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Imaging Analysis and Digital Restoration of the Holy Face of Manoppello—Part I

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Received: 28 September 2018; Accepted: 21 October 2018; Published: 25 October 2018

Abstract: The Veil of Manoppello is an icon of the face of Christ (Holy Face). Its particular characteristic is being semitransparent. The face is visible on both sides (front–back) and, depending on the lighting and observation conditions, shows some differences in the anatomical details. An analysis of this icon has allowed us to clarify some aspects of the possible physical mechanism underlying its unusual optical behavior. It is a linen fiber fabric consisting of very thin threads with a thickness of about 0.1 mm, separated by distances even double the thickness of the threads, so that about 42% of the Veil is empty space. The fibers constituting the linen threads may have been cemented by an organic substance of chemical composition similar to cellulose, presumably starch, eliminating the air between them. Such a structure causes the optical behavior of the medium to be intermediate between those of a translucent medium (thin cemented linen threads) and a transparent one (empty space between the threads). The problem of digital image restoration in spatial terms has also been tackled, since the Holy Face is deformed due to distortions of the meshes of the Veil, caused by the yielding of the very fine structure of the fabric.

Keywords: artwork; optical characterization; Veil of Manoppello

1. Introduction

The Veil of Manoppello is a small rectangular canvas of dimensions 240 × 175 mm^2 characterized by a very thin, semitransparent fabric, on which is depicted the image of a male face with long hair and a divided beard. The represented face is associated in Christian iconography with Jesus Christ and, for this reason, it is called the Holy Face. It is kept in the Sanctuary of Manoppello (PE), Italy. This is a very special icon because the image is visible on both sides, as shown in Figure 1 which shows the reliquary containing the Veil of Manoppello photographed front and back.

The cheeks are markedly unequal because one of the two is particularly swollen. At first glance the chin does not seem to be in line with the rest of the face, and the eyes do not seem to be at the same distance from the nose. All these characteristics give an evident asymmetry to the face. The image has been studied by many scholars because it is not clear how it was created [1–10]. Its peculiarity is due to the fact that, observing the face in reflected light, it is visible from both sides. When the observer and the light source are on the same side and look at the front side of the Veil, the image that emerges is that shown in Figure 1a; if, instead, the observer looks at the back side, the image represented in Figure 1b emerges. The image is as if it were two-faced, although it shows some small differences such as, for example, the direction of the gaze.

Moreover, the face is visible even if it is observed by back-illuminating it with grazing light and observing the Holy Face transmitted by the Veil, as schematically shown in Figure 2.

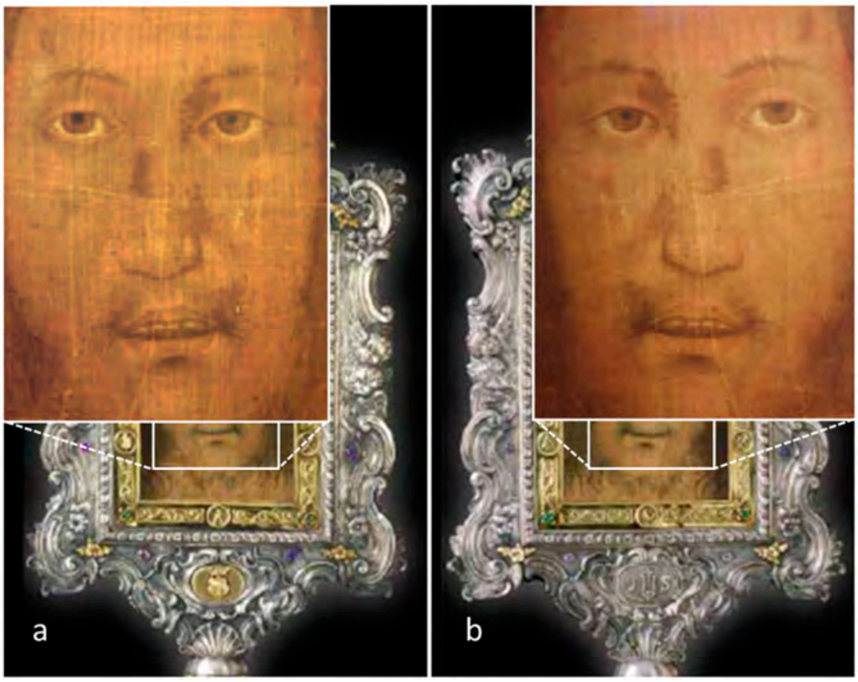

Figure 1. Face of the Veil of Manoppello seen from the front (**a**) and back (**b**), illuminated frontally and seen in reflection.

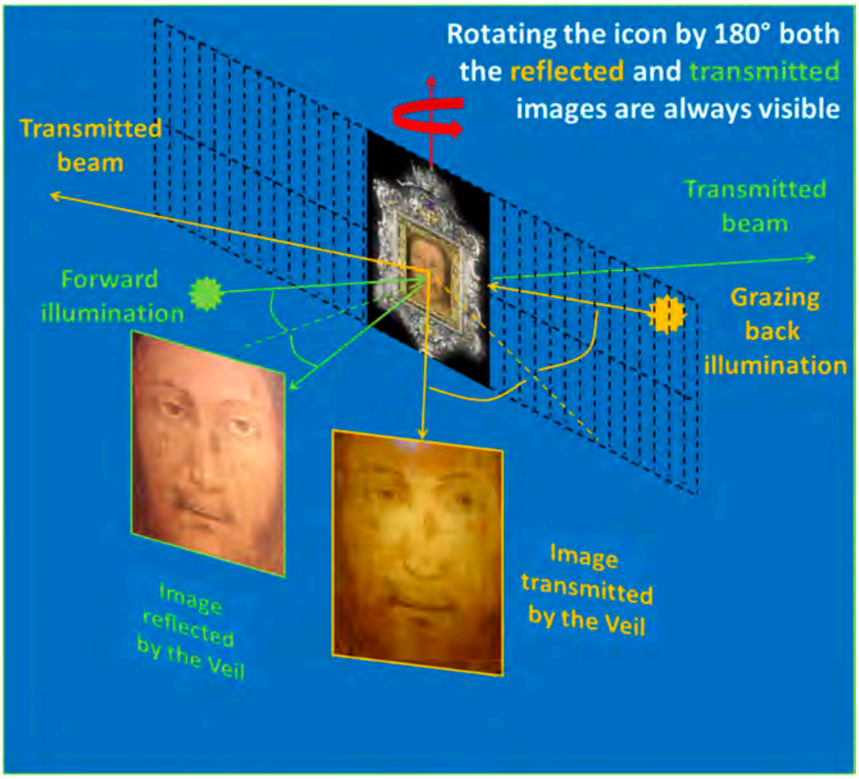

Figure 2. Images of the Holy Face visible on the Veil of Manoppello depending on the conditions of lighting and observation.

