The Body Image and the Herringbone Weave of the Shroud of Turin

Richard E. Stanley, Jr.

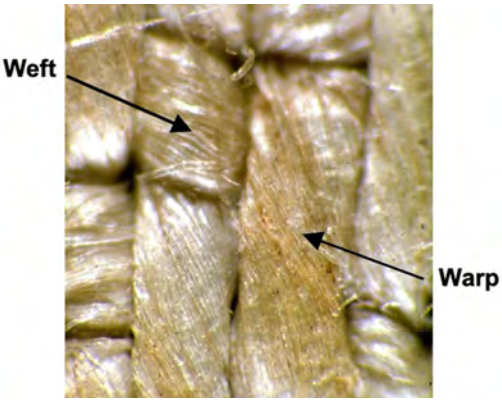

Fig. 1. ME-29. © 1978 Mark Evans Collection, STERA Inc.

Introduction

One of the well-established unique features of the Shroud of Turin is the fact that the body image is made up of individually discolored fibers of the cloth. That is, the basic cloth itself has fibers that are ivory colored which is what is seen as the background color of the Shroud. However, in areas where the body image exists, a portion of the cloth fibers have been discolored to a straw yellow color. Thus, it is the discoloration of the cloth fibers themselves which causes the body image to appear on the Shroud. A photomicrograph that illustrates the discolored fibers is reproduced as Figure 1[1], and it would be fair to describe this image as nearly famous—at least to sindonologists. In view of photomicrographs like Figure 1, as well as other tests and observations, it has been readily accepted that the body image on the Shroud is not the result of added pigments or dyes like in the case of a conventional painting. On the other hand, it still remains a mystery as to what caused the cloth fibers to become discolored like this to form the body image that we see on the Shroud.

Not only is it clear that the body image of the Shroud was not painted in any conventional fashion, but it has also been established that the body image is extremely "superficial". What is meant by this description is that the discolored fibers which make up the body image only consist of the top 1-3 fibers of the individual threads of the cloth. In other words, the body image penetrates the cloth by no more than about 0.02-0.06 mm or possibly 6-17% or less into the thickness of the cloth.[2] Another feature of the body

[1] This image is usually illustrated in landscape orientation, presumably for convenience and easier visualization. However, the author has rotated the image 90° in this paper since this is more consistent with the other images in this paper. The author has also added weft and warp labels to the image to identify the crossing threads of the cloth, which is discussed in more detail in the next section.

[2] These are rough estimates based on the fact that the fibers are between 10-20 μm in diameter and the cloth is about 0.34 mm thick. Giulio Fanti, et. al., *Microscopic and Macroscopic Characteristics of the Shroud of Turin Image Superficiality*, pg. 3, J. Imaging Sci. Technol. (2010).

image of the Shroud has been described as "double superficiality".[3] This description refers to the discovery that certain regions of the body image (mostly the face) appear on both the front and back surfaces of the cloth but not within the body of the cloth between the front and back surfaces. In other words, the surface of the cloth that observers commonly see (i.e., the front) is the surface that would have been facing the person or model that formed the body image. In contrast to the front side, the opposite surface which we rarely see (i.e., the back) has almost no body image visible thereon, and yet, on the back side of the cloth you can see a fainter image of the face (and possibly a few other parts of the body image). It is extremely difficult to explain how the body image was formed in a way that satisfies just these features of the Shroud without even mentioning the numerous other unique features of the body image. Indeed, even simple questions are hard to answer. What caused individual fibers of the Shroud cloth to be discolored like this? Why do the discolored fibers exist only on the very tops of the threads? And why are discolored fibers on both the front and back sides of the cloth at only the surfaces thereof (in the face area) but not between the surfaces?

If that were not challenging enough, the author has identified another possible unique feature of the body image of the Shroud that could be referred to as "textural superficiality". In other words, it appears that the body image is striated along the ridges and grooves of the herringbone weave of the cloth. That is, either the image forming mechanism itself or some subsequent mechanisms may have caused the discolored fibers to be concentrated along the ridges or grooves of the herringbone weave of the cloth with non-discolored fibers being interleaved between the discolored regions. At this point, the author believes he has exhausted the readily available sources in an effort to analyze this possible feature of the body image and believes that additional research is needed before this observation can be fully confirmed. However, if it is truly the case that there is a relationship between the discolored fibers and the herringbone weave, this "textural superficiality" would be one more test that could be used to evaluate proposed image forming mechanisms.

The Herringbone Weave

Another well-established unique feature of the Shroud of Turin is its herringbone weave. A variety of images showing the herringbone weave of the Shroud are reproduced in Figures 2A-2D. As described by textile experts, the herringbone weave of the Shroud is a result of the cloth having been woven in a three-to-one (3:1) twill pattern. A consequence of the herringbone weave is that the surface of the cloth has a pattern of

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[3] Giulio Fanti, et. al., *The Double Superficiality of the Frontal Image of the Turin Shroud*, J. Opt. A: Pure Appl. Opt. (2004). But see, Paolo Di Lazzaro, et al., *Pattern Recognition After Image Processing of Low-Contrast Images, the Case of the Shroud of Turin*, Pattern Recognition (2013), which calls into question whether double superficiality of the Shroud actually exists; and Giulio Fanti, et al., *About the Second Image of Face Detected on the Turin Shroud*, Shroud.com (2014), maintaining the existence of double superficiality.

Fig. 2a. Image of the Shroud showing the herringbone weave. Stephen Jones - TheShroudOfTurin.blogspot.com (acquired from Sindonology.org).

Fig. 2b. Arizona Test Sample. © 2012 STERA, Inc.

