE 1—*Correlation between the forearm/body angle of the volunteer during the bleeding and the angle of blood rivulets on his hand.*

Volunteer forearm angle (±2)	Rivulets angle
20°	86°
30°	86°
40°	63°
50°	39°
60°	30°
70°	22°

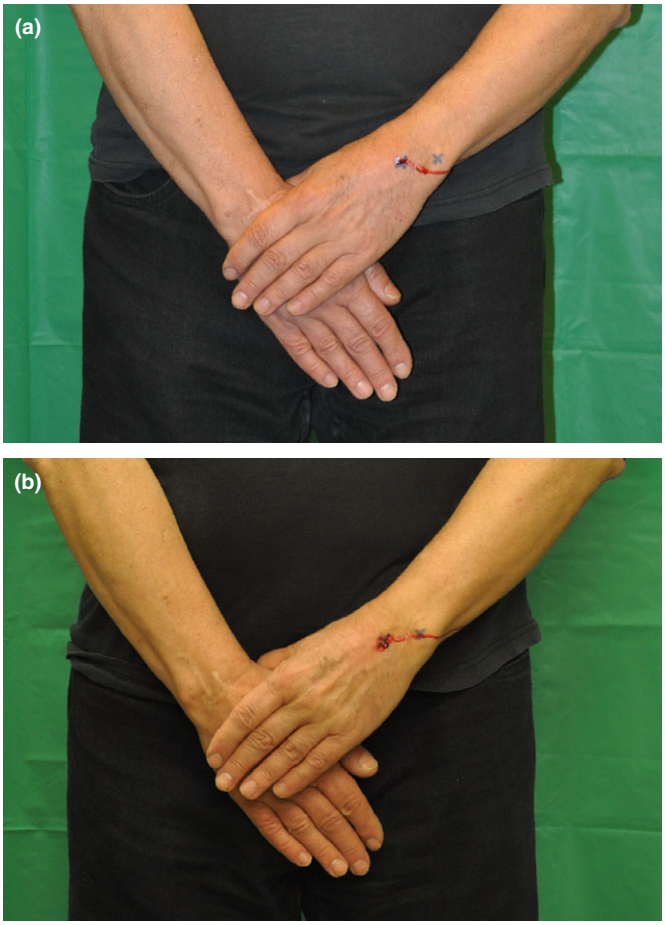

FIG. 6—*(a) Rivulet when volunteer's arm was at 40°. (b) Rivulet when volunteer's arm was at 50°.*

position, he did not let any liquid drip from the wounds to verify his calculations.

Even if the results obtained for the present experiment seems to confirm some previous hypotheses, the average angle reconstructed for the back of the hand (between 45° and 50°) is not consistent with those from the blood rivulet on the forearm itself, which instead require an angle greater than 80° (see experiment 3). Therefore, if the stains are from a bleeding wound, they could not have occurred at the same moment and with the body in the same position, but would represent the results of two different unknown events.

It is not pointless to add, regarding this analysis, that the short trickles on the back of the hand and the longer ones on the outside of the forearm are unconnected.

Test 5—Chest Wound

BPA of the spear wound on the chest was performed as follows: a sponge with the same dimensions (cm 6.5 × 2.5 × 3.5) as the wound, attached to a long handle, was soaked in synthetic blood and then attached to the corresponding area on a mannequin torso. (Fig. 7)

When the mannequin was in a standing position, vertical rivulets flow only on the front of the torso, in a direction congruent with the Shroud image. These findings seems to be consistent with the general interpretation that the Man of the Shroud was pierced with the spear while he was hanging from the cross. However, the