That is, it is visible even when the observer and the light source are not on the same side. When the observer and the light source are on the same side and look at the front side of the Veil, the reflection image that can be seen is represented by the green box in Figure 2, which reproduces the image of Figure 1a; if, instead, the observer and the source are not both on the same side and the Veil is illuminated with grazing light, the image is transmitted by the Veil and is that visible in the yellow box of Figure 2. Analogous behavior can be obtained if the icon is rotated by 180 degrees. In other words, two very similar images are visible and are of the type indicated in the green box of Figure 2—one visible from the front side, the other from the back side. Moreover, it is possible to view another couple of images, also very similar to each other—one visible from the front side, the other from the back side of the icon—of the type indicated in the yellow box of Figure 2. However, they differ in some anatomical details from the first couple (those of the green box). We pass from the images of the type represented in the green box to those of the yellow box by changing the conditions of visualization and illumination of the icon, i.e., passing from direct to grazing light and from observer and source placed on the same side to observer and source placed on opposite sides of the Veil.

Finally, the direct light backlighting does not immediately make the face visible, because the Veil is so thin that the amount of light that reaches the observer would be excessive. Instead, by placing an obstacle between observer and source to shield the excess of light, like the hand shown in Figure 3a, it is possible to see the part of the face that falls in the shielded area.

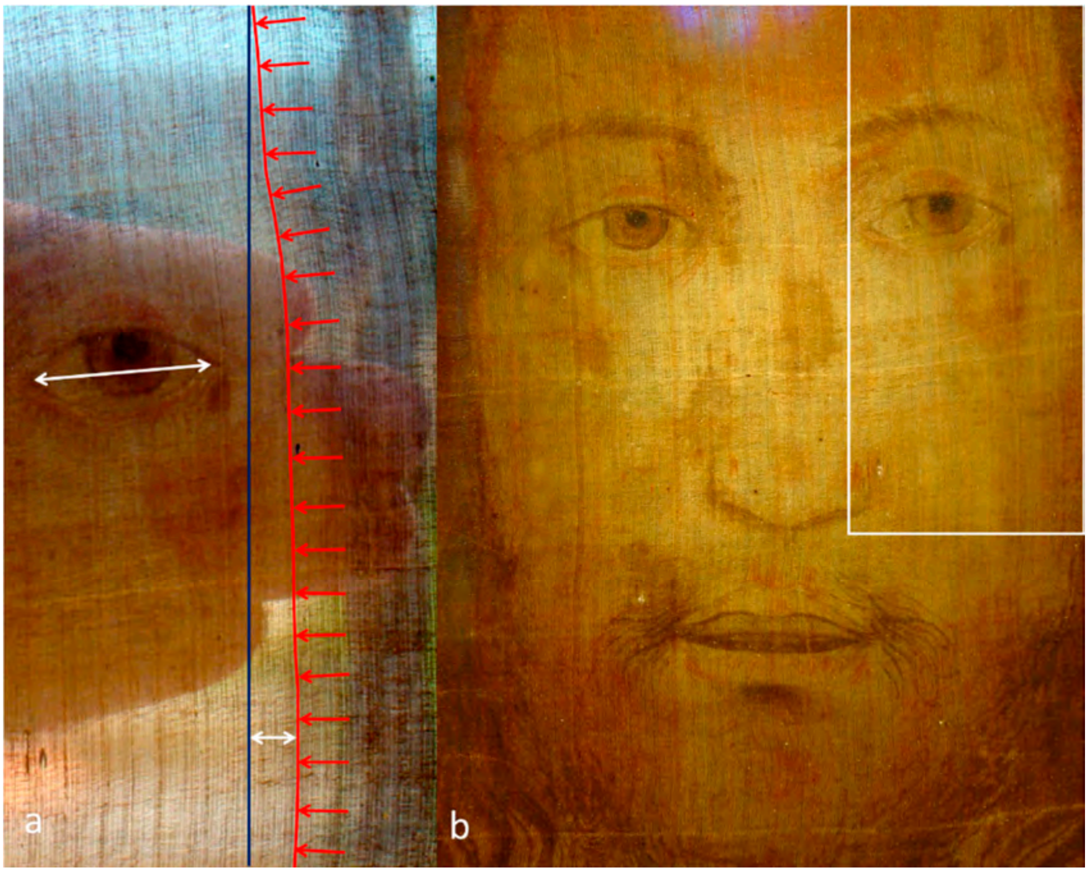

Figure 3. Veil of Manoppello deformation: (**a**) detail of the Veil of Manoppello visible when light source and observer are perpendicular to the Veil but are on opposite sides, and the direct beam is partially shielded. The thin weave of the fabric is visible. The distortion of the threads which, obviously, deforms the image has been highlighted; (**b**) face always seen in backlighting but with grazing light coming from a lateral source. The white box on the right represents approximately the region of the face on the left.

In the example of Figure 3a, the hand allows us to see the right side of the face at the height of the cheekbone and the eye, corresponding to the white box in Figure 3b, where the image of the whole face is shown as seen in backlighting with grazing light. Comparing Figure 3b with Figure 1a,b, it emerges that in this back-illumination mode the teeth are not visible, but they are visible if the lighting is direct, as shown in Figure 2 (green box). The possibility of seeing the images of the double-sided face resides in the particular structure of the fabric. These are the characteristics that have attracted the attention of several authors who have, however, studied the Veil of Manoppello from mainly the historical point of view.

Our study is divided into several parts. In this paper we first discuss the possible nature of the Veil fibers, based on its unusual optical behavior, through an accurate analysis of some experimental data obtained from optical and spectroscopic characterizations already carried out on it. Then, we digitally analyze the image with the aim of correcting the deformations of the face, a consequence of the distortion of the thin structure of the weft and warp threads due to the numerous stresses suffered by the Veil over the centuries.

2. Optical and Spectroscopic Analyses of the Veil of Manoppello

Few scientific studies have been conducted on the Veil, and they are reported only in conferences, technical reports, and essays [1–10]. As already highlighted, there seem to be more images of the Holy Face, more or less visible depending on the lighting conditions (Figure 2). P. Baraldi [10], who performed Raman spectroscopy, was unable to determine the composition of either the colors or the material constituting the Veil because there were no significant spectral peaks in the acquisitions. In the analysis a red laser at 633 nm was used as it passes without a great attenuation through the glass that contained the Veil during the measurements. It is well known that many organic dyes do not give Raman spectra when using this type of wavelength, while other dyes give distinct signals. However, no compound could be identified from the Raman measures [10].

The first investigation conducted on the Veil of Manoppello precedes the analysis of Baraldi and dates back to 1974, when the Veil was observed with ultraviolet light (UV) generated by a Wood lamp [11]. Also in this study, it was found that neither the fabric nor the image show the fluorescence typical of ancient paintings, although it must be kept in mind that the two glass panels that protect the Veil at least partially filter ultraviolet rays.

UV analysis was also repeated by the third author [12]; see Figure 4a. Although the image has a low resolution, the experimental result confirms what was previously found. Once again, in fact, no fluorescence signals were found that can be traced back to the presence of natural organic substances such as oils, fats, and waxes—traditional pictorial binders used in the past. At the same time, however, comparing Figure 4a with Figure 3b in some anatomical details such as, for example, the definition of beard and mustache hair, the definition of pupils, and iris or lip contour, in UV these details are almost absent. Moreover, the Holy Face seen under UV radiation can be better correlated to the image obtained in transmission with grazing-incident visible light. Indeed, although the UV image is rather dark and of low definition, the teeth are not visible in UV, as in Figure 3b. Moreover, the UV image reveals an upper lip characterized by a greater width than the lower lip, unlike what is visible in Figure 3b. This feature may imply that the finer anatomical details, such as beard hairs or the upper lip profile, may have also been retouched or added at a later time on a more ancient icon.