Fig. 2c. Image of the Shroud showing the herringbone weave.
Ray Downing - RayDowning.com

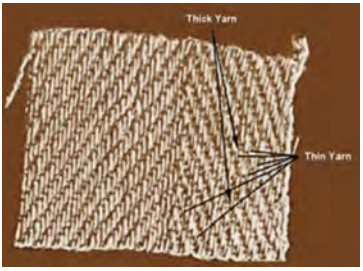


Fig. 2d. Image of the Zurich Test Sample taken from the Shroud with weave pattern inconsistencies noted by Albany International Research Company.
Raymond Hain III - HPRweb.com.

interleaved chevrons. In other words, the surface of the cloth has a series of grooves and ridges (see, e.g., Figure 2B) that periodically reverse direction to form V-shaped patterns.

Marcel Alonso described the texture of the herringbone weave like this, "The Shroud fabric has a beautiful side (the obverse) on which the warp yarn design makes a plateau (80% [of] the total area) crossed by V shaped deep furrows occupied by transverse weft threads (figure 5). The reverse side, on the contrary is flat and 80% of its surface is occupied by weft yarns."[4] As Giulio Fanti explained, "From a geometrical point of view,

[4] Marcel Alonso, *Role of Capillarity in the Image Formation Process*, pg. 5, Shroud.com (2005). See also Marcel Alonso Figure 5 for reference. It is unclear how Alonso arrives at his 80% figure, which from a purely mathematical perspective would be 75%.

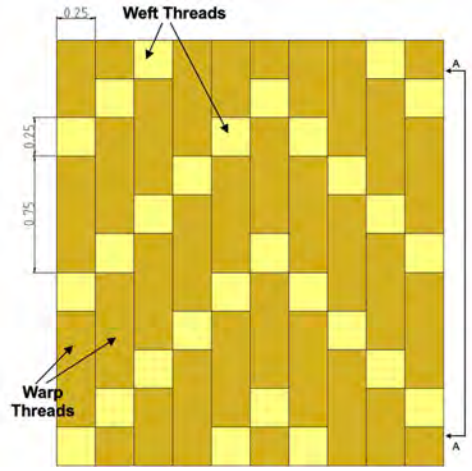


Fig. 3. Illustration of the herringbone weave pattern of the Shroud.

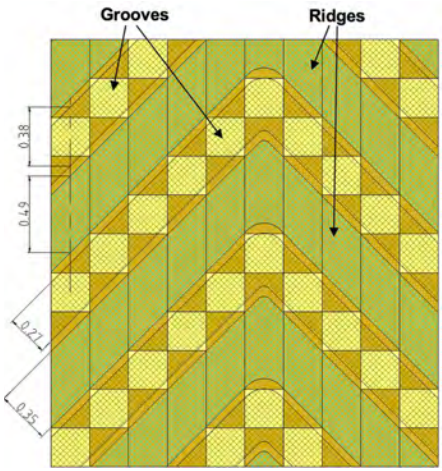
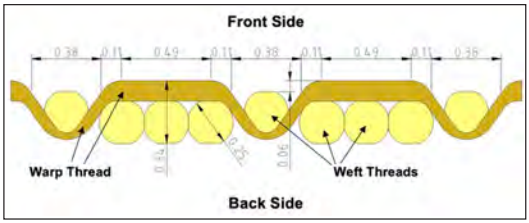


Fig. 5. Reproduction of Figure 3 overlaid with ridge and groove regions based on 0.38 mm and .049 mm dimensions taken from Figure 4.

Fig. 4. Cross-sectional illustration of the herringbone weave pattern of the Shroud (see section A-A from figure 3).



the body image surface of the TS (frontal), consists of 75% warp threads and 25% weft threads; the warp percentage, due to the 3–1 geometry gives a [3/(3+1)]=75% result."[5]

How the warp and weft threads form the herringbone weave of the Shroud is important in order to understand the texture of the cloth. A schematic view of the warp and weft threads is shown for reference in Figure 3. It is helpful to remember that the warp threads extend along the length of the cloth from end-to-end whereas the weft threads extend across the width of the cloth from side-to-side. A schematic cross-sectional view of the cloth is shown in Figure 4. In reconstructing this cross-section, the author relied principally on information published by Giulio Fanti, including a thread thickness of 0.25 mm, a cloth thickness of 0.34 mm and his photo of a sample cross-section.[6] What

[5] Giulio Fanti, et. al., *Microscopic and Macroscopic Characteristics of the Shroud of Turin Image Superficiality*, pg. 4, J. Imaging Sci. Technol. (2010). See also Giulio Fanti Figure 4 for reference.
[6] Ibid., pg. 3, Figure 5.

one can now start to understand from these illustrations, is that the warp threads form the raised flat-topped ridges of the herringbone weave, and the exposed portions of the weft threads are recessed below the exposed warp threads to form the grooves of the herringbone weave. Thus, the ridge and groove areas of the cloth can be schematically overlaid over the herringbone weave as shown in Figure 5. As can be seen in Figure 5 (see also Figures 2B and 2D for comparison), the width of the ridges is noticeably wider than the width of the grooves, with the ridges probably being about 30% wider than the grooves (0.35 / .027 – 1). As shown in Figure 6, a simplistic reconstruction of the ridges and grooves of the herringbone weave can be drawn using the dimensions of Figures 4-5. As shown, one notable feature of the ridges and grooves (besides the difference in widths) is that the grooves are extremely shallow, probably being about 0.06 mm deep (see Figure 4). It should be noted, of course, that Figure 6 is merely a schematic model of the ridges and grooves of the herringbone weave,[7] and one obvious difference with the actual Shroud cloth is that the sides of the ridges and grooves have jagged edges caused by the over and under weave of the warp and weft threads (see Figure 5 and 2B).