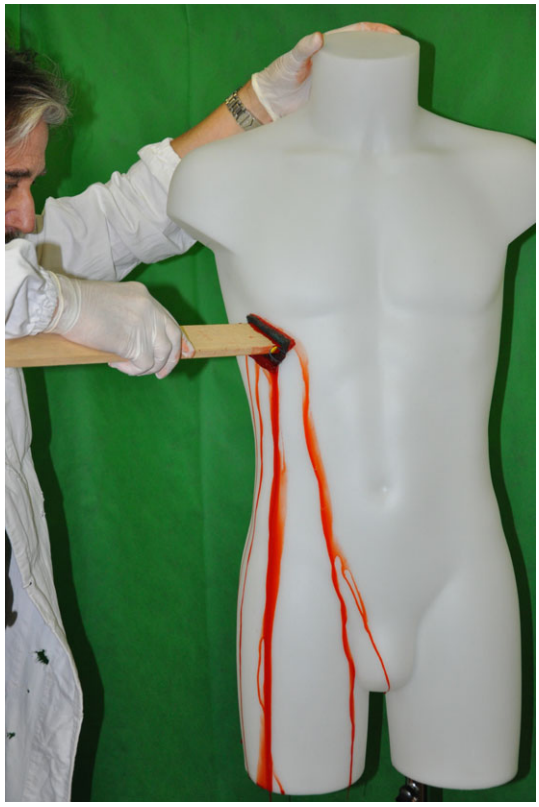

FIG. 7—*Simulation of the spear wound on a standing mannequin torso.*

rivulets obtained during the experiment run independently, without creating a large, filled stain as seen in the Shroud.

Test 6—Stains on Lumbar Region

This test was performed using the same process as in experiment number 5, but with the mannequin torso lying on a flat surface covered with fabric. The experiment was repeated after the surface on which it was lying had been tilted 5° both clockwise and counterclockwise (See Fig. 8*a,b*).

The rivulets from the chest wound flow sideways and posteriorly to the scapular region, where they create a single large pool absorbed by the fabric and a corresponding imprint on the body (Fig. 8*b*). The general pattern is therefore rather different from the Shroud of Turin, where it is possible to recognize the so called "blood belt" as multiple winding lines across the lumbar region (Fig. 1*b*).

The authors also placed the mannequin in supine position even after the vertical bleeding (experiment number 5), but in this case no stains were produced on the dorsal side.

Conclusions

The present study represents the first proper experimental Bloodstain Pattern Analysis (BPA) performed to better understand the evidence on the Turin Shroud and the behavior of the blood flowing from the wounds of a crucified individual.

The analysis of the trickle from the nail wound on the dorsal forearm (test number 2 and 3) demonstrated that, to obtain the same pattern present on the "Man of the Shroud," the individual would have to be in a standing position with his upper limbs raised at an angle between 80° and 100°. Other positions, with

FIG. 8—*(a) Simulation of the spear wound on a lying mannequin torso. (b) Blood pattern in a lying mannequin torso from a simulated chest wound.*

lower (e.g., the classical artistic representation of a crucifix) or higher (crucifixion to a single vertical pole) arms, and also *postmortem* bleeding in a reclining subject cannot account for the blood pattern on the forearms.

However, the direction of the short blood rivulets on the back of the hand (test 4) would require a standing subject with arms nailed at *ca* 45° angle; also in this case, the theory of *post mortem* bleeding in a reclining subject needs to be rejected.

The comparison between the outcomes of tests number 2, 3, and 4 demonstrates that the blood patterns on the forearms and on the back of the hand are not connected: they would have to occur at different times, and (should the Shroud be authentic) a particular sequence of events or movements would have to be imagined to account for these patterns.

Additionally, the BPA of the chest wound (tests 5 and 6) points to some contradiction between the stains on the Shroud. If the rivulets on the frontal image are roughly consistent with bleeding in a standing position, the hypothesis of a *post mortem* bleeding to generate the lines on the lumbar area ("belt of blood") seems to be unrealistic.

The authors performed the BPA to understand the different behavior of blood flowing from a crucified individual, rather than to find an explanation for the patterns on the Shroud.

Assuming that the red stains on the Turin linen are actually blood from the crucifixion wounds, the results of the experiments demonstrate that the alleged flowing patterns from different areas of the body are not consistent with each other. Even supposing possible different episodes of bleeding (e.g., movements of the body, *postmortem* bleeding), these are not only nondocumented, but also, as for the lumbar stains, they appear to be unrealistic.

The inconsistencies identified by the authors seem not only to point against their own reality, but against the authenticity of the Shroud itself, suggesting that the Turin linen was an artistic or "didactic" representation from the XIV century. This new Bloodstain Pattern Analysis supports the historical records (27), the radiocarbon dating (1), and the chemical analysis (6–11).

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