Further investigations conducted in 1984 and in 2007 with infrared (IR) light have allowed for verification that in the Veil there are neither traces of preliminary sketches of the face, typical of all paintings, nor a visible signature or brand of the author, as shown in Figure 4b [12]. Comparing Figure 4b with Figures 4a and 3b, it should be noted how much the IR face is better correlated with the image seen with visible light when observer and light source are on the same side of the icon (Figure 1).

Figure 4. Manoppello Veil photographed under ultraviolet and infrared light. (**a**) Ultraviolet photograph taken by laying the Veil for 15 seconds and moving the light source; therefore, there are some reflections due to the glass that were not possible to remove during the measurements; (**b**) Infrared photograph with source and observer placed on the same side with respect to the icon.

Infrared photographs generally have the characteristic of highlighting discontinuities caused by pigments or extraneous components added at a later stage. The Veil was lit with an incandescent lamp and photographed with infrared-sensitive film. It should be noted, in Figure 4b, how some areas of the hair show a different coloring. In this regard, note that many materials reflect, absorb, and transmit infrared light differently than visible light. For example, blue/azure seen under IR usually appears lighter than when viewed with visible light; sometimes it appears darker, depending on the chemical composition [13,14].

The IR characterization indicates that the color of the hair gradually changes from a lower intensity in the upper part of the head to a higher intensity in the lower area. These experimental data could be compatible with a hair color that from brown in the upper part of the head becomes brown-red in the lower area. However, if you look at the Veil with direct visible light, the hair color is more uniform, both in the upper and in the lower part. It should also be noted that the color of the iris is clearer than what can be observed in the visible light, although colors that tend to brown become darker under IR [14]. Moreover, the corneal limbus, which is the darker-color circle that characterizes the outermost part of each iris immediately before the white sclera of the eye, is clearly visible with visible light (Figure 3b), but disappears almost completely and shows noncircular contours under IR (in particular, see the left eye). These results could suggest the possible presence of some touch-ups and the possible contribution of another, different underlying chromatic component, not directly detectable in visible light. Finally, note that the glass enclosing the Veil absorbs part of the IR radiation. This may have prevented the detection and recording of any weak signals generated by the interaction with the incident radiation. The same could have happened with the Raman spectroscopy, i.e., the weaker signals coming from the Veil could have been covered by the glass signal. To confirm all these findings, more detailed and accurate UV and IR characterizations would be very useful. To perform new optical measurements, direct access to the Veil would be necessary; this has to be previously authorized by Manoppello's Sanctuary.

D. Vittore [15] analyzed the Veil using a very-high-resolution digital scanner and did not detect any color residues in the interspace between the warp and the weft threads. The presence of any pigment, therefore, is circumscribed within the region of the threads, which have dimensions of the order of 100 μm (0.1 mm).

C. Vigo, an expert in the processing of sea byssus, found some characteristics on the fabric, such as its unusual luster, which could be ascribable to the filaments produced by the *Pinna nobilis* mollusk, worked since ancient times [16]. The third author of this paper, however, performed a microscopic analysis with cross-polarized light to highlight any birefringence useful for characterizing the fibers constituting the threads of the fabric. He noted iridescence not typical of the byssus, but rather of linen [12]. It is known that flax is birefringent and, unlike sea byssus, shows a marked variability of colors from blue-green to yellow-red in light transmitted to cross polarization. The microscopic investigations with cross polarization highlighted the presence of birefringence on parts of the fibers, indicating that it may be linen, as shown in Figure 5.

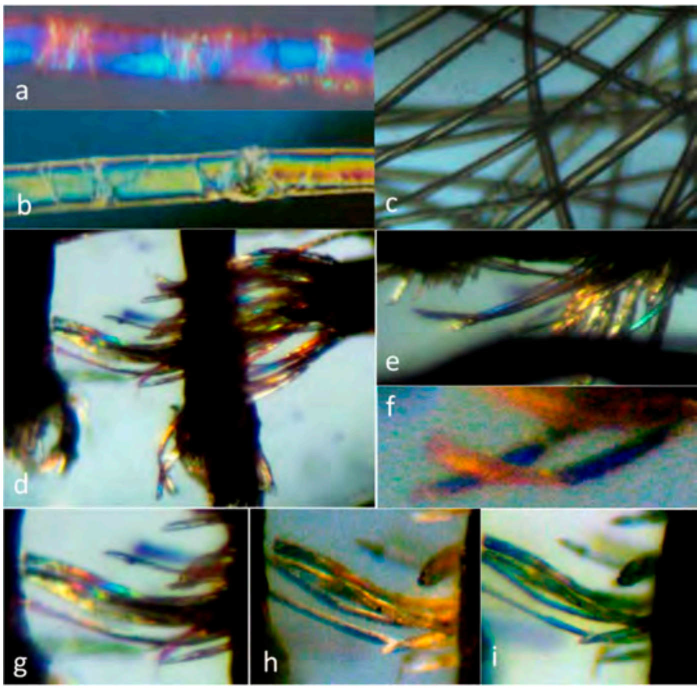

Figure 5. Optical characterization of the Manoppello Veil's fibers with polarized light: (**a**,**b**) for comparison, two flax fibers, seen in polarized light, which show the typical colors due to birefringence; (**c**) for comparison, some sea byssus fibers seen in polarized light that do not show birefringence; (**d**–**f**) photographs of some fibers of the Veil of Manoppello, acquired with an incandescent lamp; (**g**) magnification of (**d**), taken with an incandescent lamp; (**h**,**i**) same region as (**g**) but obtained with a neon lamp; all the fibers of the Veil seen in polarized light show birefringence.

Figure 5a,b, for comparison, show two linen fibers as seen in polarized light. In both, the typical color due to birefringence is visible. Figure 5c shows, for comparison, some sea byssus fibers seen in polarized light. They maintain the same coloration that they have under a nonpolarized light beam and do not show signs of birefringence. Figure 5d–h show some images of threads of the Veil acquired in polarized light at a tear of the fabric. All the fibers analyzed show the birefringence that is typical of linen, jute, and hemp. Figure 5d–f are photographs taken with an incandescent source. In particular, Figure 5f can be compared with Figure 5h. Figure 5g, which is a zoom of Figure 5d, taken with an incandescent lamp, can be compared with Figure 5h,i, regarding the same region but obtained with a neon lamp. In these last figures the presence of birefringence is also evident. From the analyses carried out in polarized light, we can exclude the possibility that it is sea byssus. It seems confirmed, instead, that the Veil consists of thin linen threads.

It should be noted, too, that sea byssus fibers are characterized by slightly higher diameters (20–30 µm) than are those of linen (10–20 µm), which are similar in size to those found in the fabric of the Veil (14 ± 6 µm). Moreover, the fibers of the Veil, seen enlarged, show evident traces of cementation, even if the spectroscopic analyses, as already mentioned, did not show the presence of any specific binder used in painting [12].