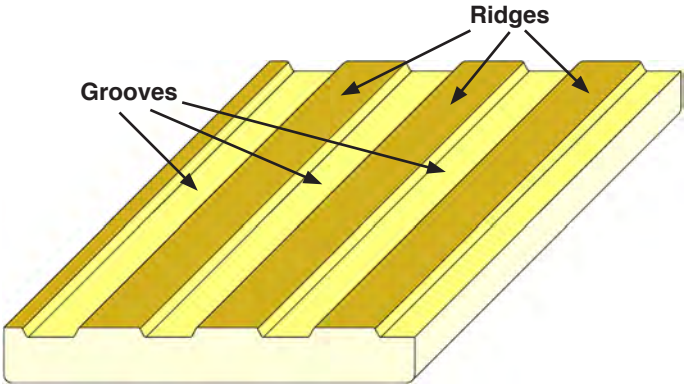


Fig. 6. Illustration of the ridges and grooves of the herringbone weave based on Figures 4 and 5. Reproduction is permitted if associated with a study, presentation or other discussion concerning the Shroud of Turin and with attribution to Richard Stanley, Jr.

[7] After creating Figures 3-6, it was pointed out to the author that Pietro Vercelli published detailed textile data about the Shroud in 2000 (*The Cloth of the Holy Shroud: A Technical Product Analysis of the Cloth and its Reproduction with Similar Characteristics*, The Turin Shroud – past, present and future, proceedings of the Villa Gualino conference). Vercelli's data shows that the linear density of the warp threads is about half the linear density of the weft threads and that the number of weft threads / cm is about 65% of the number of warp threads / cm. What this means is that the warp threads are thinner and more numerous relative to the weft threads. For example, it could be the case based on the author's calculations that if the warp threads are about 0.25 mm in diameter that the weft threads are actually about 0.35 mm in diameter. Further, Vercelli noted that "I wish to point out that as the Shroud cloth was woven manually using very irregular yarns it has a different density of threads and wefts depending on the points examined; the weight also varies in consequence." In any event, it would be difficult for the author to accurately adjust Figures 3-6 to match Vercelli's data but the exact measurements of the herringbone weave are not critical to the focus of this paper.

Striations in the Body Image

The features of the Shroud of Turin that have been discussed thus far are generally well-accepted by sindonologists (although the reconstructed dimensions of the herringbone weave are new, e.g., Figures 4-6). However, what comes next is not commonly described or considered in Shroud research. Turning to Figure 7A, this image should be recognizable by the reader as the face area of the Shroud—from right above the eyebrows to right below the mouth. This image was acquired by taking a screen print from the Shroud Scope at Sindonology.org of the Durante 2002 Vertical image at the maximum zoom setting. Figure 7B shows an enlargement of the area circled in Figure 7A, which now includes only the tip of the nose, part of the mustache and an area between the nose and the mustache. This image was obtained simply by cropping and stretching that portion from Figure 7A. What appears to be shown in Figures 7A-B is that the body image of the Shroud is actually made up of interleaved light and dark colored striations. And in particular, the striations that are visible in Figures 7A-B appear most certainly to be following the ridges and grooves of the herringbone weave of the cloth. If the reader has any difficulty seeing striations in the images, the author encourages the reader to go to the website http://sindonology.org/shroudScope/shroudScope.shtml and access the Shroud Scope where the reader can select the Durante 2002 Vertical image, pan to the nose and mustache area and select the maximum zoom setting.

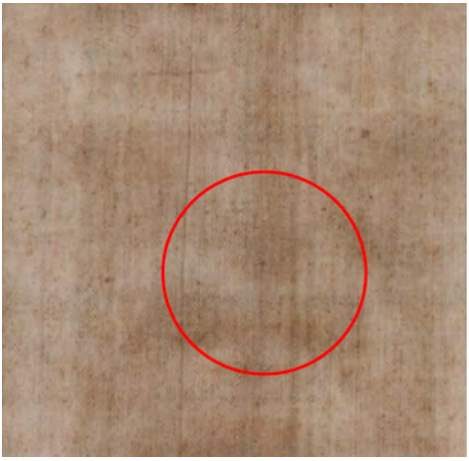


Fig. 7a. Image of the face on the Shroud.
© Durante 2002 - Sindonology.org.

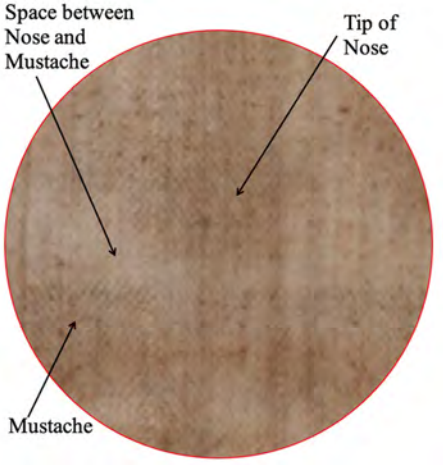
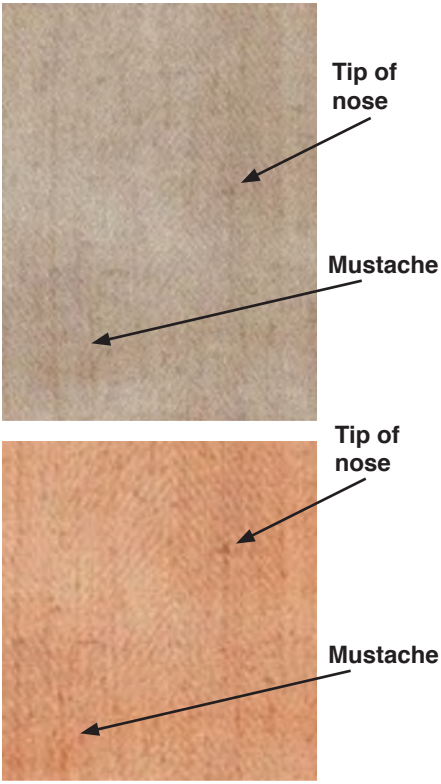


Fig. 7b. Enlargement of Fig. 7a.
© Durante 2002 - Sindonology.org.

What is evident from these images is that where the body image is darkest (the tip of the nose and the mustache) there are actually pronounced dark colored striations interspersed with light colored striations. As the image transitions from the dark body image areas to a light body image area (e.g., the space between the nose and the mustache), the dark colored striations become thinner and fade away while the lighter colored striations become wider and more pronounced. However, what is critically

important is that in most areas, including both the dark and light body image areas, light and dark striations are interspersed adjacent each other. In fact, there is almost no area in these images where the dark color saturates a region. That is, even in the darkest body image areas, there are visible light colored striations interspersed with dark colored striations. And as noted and worth emphasizing, it appears that these interspersed striations are following the herringbone weave of the cloth.



Figs. 8a and 8b. Images of an enlarged portion of the face on the Shroud.
© Vernon Miller, 1978.

In order to confirm the existence of these striations in the body image, the author has referenced several other sources as well. In Figures 8A and 8B, enlarged portions of two different images are shown of the same nose and mustache area as Figure 7A which were acquired from Vernon Miller's 1978 photos located at ShroudPhotos.com. The same light and dark striations appear in these images as well, although they are noticeably more blurry. To test different areas of the body image, Figures 9 and 10 show one of the calves on the dorsal side and the top hand on the ventral side, which were also acquired from the Durante 2002 Vertical image at Sindonology.org at the maximum zoom setting. These images show the light and dark striations even more clearly.

The rest of this paper will delve into what these light and dark striations might be. But first, the author will emphasize two points. First, it seems highly unlikely that the striations which are visible in these images are merely an imaging anomaly that doesn't actually exist on the cloth. The author believes that it is safe to assume, especially in view of the additional information below, that these striations actually do exist in the body image of the Shroud. Second, as emphasized again, the striations most definitely appear to be following the herringbone weave of the cloth, which potentially makes this a critical feature to better understand when evaluating possible image forming mechanisms.

Why Aren't the Body Image Striations Commonly Seen in Images of the Shroud?

The author has viewed numerous images of the Shroud from a variety of sources and has almost never noticed these striations in any of the images. Why is this? Is it because

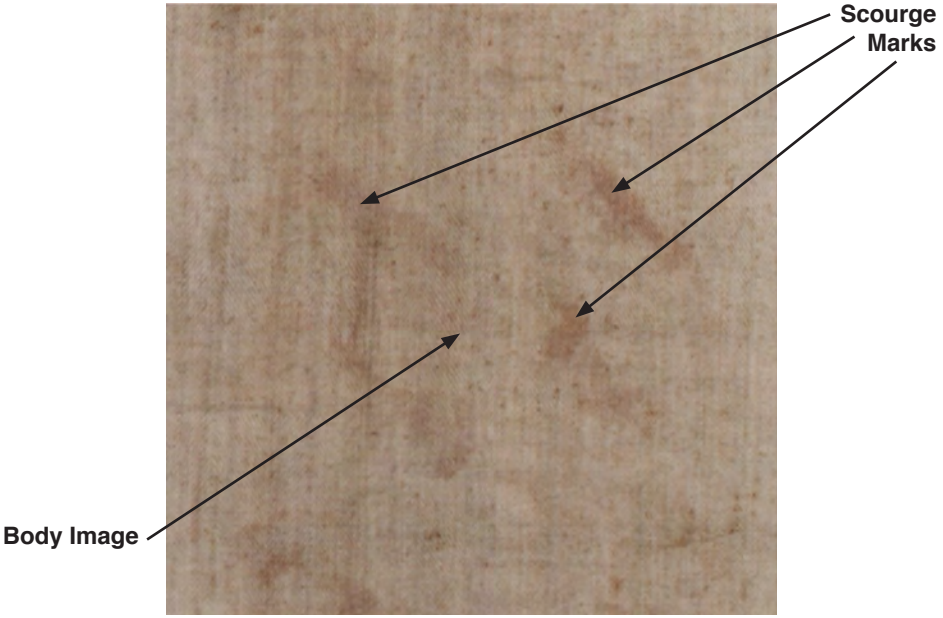


Fig. 9. Image of the dorsal side of one calf on the Shroud.

Fig. 10. Image of the hand on the Shroud.

they don't actually exist? The answer seems to come down to a simple matter of magnification, and probably reproduction quality in some cases. That is, the Shroud must be viewed within a particular range of magnification in order to see the striations, and most images of the Shroud are either under-magnified or over-magnified which prevents the viewer from distinguishing the striations.

The author has made estimated calculations of the images he has viewed where the striations are visible and has come up with a range of about 1.3x-3.5x magnification which makes the striations reasonably evident. By contrast, the photomicrographs that are often used to show the discolored fibers of the Shroud (see, e.g., Figure 1) are magnified 64x, which is far too magnified to see the texture of the herringbone weave. On the other hand, if one is viewing a full-length image of the Shroud reduced to 9in on a 8? in x11in sheet, the image is at about .05x. If one is only viewing the frontal image of the Shroud on a 8? in x11in sheet, the magnification is still only about .1x. Thus, most images are simply not magnified within an appropriate range to be able to see both the body image and the herringbone weave together.

However, based on the author's estimations above, it seems that it would not be hard to see the striations even with the naked eye looking directly at the actual Shroud itself. But then again, let's remember that the viewer's eyes would need to be within 1-2 feet of the Shroud, and very few people have had the opportunity to be that close to the Shroud while being allowed to freely gaze at the body image with no time constraints. There is no doubt that millions of people would love to be able to linger that close to the Shroud, but the actual number of people who have been able to do so is exceedingly few.

And yet, in another example, if you take the face area only of the Shroud and reduce it to fit a full page in a hardcover book, the author estimates that the magnification would be about .5x. This is still outside of the ideal range estimated by the author (1.3x-3.5x), but it is at least closer to the range where the striations are likely to be seen. This realization caused the author to scour his library for such an image and has found one such image in Ian Wilson's 2010 book.[8] In his book, Wilson reproduces an image of the Enrie negative in Figure 5 in the insert after page 82. And sure enough, the image appears to show striations in the body image following the herringbone weave, although the image is a negative photo image as opposed to the positive photo image (reproduced below as Figure 11).