3. Veil Structure and Image Dependence on Lighting Conditions

A very important characteristic of the Veil of Manoppello is its semitransparency, as shown in Figure 3a. The Veil is enclosed between two glass panels, which the religious authorities prefer not to be opened; it is framed in a case with a visible space of 240 × 175 mm^2, and it exceeds the frame dimensions by 5 mm. In the horizontal direction there are 27 ± 2 threads per cm, with a pitch of $1/(27 - 1) \cong 0.39 \pm 0.03$ mm. In the vertical direction there are 33 ± 2 threads per cm of fabric, obtained with a traditional weaving with ratio of 1:1 between the weft (horizontal) and warp (vertical) threads. The vertical step, therefore equal to $1/(33 - 1) \cong 0.31 \pm 0.02$ mm, is on average narrower than the horizontal one. Their ratio is 0.79 ± 0.11. The threads are on average 0.12 mm thick. Therefore, between the threads there is a considerable gap, ranging from 0.18 to 0.25 mm, equal to about twice the thickness of the thread. The ratio between the empty region left by the threads and the surface of a rectangle of dimensions 0.31 × 0.39 mm^2, equal to the product of the weft and warp steps, is given by $(0.31 - 0.12) \times (0.39 - 0.12)/(0.31 \times 0{:}39) \cong 0.42$. Therefore, about 42% of the Veil of Manoppello consists of empty space. This explains why it is semitransparent under direct light, as shown in Figure 3a. At the same time, however, it is not clear how it was possible to obtain the different images that emerge depending on the following lighting conditions: (1) light and observer perpendicular to the Veil on the same side (Figure 1a,b); (2) light and observer perpendicular to the Veil but from opposite sides (Figure 3a); (3) observer perpendicular to the Veil and grazing backlighting of the Veil (Figure 3b). Further, as can be seen by comparing the images in Figures 1–3, it is not clear how it is possible to highlight different anatomical details, such as the differently opened mouth, to allow the teeth to be seen or not, by changing the lighting conditions.

This singular behavior is summarized in Figure 6, in which the details of the mouth and of the right eye are reported. Figure 6a shows the detail of the mouth and the right eye of the front side of the Veil, when the observer and the source are on the same side.

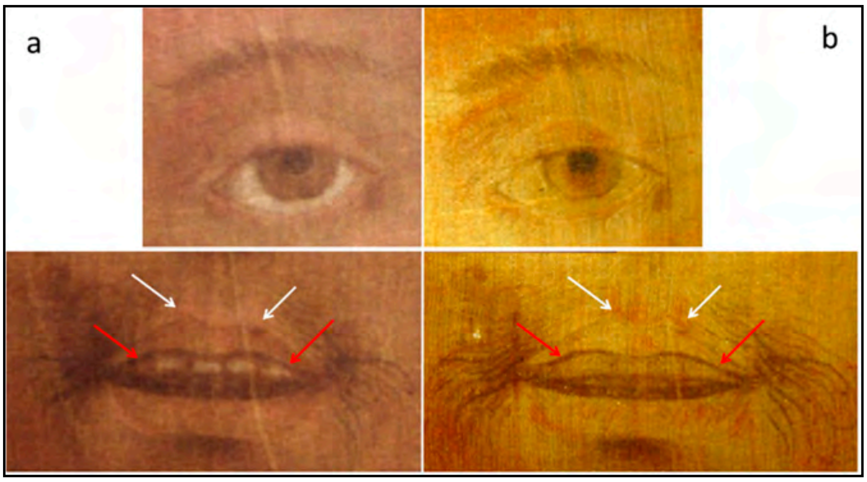

Figure 6. Details of the mouth and the right eye of the Manoppello's Holy Face. (**a**) Detail of the mouth and the right eye of the image reflected from the front side of the Veil when observer and source are on the same side. The image of the back side, obtained under the same lighting conditions, shows anatomical details similar to those of the front side. (**b**) Detail of the mouth and the right eye of the reflection image transmitted from the back side of the Veil when it is illuminated with grazing light.

Under this lighting condition, the same anatomical details such as, for example, the white teeth and the sclera of the eye, are present when looking at both the front and back sides. However, if the observer and the light source are on opposite sides to the Veil, to see the face it is necessary to use grazing light. In this case, as shown in Figure 6b, the white color disappears both in the area of the teeth and in the sclera of the eye. The pupil appears to be reduced in size, since the sclera of the eye of Figure 6b appears to be more extended than that of Figure 6a, although the dimensions corresponding to the opening of the eye in Figure 6a,b are the same. Moreover—and this is the most unusual aspect—not only is the white of the teeth no longer visible, but in grazing light the teeth themselves are no longer visible. It is as if in the image visible in grazing light the upper lip is placed lower and covers the teeth, which are therefore no longer visible. At the same time, however, as evident from the comparison of the red and white arrows shown in Figure 6a,b, the highest edge of the upper lip, visible when light source and observer are on the same side, continues to remain visible even when light source and observer are not on the same side. In this regard, note also the change of hue: darker in the part of the upper lip that falls below the profile indicated by the red arrows in Figure 6b, with respect to the lighter shade of both the lower lip and the part of the upper lip delimited by the white arrows in Figure 6b. Everything should be related to what is visible to UV (Figure 4a), and may imply that the lip profile of Figure 6b, indicated by the red arrows, is compatible with a retouching performed on an ancient icon. Probably, the profile of the upper lip was that indicated by the white arrows in Figure 6b. Finally, as also visible from the anatomical details shown in Figure 6, the image obtained with grazing lighting (Figure 6b) shows red details much more evident, similar to wounds, excoriations, etc., not so visible in the image obtained with direct illumination (Figure 6a). This is an important point we will return to in a later section.

Ultimately, as already observed in commenting on Figure 2, it is as if several images coexisted on the Veil of Manoppello. Two of them, very similar to each other, almost identical, are visible in front and back if observer and light source are on the same side. Two more images, always visible front–back, emerge from the Veil when source and observer are not on the same side. These images are very similar to one another, but they show some evident differences if compared with the previous couple of images. The color tones of the visible image with grazing lighting tend to yellow-gold in the lighter areas (Figure 3b) but, as mentioned above, the semitransparency of the Veil, its natural coloring, and the particular angle of incidence of light grazing, could contribute, not a little, to the final tonality of the image.

It should also be noted that with several images on the same support, visible according to lighting conditions (as happens with the Veil of Manoppello), intermediate conditions are often created in which some details of the two images are simultaneously visible. This is the phenomenon of so-called phantom images. In practice, by changing the lighting or visualization modes, neither of the two images can be completely suppressed; they are seen partially overlapped, one more intense than the other. Thus, the profile of the lip indicated by the white arrows in Figure 6 is visible both with direct light and with grazing light, but only in one case is it better seen. This also happens for the lip profile indicated by the red arrows in Figure 6. This is also present in both images, but is not immediately noticeable because it is superimposed on the profile of the teeth. The phenomenon of phantom images means that while observing the icon, moving sideways with respect to it, the lighting conditions change with respect to the observer. This means that the contribution of the different images is variable and depends on the relative position of the source, Veil, and observer, giving the impression that the face slightly moves the lips and the eyes while the observer changes position.

The Veil of Manoppello, therefore, should be considered as the first example in the History of Art of an artwork in which multiple images are visible on the same support, depending on the lighting and/or observation conditions. Indeed, according to the Relatione Historica written by the Capuchin preacher Father Donato da Bomba between the years 1642 and 1645, the Veil could have arrived at the convent, where it is still preserved today, at the beginning of 1500, with more certainty around 1600 [7]. Instead, the first historical example of a painting with the coexistence of two images, until now considered, is the double portrait of King Frederick IV and Queen Louise Mecklenburg-Güstow of Denmark, painted by Gaspar Antoine de Bois-Clair in 1692. These are two visible portraits independently of each other, of the king or queen, on the same picture, depending on the angle of view. But the technique used in this case clearly shows the coexistence of two paintings on the same painting, unlike the Veil of Manoppello, for which the image of the face with the ajar mouth is not immediately visible and emerges only if it is illuminated with grazing light.