What Have Other Sindonologists Said About This Feature?

Considering how much has been written about the Shroud of Turin (which is vast indeed), it is surprising how little has been written about the striated body image feature studied in this paper. The author has conducted an extensive search of papers available on the internet using a variety of search terms that may be used to describe this feature

[8] Ian Wilson, *The Shroud – The 2000-Year-Old Mystery Solved* (2010).

Fig. 11. 1931 Enrie photo.
Ian Wilson, *The Shroud - The 2000-Year-Old Mystery Solved,* Figure 5 (2010).

and only a few papers have been found that even peripherally address this feature. The relevant papers that the author has found do appear to confirm that there is something real to this feature, but none of these papers clearly answer the question of what exactly this feature is.

STURP team member Samuel Pellicori stated in 1981 that "The body stains, however, appear lighter and straw yellow in tone and, significantly, are generally restricted to the top three or four fibrils of each thread crown. In other words, this shallower coloration does not usually follow the bends or crevices caused by intersecting threads of the weave—a distinction that proved to be of great importance." He also stated that "The body image itself is a uniform, light sepia yellow color on the points of highest relief of the threads, or in other words, on the outermost surface of the Shroud."[9] On the one hand, Pellicori was clearly describing the type of superficiality that sindonologists are now well-familiar with, i.e., that the discoloration does not penetrate deeply into the threads of the cloth. But, his description of the bends, crevices, intersecting threads and points of highest relief of the threads suggest that he was describing something more than the type of extreme superficiality that is commonly understood about the Shroud. However, specifically what Pellicori was trying to describe remains unclear since he did not specifically refer to the herringbone weave, did not identify this feature in any photographs, and did not provide any graphical representations of what he was describing.

In 2005, Giulio Fanti stated that "Direct microscopy showed that the image color resides only on the topmost fibers at the highest parts of the weave." Fanti also stated that "the color of the image-areas has a discontinuous distribution along the yarn of the cloth: striations are evident. The image has a distinct preference for running along the individual fibers making up a yarn, coloring some but not others. Fibers further from

[9] Samuel Pellicori, et. al., *The Shroud of Turin Through the Microscope*, Archaeology (1981).

a flat surface, tangent to the fabric, are less colored, but a color concentration can be detected in correspondence to crevices where two or three yarns cross each other."[10] Fanti's description more clearly states that the body image is in fact striated with both discolored and non-discolored fibers. However, Fanti's 2005 description remains somewhat vague and lacking in clarity without providing references to marked-up photos, etc.

Raymond Schneider more clearly recognized in 2008 that the coloration of the body image is striated, and importantly, that the striations follow the herringbone weave. He referred to the darker lines as stripes and the lighter lines as interstitials.[11] However, he did not specifically analyze fiber discoloration itself or location concentrations of discolored fibers, and he made no attempt to deduce whether the stripes and interstitials correspond to the ridges or grooves of the herringbone weave. Notably though, and discussed further below, Raymond did recognize that the striated coloration of the Shroud is not limited to the body image only, but is also a feature of the blood marks as well as the non-imaged regions of the Shroud.

In 2010, Giulio Fanti stated that "The color only resides on the external surface of the TS. According to the fabric model described earlier, that surface is not flat. In any given region of the body image, there are more colored warp threads than adjacent weft threads: the image is mainly carried by the warp threads. However, some weft threads are also colored."[12] Although indirect, Fanti's description was clearly referring to the herringbone weave of the cloth, since as the reader will remember from above, the ridges of the herringbone weave are formed by the warp threads and the grooves of the herringbone weave are formed by the weft threads. Thus, what Fanti was actually saying is that the discolored fibers are predominantly on top of the ridges of the weave and markedly less so in the grooves of the weave. In that same paper, Fanti also stated that "Where one of the image-threads crosses over another, the yellow coloration of the fibers is often interrupted on the lower thread."[13] Although not being as clear as he could have been, this description is most likely referring to the same feature. That is, when he refers to a thread that "crosses over another", he is probably referring to the weft threads (in the grooves) which "cross over" individual warp threads. Additionally, the weft threads are best described as the "lower thread" in the weave relative to the warp threads. Fanti also noted that "A color concentration can be detected in correspondence to furrows where two or three yarns cross each other, or between two colored parallel yarns." To support this statement, Fanti provided a useful comparison that clearly demonstrates that the discolored fibers of the Shroud do in fact penetrate into the crevices of the weave and are not only on the top of the ridges of the herringbone weave.[14]

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[10] Giulio Fanti, et. al., *Evidences for Testing Hypotheses About the Body Image Formation of the Turin Shroud*, ResearchGate.net (2005).

[11] Raymond Schneider, *Digital Image Analysis of the Shroud of Turin: An Ongoing Investigation*, Figures 3 and 15, section 7.8, Shroud.com (2008).

[12] Giulio Fanti, et. al., *Microscopic and Macroscopic Characteristics of the Shroud of Turin Image Superficiality*, pg. 4 (1), J. Imaging Sci. Technol. (2010)

[13] Ibid., pg. 4 (3).

[14] Ibid., pg. 4 (4), Figures 7(a)-(c).

What Are the Striations in the Body Image?

Although it is tempting to jump to conclusions, the author realizes that there are potentially a number of different reasons that the body image has a striated appearance along the herringbone weave. Thus, the author does not feel that a final conclusion about what the striations actually are can be made in this paper. Instead, the author has chosen to provide the following possible list of factors that should be considered by future researchers.

The Widths of the Ridges and Grooves of the Herringbone Weave

One factor to consider when trying to analyze the visible striations on the Shroud is the geometry of the ridges and grooves of the herringbone weave. With reference back to Figures 4 and 6, although these are reconstructed models and are not asserted to be perfectly accurate, it is certain that the ridges of the herringbone weave are noticeably wider than the width of the grooves. As calculated above, the ridges are likely to be about 30% wider than the grooves (also compare Figures 2B and 2D).

A separate geometrical factor to also keep in mind is that the grooves are also likely to be wider than they are deep. Besides the reconstructions of Figures 4 and 6, this second conclusion can also be readily gleaned from measurements that have been taken of the cloth which place the thickness of the cloth at 0.34 mm and the thickness of the threads at 0.25 mm. Using these measurements, one can roughly consider the groove width to be about 0.25 mm (i.e., the thickness of one thread) and the depth of the groove to be no more than 0.09 mm (0.34 - 0.25). Thus, the width of the grooves must be at least twice as wide as the depth of the grooves, or using the author's dimensions from his reconstructions of the cloth, the grooves may be about 4.5 times wider (0.27 / 0.06) than the depth of the grooves.

So how can these geometrical factors be used to analyze the striations of the Shroud? The simple answer is that if one can distinguish differences in the widths of the striations (i.e., between light and dark striations), one might be able to ascertain whether the light or dark striations represent the grooves or the ridges. Unfortunately, this is not so easy to do with the images that are available to the author. Viewing Figure 7B for instance, the author can only say that it appears that the light colored striations may be wider than the dark colored striations. If this is the case, it would indicate that the discolored fibers that make up the body image are actually concentrated within the grooves and not on top of the ridges. However, this conclusion seems to directly contradict other observations that place the discolored fibers of the body image "on the outermost surface of the Shroud".

One final point worth mentioning here is that if one could visually distinguish individual threads in an image that alone would allow one to determine which striations constitute ridges or grooves. In other words (see, e.g., Figures 1, 2B and 3), if one is seeing a single exposed thread portion both at the ends of the thread portion and at its sides, then this necessarily means you are looking at a groove in the cloth (i.e., a weft thread). On the

other hand, if one can see that an exposed thread portion extends longer than the width of a thread and the exposed thread portion is adjacent to another parallel thread, then this necessarily means you are looking at a ridge in the cloth (i.e., a warp thread). Unfortunately, it is not possible for the author to see this level of detail in the images where the striations are evident.

Shadows

If one were to limit one's consideration to only the body image and only the nose and mustache region of the Shroud, an assumption might be quickly made that the striations constitute discolored fibers on top of the ridges of the herringbone weave and non-discolored fibers located in the grooves of the herringbone weave adjacent to the discolored fibers on the ridges. However, it may be more complicated than this when we consider all of the possible factors that may be involved. And, one important piece of information is the fact that striations following the herringbone weave exist everywhere on the Shroud, including the body image, the blood marks and the non-imaged parts of the cloth. This was recognized by Raymond Schneider and it is recommended that the reader review Figures 3 and 15 in his 2008 paper for confirmation.[15] Although not as clear as the photos in Schneider's figures, one can also see striations in the non-imaged parts of the cloth by viewing the image of the Shroud using the Shroud Scope at http://sindonology.org/shroudScope/shroudScope.shtml.

If we are to truly understand what the striations are in the body image of the Shroud (e.g., Figures 7-11), we must also understand what the striations are in the non-imaged parts of the cloth and what the striations are in the blood marks as well. Focusing on the non-imaged parts of the cloth, one possible answer might be that the striations in these areas are shadows that occur when pictures are taken of the Shroud. That is, could the ridges of the herringbone weave (which in this scenario would be the lighter striations) be causing shadows to form in the grooves of the herringbone weave (so that the grooves are seen as the dark striations)? This possibility makes some logical sense, and it is the only explanation that the author can come up with to explain the light and dark striations in the non-imaged parts of the cloth.[16] In fact, if one gazes for a bit on Figures 2C-D, it does appear that the grooves in the cloth have a somewhat darker appearance than the tops of the ridges, which might provide some confirmation of this theory. One possible counterpoint to a shadows theory is that the grooves are probably significantly wider than they are deep, which would seem to weigh against the possibility of light being substantially blocked from illuminating most of the surface within a groove.

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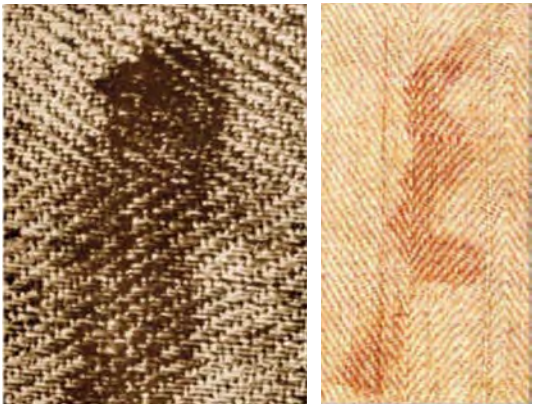
[15] Raymond Schneider, *Digital Image Analysis of the Shroud of Turin: An Ongoing Investigation*, Figures 3 and 15, section 7.8, Shroud.com (2008).

[16] The only other possibility that the author can think of is that grime, dust or some other foreign material has collected in the grooves of the herringbone weave to cause the grooves to appear as darker striations. However, this possibility can probably be easily dismissed because photomicrographs of the cloth do not show any obvious foreign material coating the grooves (i.e., the weft threads) of the herringbone weave.