4. Hypotheses on the Optical Mechanism of Image Formation and on the Structure of the Veil

The presence of two images on the same icon is quite unique. It is not unusual, however, that depending on the angle of incidence of light, different intensities and spectral components can be reflected or transmitted, depending on the chemical composition and microscopic structure of the physical medium, thus generating visible color variations depending on the angle lighting and observation. However, it is unusual that depending on the viewing angle, images with different anatomical details can be seen.

Figure 7 presents an enlargement of a detail of the Veil of Manoppello, made by the third author of this paper [12]. A manual joint of two threads and a certain degree of transparency are visible, which may have induced C. Vigo to hypothesize marine byssus [16]. But, as already summarized, there is experimental evidence that the fibers may be linen. Recall that the thickness of these fibers is about 0.12 mm and their section is pseudo-cylindrical.

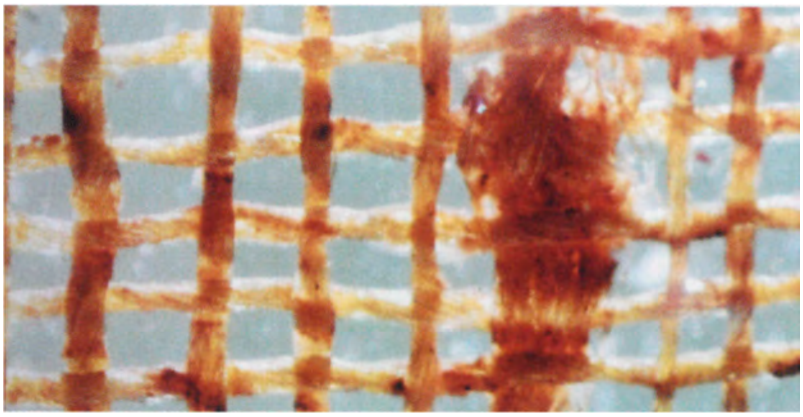

Figure 7. Zoomed view of a detail of the Veil of Manoppello, showing its fine structure and its transparency.

The structure of a linen thread is particularly inhomogeneous from the optical point of view, because regions composed of cellulose (linen microfibers of typical size of the order of 10 µm), with refractive index values close to 1.5, alternate with air regions (interspaces between microfibers) with a refractive index of 1. In a nonhomogeneous microstructure the light propagates essentially by diffusion, since the continuous change of the refractive index from 1 to 1.5 causes multiple refractions, making the medium opaque. The small thickness allows you to see what is on the other side, but with details that are not well defined. This is what happens, for example, when looking through a sheet of photocopier paper, essentially made of cellulose and of a thickness of the order of 100 µm, such as the threads of the Veil of Manoppello. The sheet is opaque, but given the small thickness, we see the shadow of whatever is placed beyond it and in direct contact, without being able to define well the finer details.

The image shown in Figure 7, however, shows that the threads of the Veil are characterized by a certain brightness and transparency. They do not behave, that is, as an opaque medium but as a translucent one. Translucency occurs when the transmission of light occurs partly by refraction, as in a homogeneous and transparent medium, and partly by diffusion, as in a nonhomogeneous and opaque medium. Even paper can become translucent if, for example, a drop of oil soaked the sheet of paper of the previous example. Near the spot, the optical behavior of the medium would radically change, transforming the sheet from opaque to translucent; this would allow us to see even the finer details of an object placed beyond it, especially if it is in direct contact with the paper. This is because the air interspaces between the paper fibers would be filled with oil, which has a refractive index closer to that of cellulose. All this would increase the refractive component and decrease the diffusive component, making the optical behavior of the medium translucent. This is the principle that has allowed the development of translucent paper, much used by artists to reproduce faithful copies of the drawings placed in contact with the translucent sheets. The translucent paper was obtained by impregnating common paper with oils, greasy substances, and resins with a refractive index as close as possible to that of cellulose [17]. In this way the opacity of the common paper is considerably reduced. To get an idea of the orders of magnitude, the sheet of a daily newspaper has an opacity of 90% (if it were 100%, the sheet would be totally opaque). For a sheet of ultra-thin white paper, 60 µm thick, it falls to 60%. For a sheet of translucent paper, even thicker at more than 100 µm, opacity drops to 30% [18], demonstrating how important it is to fill (eliminate) the air spaces between cellulose microfibers with a material of refractive index very similar to that of cellulose.

One could therefore hypothesize that the fibers of Veil of Manoppello were impregnated with some substance that made them translucent, as seems to emerge from Figure 7. However, as mentioned, spectroscopic analyses did not reveal any such compound, and microscopic investigation showed the presence of a cementing substance among the linen fibers. This finding is also deducible from Figure 7 showing that the fibers are not well distinguishable due to the lack of empty spaces. They therefore appear to be cemented. But by what?

To answer this question, we have to remind ourselves of some historical information concerning the Veil of Manoppello. A report kept in the convent of Manoppello, written in 1618 by Fabritiis, underlines that the image of the Holy Face was in the middle of a square veil with size equal to about four Neapolitan palms, i.e., about 4 × 26.5 cm, so with size equal to about 1 meter [7]. Since the peripheral part of the Veil was all ruined, a certain Father Clemente cut the central rectangle, still kept in the reliquary of Manoppello, leaving only a small border now covered by the reliquary. A veil of linen so big and so thin cannot be placed in relation to a painter's canvas, but rather to a garment, suitable for a woman of a certain social rank. If, therefore, the linen fibers were impregnated with some substance that had made them even more shiny and translucent, in the hypothesis that it was a garment, it certainly will not have been treated with an oily or greasy substance, or a typical wax of the canvases of painters. Much more likely, the garment would have been impregnated with starch, since the practice of starching clothes and linen is very ancient, dating back to the times of the ancient Egyptians [19,20]. It is beyond the scope of this study to explain why the Holy Face of Manoppello is related, according to our hypothesis, to a garment and not to a painter's canvas. The sure fact is that the support on which the image is visible is unique in the art world and, by its peculiar characteristic of very thin fabric, the history of the Veil of Manoppello should be placed in relation to that of the Veil of Veronica, the icon/relic of the face of Christ that the Christian tradition binds to his Passion and death. For further information on these interesting historical relationships between the two icons, see the essay by S. Gaeta [7].

Starch is neither an oil nor a fat but a carbohydrate, a polymer having the same chemical composition as cellulose and a very similar structure. There is only one difference between starch and cellulose: in starch, all glucose molecules are oriented in the same way (alpha bonds). In cellulose, on the other hand, each successive glucose unit is rotated 180 degrees around the axis of the main polymer chain with respect to the preceding monomeric unit (beta-glycosidic bonds). The particular orientation of the monomers, compared to the structure of the starch, makes the cellulose polymers much more resistant longitudinally and insoluble in water once combined with hemicellulose and glycoproteins, so as to be suitable for making textile fibers. But the two materials have almost the same index of refraction. Therefore, the starched linen threads would have no gaps between one microfiber and another and, from an optical point of view, the fabric would become particularly homogeneous; this would allow light to propagate with a dominant refractive component and with a reduced presence of diffusion, making it translucent, even for the small average thicknesses of the threads involved (less than 100 μm).