If shadows are the reason for striations in the non-imaged areas of the Shroud, can shadowing explain the striations in the body image? Although shadowing might play a part in what we are seeing in conventional photographs of the Shroud, it does not seem that this possibility completely answers what the striations are in the body image. For one, the striations are darker in the body image than in the non-imaged parts of the cloth. This could mean that shadowing is a compounding factor of the dark striations in the body image, but the dark striations in the body image are probably not caused by shadowing alone. Secondly, the dark striations in the body image fade from dark regions to lighter regions, but if shadowing were the cause of the striations in the body image, the dark striations would be expected to be uniform across these regions. Thus, while it might be the case that shadowing does occur and may affect how we see striations on the cloth, it also seems fairly certain that the striations seen in the body image are not primarily caused by shadowing of the grooves of the herringbone weave.

Abrasion of the Ridges and Protection of the Grooves

Another theory could be that due to the extensive handling that the Shroud has experienced (possibly over a period of 2,000 years) some of the discolored fibers that make up the body image have been abraded away. If this were the case, one would expect the tops of the ridges of the herringbone weave to lose fibers from abrasion at a greater rate than within the grooves, which would have been protected from abrasion by the ridges. What this could mean is that the light colored striations are actually the ridges of the herringbone weave and the discolored image fibers which were once also on top of the ridges has been abraded away so that non-discolored fibers now cover the tops of the ridges. Continuing with this theory, the darker striations could constitute the grooves of the herringbone weave where the discolored fibers have been protected from abrasion and are now concentrated therein.



Figs. 12a-b. 1931 Enrie photo (left) and Archdiocese of Turin (right). Marcel Alonso, *Role of Capillarity in the Image Formation Process,* Shroud.com (2005).

Some support for this theory can be taken from the blood marks. As shown in Figures 12A-B, it is pretty clearly shown that the blood has concentrated in the grooves of the herringbone weave and that the ridges, while also having some blood thereon, are less covered by the blood and are often lighter colored. Marcel Alonso confirms this by stating with respect to Figure 12A (Figure 7 in his paper) that the blood "mak[es] compact bridges between some prominent warp yarns, and filling all the weft furrows."[17] With respect to Figure

[17] *Marcel Alonso, Role of Capillarity in the Image Formation Process*, pgs. 5-6, Shroud.com (2005).

12B (Figure 9 in his paper), Alonso stated that "on the warp face . . . [the blood] has been probably erased . . . and now the remaining 'pieces' of blood are stuck on the weft threads at the bottom of the furrows".[18] It is not completely clear why ridges of the herringbone weave within the blood marks have less blood thereon, but one logical theory could be that blood did fully cover the tops of the ridges at one time in history, but subsequently due to years of handling, some of the blood was abraded away from the tops of the ridges. Could this theory also apply to the discolored fibers of the body image?

However, the blood marks and the body image of the Shroud are unquestionably different from each other in numerous ways, and just because there is evidence that the blood has been partially abraded away from the tops of the ridges does not mean that this also occurred to the cloth fibers that make up the body image. Further, as noted above, if a theory suggests that the tops of the ridges constitute mostly non-discolored fibers, this would seem to contradict the oft-cited feature of the Shroud that the discolored fibers of the body image are "on the outermost surface of the Shroud".

Interfaces Between the Body Image and the Blood Marks

One possible way to gain some insight into the striations on the Shroud is to look at the boundaries between different areas of the Shroud. One boundary to consider is that between the body image and the non-imaged parts of the cloth. However, the author has not been able to gain any useful information from this boundary because, as is well-known, the body image has no clear outline and the edges of the body image fade away in such a subtle way that it is indistinguishable where the body image and the non-imaged areas start and end.

On the other hand, the boundaries between the blood marks and the body image are more distinguishable. This boundary might tell us something useful because in the previous section the author has established that the blood is concentrated within the grooves of the herringbone weave and the ridges of the herringbone weave are partially uncoated by the blood and are light-colored compared to the grooves which are filled with blood. This being the case, if the body image consists of discolored fibers on top of the ridges and non-discolored fibers in the grooves, the body image striations would be opposite of the blood marks. That is, in this scenario, the ridges would constitute the dark striations and the grooves would constitute the light striations in the body image (in contrast to the blood marks where the grooves are the dark striations and the ridges are the light striations). If this scenario for the body image striations is true, one would expect to see a distinct flip-flop in the striations at the boundaries between the blood marks and the body image. That is, a dark striation running through a blood mark would distinctly change in an opposite fashion to a light striation at the boundary with the body image.

Two such blood marks (the forehead epsilon and the wrist wound) are reproduced here as Figures 13A-B. However, in viewing the boundaries around these blood marks, the

[18] Ibid., pg. 6.

Figs. 13a-b. Images of the epsilon blood mark on the forehead (left) and of the wrist wound blood mark (right) on the Shroud. © Durante 2002 - Sindonology.org

author has not been able to detect any obvious changes in the striations as they pass between the blood marks and the body image. In fact, it appears that the striations run continuously across the boundaries between the blood marks and the body image and only change in intensity (the blood mark striations being darker than the body image striations), but no flip-flopping of the striations appears to occur at the blood mark-body image boundaries. This might indicate that the discolored fibers that make up the body image are concentrated within the grooves of the herringbone weave like the blood marks. Nonetheless, the author does not find this observation to be conclusive.

There is Insufficient Evidence to Establish What the Striations Are

At this stage, the only definitive conclusion that the author is comfortable with is that striations following the herringbone weave do exist in images of the Shroud within the body image, and also within the blood marks and the non-imaged parts of the cloth. Unfortunately, the author is unable at this point to answer even the simplest question of whether the dark striations within the body image represent the ridges or the grooves of the herringbone weave. And more involved questions of whether this means that the discolored image fibers are concentrated more on the ridges or within the grooves of the herringbone weave must wait until more evidence becomes available.

Considerations for Possible Image Forming Mechanisms

Assuming the striations in the body image are not an imaging anomaly, which is unlikely, this feature would constitute yet one more unique characteristic of the Shroud. And in particular, the striated nature of the body image could be a valuable feature for evaluating the numerous hypotheses that have been proposed for how the image was formed. That is, it appears that the image forming mechanism may have favored the ridges or the grooves of the herringbone weave of the cloth (but as yet it is undetermined which part was favored). If it is the case that the discolored image fibers are concentrated on the ridges or within the grooves, and that this concentration cannot be explained by

subsequent events like repeated handling, then it would mean that there was some property of the image forming mechanism itself that resulted in this concentration.

Of course, what the striations even are and whether they are the result of some distinguishable property of the image forming mechanism remains a matter of conjecture at this point. But here is one example of how the striations could be determinative of certain hypotheses that have been proposed. If it is established that the discolored image fibers are concentrated on the ridges or within the grooves of the herringbone weave, and that this favoring most likely occurred when the image itself was formed, this would mean that image forming mechanisms that should have resulted in saturated regions of the cloth could be discarded as possibilities. Light and other similar forms of radiation would fall into this category because these image forming mechanisms would be expected to discolor the cloth fibers evenly on top of the ridges and within the grooves.

But, without more information about the striations, nothing definitive can be said about how the image was formed. It can only be said that additional information about the striated nature of the body image has the potential to significantly narrow the numerous mechanisms that have been suggested.

Research Proposal

As we have seen, there is inadequate information available publicly to make determinative conclusions about what exactly the visible striations are in the body image of the Shroud. Although there certainly does appear to be something about the body image that results in visible striations following the herringbone weave, what actually causes the striations to appear as they do is not at all clear. And yet, this question should not be difficult to answer if additional imaging information were made available for study. Thus, the author proposes the following research project to collect additional imaging information from the Shroud, which the author believes has never been done in the manner proposed here.

Briefly described, the author believes that video images of the Shroud at varying magnifications would reveal new information about the Shroud that cannot be easily ascertained from still photographs. The proposed research project would require the following components.

1) A gantry that would contact the support table beyond the edges of the Shroud to prevent any physical contact with the Shroud.
2) The gantry would have a slide above the Shroud that moves in a single (x) direction or in two (x-y) directions.
3) A motor and a controller would move the slide across regions of the Shroud.
4) A positional indicator would electronically record the position of the slide.
5) A camera would be mounted on the slide and would face the Shroud to record images as the slide moves across the Shroud.
6) The camera would have a variable magnification lens that would allow the magnification to be changed (e.g., 1x-100x).

The system outlined above could be used in a number of ways to collect new imaging information from the Shroud. The author suggests that the system be used to collect the following data which could be used in at least the following ways.

1) The camera could make multiple passes along identical tracks using different magnifications for each pass. This would allow researchers to see a variety of features on the Shroud at different magnifications. For instance, the texture of the herringbone weave could be seen more clearly at lower magnifications and individual fibers could be seen at higher magnifications.
2) Another way to use the camera would be to position the camera in one location of interest and slowly vary the magnification at that location.
3) By recording the location of the camera using the positional indicator, researchers would be able to easily match images of different magnifications, wavelengths, etc. for the same location. It may be particularly helpful for the recorded location information to be stamped on the images themselves.
4) The author's proposal does not contemplate scanning the entire Shroud. Instead, tracks would be planned beforehand of specific features of the Shroud which would be especially useful to researchers. The author suggests the following examples: boundary areas between the non-imaged part and the body image; boundary areas between the body image and the blood marks (e.g., the wrist wound and the forehead epsilon); the nose, mustache and depression therebetween; the chin crease; and the scourge marks.
5) The camera could also be provided with the ability to record images in specific wavelengths or wavelengths beyond the visible wavelengths. Other sensors could also be included on the slide to record other useful data.
6) Preferably, the image data would be made publicly available to provide as much access as possible to researchers of various backgrounds. The Shroud Scope at Sindonology.org is a good example.

Although the final details of a research project would need further work before being ready to be carried out, a research project based on this outline would doubtlessly provide valuable new information about the Shroud. But, of course, this research proposal remains only a proposal until such time that the Vatican agrees to accept the proposal and allow access to the Shroud in order to collect additional images.

Conclusion

Without a doubt, the Shroud of Turin is the most studied historical object of any, and despite the enormous work that has gone into studying the Shroud, no clear answers can be given as to what it originally was or how the body image was formed. In this paper, the author has identified yet one more feature of the Shroud that adds to its mystery. That

is, the body image (which is at the heart of the mysteries of the Shroud) can be seen to be striated with light and dark lines that follow the texture of the cloth (i.e., the herringbone weave). At this time, there is insufficient information publicly available to ascertain exactly what the striations are. However, unlike some features of the cloth which are incredibly difficult to explain, the feature identified in this paper should not be difficult at all to explain (at least as to what it is) with additional imaging data. Thus, a research proposal has been made that would in all likelihood provide answers to at least this one question about the Shroud.

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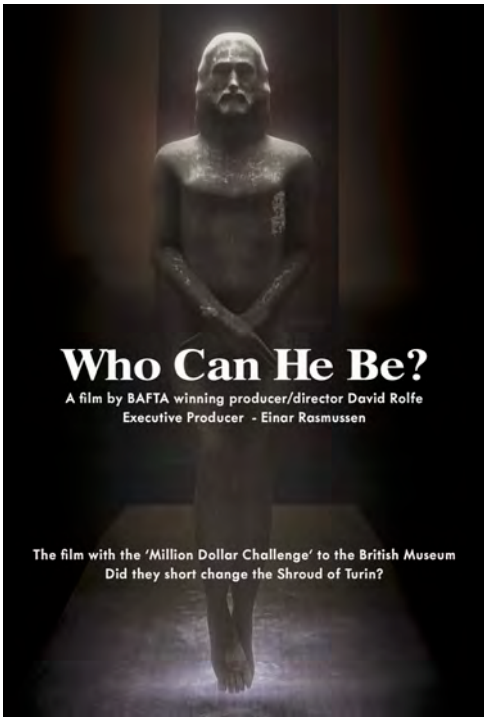

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