The cellulose structure, in fact, can become so ordered from the atomic point of view as to make it even transparent, and not only translucent, at thicknesses less than 0.1 mm [21]. In the case of the Veil of Manoppello, the linen threads—which, according to our hypothesis, were starched—would behave from the optical point of view as a translucent material. In addition, the linen fibers of the Veil are very thin and are also very distant from each other, so as to preserve the sharpness of the details of the image visible in transmission with backlighting. Indeed, due to the structure of the Veil, diffusion is limited transversally by the dimensions of the order of 0.1 mm; that is, by the dimensions of the linen threads. Because the resolving power of the human eye is of the same order of magnitude, the contours of the image remain clear. For the same reason, given the distance that exists between the fine threads, the Veil also behaves as a semitransparent medium since the propagation between thread and thread, when the light illuminates it with a grazing incidence, takes place in the air. All this implies that the chromatic characteristics of the images of the Holy Face could be explained as a consequence of the combined action of translucency and transparency of the medium, preserving the sharpness of the anatomical details even when the Veil is back-illuminated with grazing light crossing through it to reach the observer. However, the chromatic components are markedly influenced. They can be appropriately compensated in order to reconstruct the original colors of the Holy Face by eliminating the background contribution of the yellow coming from the thin translucent threads (Figure 7), consisting of antique linen yellowed over the centuries.

This hypothesis could also explain why the spectroscopic analyses carried out on the Veil of Manoppello did not highlight the typical pictorial binders (oils, greases, waxes): not because the binder that cements the fibers does not exist, but because it has the same chemical composition and a polymeric structure very similar to that of cellulose. In this regard, note that in the History of Art, starch has been used as an impregnation of the fibers of canvases, but the use of linen impregnated with starch glue began only in 1850 [22]. The resulting support was resistant, translucent, and suitable for artistic techniques like pencil, ink, and watercolor. Because of the significant production costs, the use of this support began to decline towards 1930 until it disappeared around 1970, thanks to the discovery of transparent plastic materials.

5. The Unusual Optical Behavior of Reddish Details

In light of what was discussed in the previous section, given the translucency of the thin starched linen threads, we can understand why the image of the Holy Face is visible both when illuminated in direct light, with observer and light source placed on the same side, and when illuminated with grazing light, with observer and light source placed on opposite sides. In the second case, in fact, the light incident from the back of the Veil is partially diffused, reflected, refracted, and transmitted by the thin threads. Therefore, the more the incidence is grazing, the more the image acquires a yellow-gold hue from the contribution of the yellowish color, typical of the ancient linen, which characterizes the light that passes through the threads. In the first case, instead, when observer and light source are placed on the same side, the reflected component from what is on the surface of the threads dominates, and the colors of the Holy Face are less influenced by the underlying support that is not chromatically neutral.

In this regard, it is important to note that the reddish details of the Holy Face are clearly visible only with grazing light, as, for example, can be seen for the lip area (Figure 6a,b), i.e., when the component due to transmission through the linen threads becomes important. The fact that reddish details are less visible with direct lighting implies that they are located at greater depths than other colors and, for this reason, become visible only when the light passes through the threads. This would imply that the reddish details colored the linen threads before the addition of the other colors, when there were still no anatomic details of the face, which were added later. All that is singular because the pictorial praxis, and the same practical possibility of realizing the work on such thin threads, would require representing the whole face first and only then adding other details, such as, for example, the traces of blood linked to the Passion of Christ represented in the image. Also, this unusual optical behavior of the reddish details of the Holy Face of Manoppello should be placed in relation to one of the many traditions linked to the Veil of Veronica, which would associate the image of the Holy Face to a pious woman ("Veronica") who would have wiped the sweat and the blood from the face of Christ during the ascent to Calvary. But, in addition to blood, the complete image of the face would also appear. What emerges from an accurate analysis of the Holy Face of Manoppello seems to represent this tradition. It remains unexplainable how this particular sequence of coloring the icon, with reddish details placed at a greater depth and impressed before the other colors, could have been obtained on a such a thin starched linen veil. A more accurate Raman characterization than those already done, using modern instrumentation, or an X-ray characterization could provide useful experimental data about the nature and chemical composition of the reddish details, Veil, and other pigments.

6. Deformation of the Veil and Correction of Image Distortions

The thin structure of the Veil predisposes it to deform easily, as shown in Figure 3a. Moreover, tensions developed over the centuries between the Veil and supporting structure have also generated rips, such as the one shown in Figure 8, the genesis of which is schematically explained in Figure 9 [12].

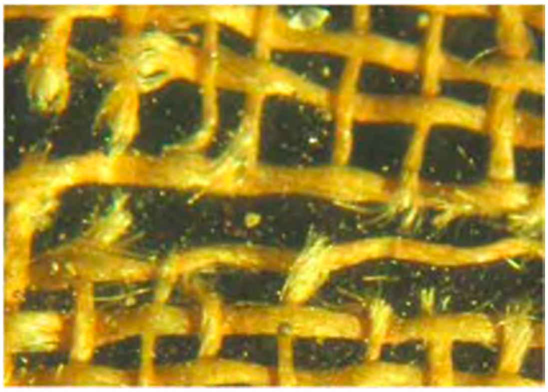

Figure 8. Optical microscope magnification of a Veil rip.

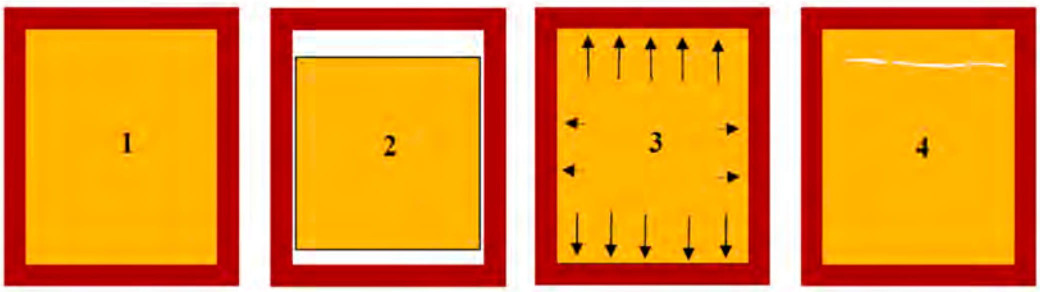

Figure 9. Phases of the possible formation of rips in the Veil: (**1**) Initial state: Veil framed on a rigid support. (**2**) Due to aging, the fabric would shrink if it were not bound to the frame. (**3**) For the Veil to remain bound to the frame, internal coaction tensions must be developed; forces have been represented by black arrows. (**4**) Due to the application of these forces, the fabric gets ripped.

The thin structure of the Veil is certainly at the base of its peculiar characteristics of the Holy Face being visible in both sides and of showing different images depending on the angle of illumination and observation. At the same time, however, it causes structural failure of the fabric (Figures 3a and 8) and, consequently, non-negligible deformations of the image. In fact, as shown in Figure 3a, the red line and the arrows must follow a curvilinear path to remain parallel to the vertical threads.

There is a consistent shift with respect to a straight line (vertical blue line). Quantitative analysis of Figure 3a shows that the rotation of the vertical threads is equal to ±7°. The white arrow at the bottom indicates the maximum displacement detected in the weaving of the fabric caused by the deformation. For comparison, another white arrow is drawn inside the right eye, which allows us to assess the extent of the deformation—equal to about a quarter of the width of the eye. Since a human eye, in proportions of 1:1, in correspondence with the anatomical area in which the white arrow lies has an average opening of 2.3–2.4 cm, it follows that the distortion of the weaving causes a displacement of about 0.5–1.0 cm in the horizontal dimensions of the right cheek. This deformation falls just in correspondence with the swollen cheek and can, for this reason, have been unnoticed before. In light of this analysis, part of the swelling of the right cheek is due to the deformation of the fabric structure. Also, other evident asymmetries of the face, like the different distances of the eyes from the nose–mouth axis, could have their origin in the deformation of the Veil. Since B. P. Schlòmer [5] hypothesized that the face represented on the Veil of Manoppello is superimposable to the image of the face of the Man of the Shroud of Turin if it is suitably rotated, in order to verify this hypothesis correctly, it is necessary first to remove the distortions due to the yielding of the Veil fabric. To our knowledge, this type of correction to the image of the Manoppello face has never been made. But this is an important step, since these deformations are not negligible, and exceed the limits of spatial resolution with which the face appears in the photographic negative of the Shroud image, equal to 4.9 ± 0.5 mm [23]. The distortion can be eliminated digitally by processing the image, imposing that the weave of the fabric becomes rectangularly symmetrical as much as possible. It is possible to compare a detail of the Manoppello face before correction (Figure 10a) and after (Figure 10b).

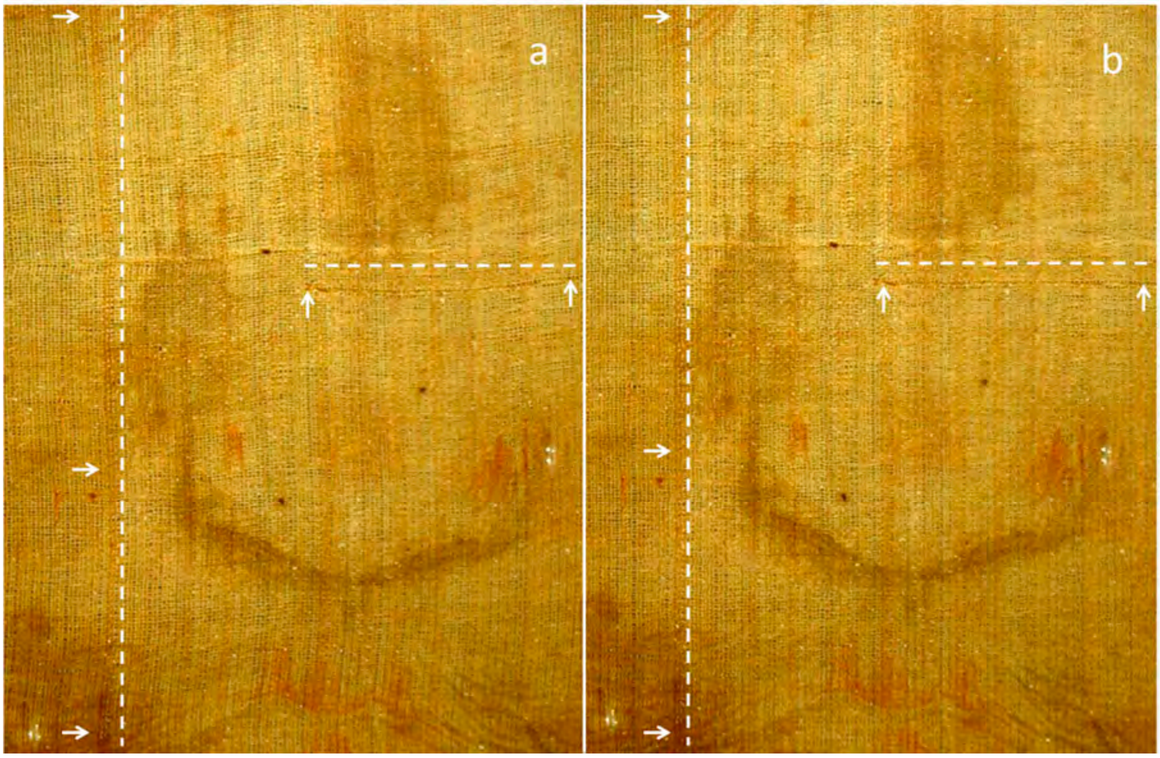

Figure 10. Detail of the face of Manoppello: (**a**) before the correction of the distortion; (**b**) after the correction.

The vertical dotted white line, together with the arrows, is useful to highlight the distortion of the image (Figure 10a), almost completely absent in the correct image (Figure 10b). The same can be said for the horizontal dashed line placed near a defect in the weaving of the fabric which is curved in the distorted image (Figure 10a) and becomes straight in the correct image (Figure 10b).

Figure 11 shows the image as a whole, original (a) and corrected by distortion (b), on a black background to highlight the total deformation of the Veil.

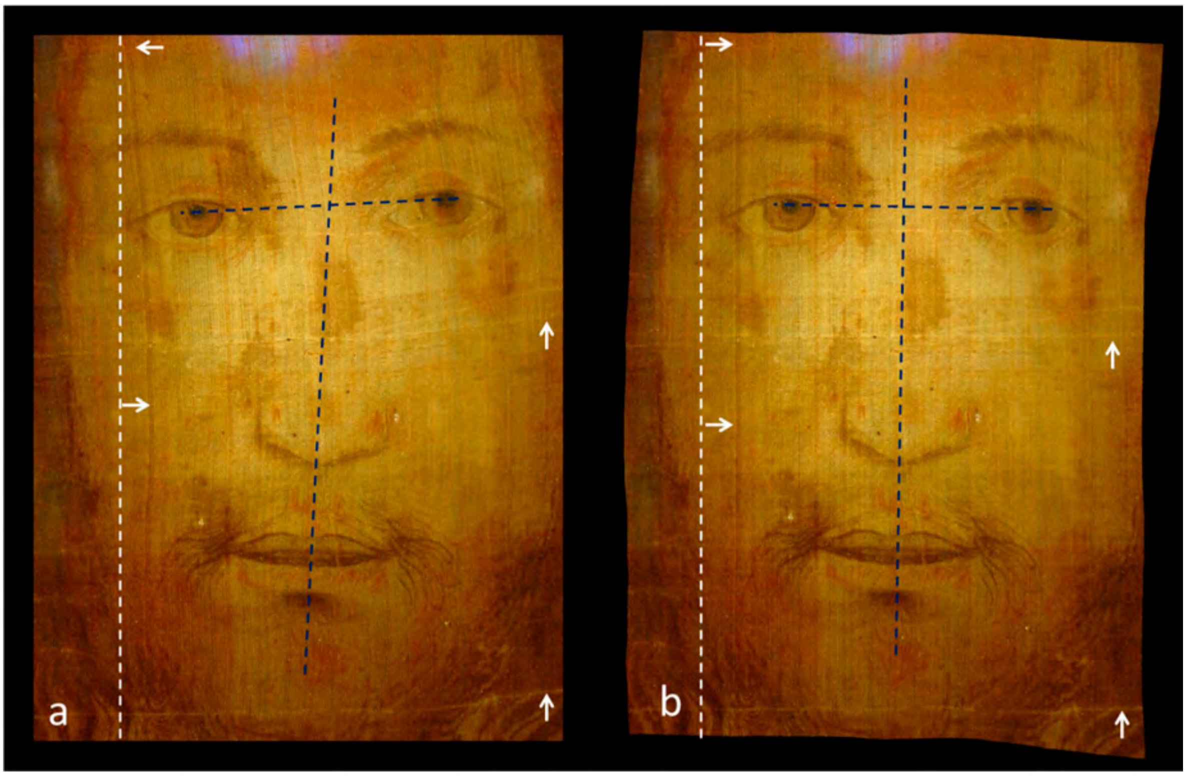

Figure 11. Holy Face of Manoppello: (**a**) before the correction of the deformation; (**b**) after the correction.

The dashed white vertical line and the arrows highlight the presence of the distortion in the fabric on the left (Figure 11a) and its absence on the right (Figure 11b). The horizontal dotted blue lines intersect the pupils of the face, while the vertical ones are on the axis of specular symmetry right–left, taking the mouth and nose as a reference. In Figure 11a the two blue dotted lines do not intersect perpendicularly (distorted image) as they do after the corrections (Figure 11b).

In Figure 12a,b we have reported the Fourier Transform (FT) module of Figure 11a,b, on a logarithmic scale, after subtracting the components with the lowest spatial frequency (typical of the anatomical features) to highlight the higher ones, the latter linked to the smallest details present in the image, such as, for example, the threads of the fabric. The FT of the image in Figure 11a, shown in Figure 12a, is strongly directional, i.e., it is not isotropic from a rotational point of view. In paintings, the rotational anisotropy can be a consequence of the directionality with which the painter has spread the color on the canvas, that is, how he has moved the brush, or the pictorial technique used. In the case of the face of Manoppello, however, the structure of the fabric also contributes to the FT module. In the present case, it appears that the peaks (white in the image), are at multiple spatial frequencies (typical of a periodic structure), which correspond precisely to the mean distance between the threads of the Veil. As shown in Figure 12a, since the angular opening of the visible structures in the FT is about 13° in the vertical direction and 20° in the horizontal direction, and since the direct measurement obtained by the local distortion of the image in Figure 3a, along the red line, gives a total angular variation of 14°—of the same order of magnitude—it is deduced that much of the anisotropy of the FT should be caused precisely by the distortion of the structure of the Veil.

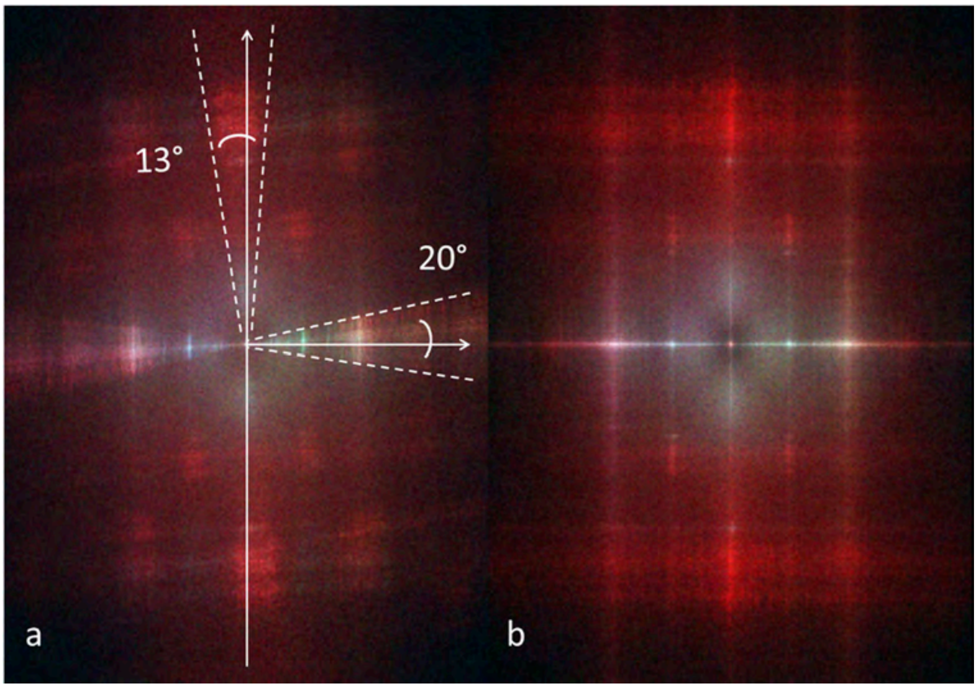

Figure 12. Fourier Transform module of the Manoppello's Holy Face: (**a**) before correction of the distortion; (**b**) after correction.

Furthermore, the anisotropic component of the FT of Figure 12a is rotated about 2° relative to the vertical and horizontal axes, implying a rotational component of the entire image. The FT of the corrected image from the deformation, shown in Figure 12b, shows a substantial change in the rotational anisotropic component. Indeed, we highlight (a) the absence of rotations, present in Figure 12a; and (b) a residual rectangular symmetry that seems to be directly related to the FT of the weaving of the Veil, which after the correction of the deformation has become rectangular, as it was, presumably, originally.

7. Conclusions and Future Works

The Veil of Manoppello is a unique artwork in the panorama of the History of Art dedicated to the Passion of Christ. An analysis of the few experimental data available on this icon has clarified some aspects of the possible physical mechanism underlying its unusual optical behavior, and the probable structure of the fabric that composes it. It should be a linen fiber fabric consisting of very thin threads, 0.1 mm thick, separated by double distances, so that 42% of the Veil consists of empty space. The linen fibers are probably cemented by starch. This particular structure would make the thin linen threads translucent to the passage of visible light. This feature allows us to see slightly different faces depending on the lighting conditions and observer's viewing angle. In particular, the Veil can also be observed with grazing light, which is partially transmitted by the translucent threads. The signs of the Passion, the reddish details that should represent the blood, are well visible only with grazing light. This implies that the reddish details of the image should be found at a greater depth in the fibers than the other colors, as if the Holy Face had been imprinted on the linen threads after the reddish sign of the Passion. This is a singular result, as this should have been quite difficult to realize, taking into account how thin the linen threads are.

The thin structure of the fabric has caused mechanical deformations over the centuries, which obviously have also distorted the image of the Holy Face. In this paper, we have digitally restored the image by compensating for the distortions in the threads. In a future study it will be possible to proceed with the chromatic restoration of the undistorted image. In particular, it should be possible to correct the Holy Face visible when the icon is illuminated with grazing light, in order to eliminate the yellowish component produced by light crossing the ancient translucent linen fibers. Moreover, it will be possible to investigate the possible technique used to realize the icon by analyzing its Fourier power spectrum. Of course, other and future experimental measurements (Raman, X-rays, ultraviolet, infrared) could help to clarify the actual chemical composition of the fabric and colors of the Veil.

Author Contributions: Writing of the paper and discussion of the results involved all the authors. G.F. performed the optical characterization of the icon.

Funding: This research received no external funding.

Acknowledgments: The original photographs of the Holy Face analyzed in this work (Figures 2, 3, 6, 10, and 11) were taken by Paul Badde.

Conflicts of Interest: The authors declare no conflict of interest.

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