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Research article

Multiple Dating of the Turin Shroud: Data Synthesis and Comments

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Summary

This paper summarizes and comments on the various results obtained regarding the age of the Turin Shroud or Holy Shroud (TS) since 1988 when a radiocarbon dating declared that results provided "conclusive evidence" of its mediaeval age. This result, far from conclusive, has been debated for several decades also because it may influence religious aspects. In fact, if the Relic were dated to the 1st century A.D., it would validate everything written about Jesus Christ, up to His Resurrection. On the other hand, if dated to the Middle Ages, it would indicate that it is an artifact, albeit one produced in a way that remains scientifically inexplicable up to now. Therefore, the great interest in determining the age of the TS has led to various datings, also using alternative and, in some cases, entirely innovative methods that produced an age of the 1st century AD. In this article, the discordant results are discussed, also considering the lightness detected in the 1988 result (because the selective radioactivity of the TS was not evaluated), incompatible with other chemical-physical and mechanical results, proposing a solution that could reconcile all the apparently heterogeneous results and leading the TS to a probable age of the 1st century AD.

Introduction (1)

The TS is one of history's most studied and debated religious Relics [1-6]. It is a handcrafted linen textile woven in a 3:1 herringbone twill pattern, measuring approximately 4.4 meters in length and 1.1 meters in width. The fabric bears the full-length, front and dorsal images of a human figure, inexplicably impressed upon the cloth. This figure displays wounds consistent with those of a man who underwent severe torture and crucifixion, aligning with descriptions found in the Christian Holy Bible regarding the Passion and Death and Resurrection of Jesus Christ, Figure 1.

Figure 1: TS photographed by G. Enrie in 1931.

Throughout history, the TS has been venerated as a sacred relic, with documented accounts tracing its presence across various locations over the centuries. Pope Julius II (1443-1513) officially recognized it as an object of adoration [7], cementing its significance within Christianity. Historical analyses suggest that the TS may have been in Byzantium before the Sack of Constantinople in 1204 and later made its way to Chambéry, France before ultimately being enshrined in Turin, Italy, where it remains. Byzantine coins [8,9] dating as early as the 7th century depict facial features strikingly similar to those on the TS, fueling speculation that the Relic was known and venerated long before its documented appearance in Western Europe in the 14th century. This resemblance has fueled ongoing speculation regarding its early history and significance. Until the end of the 19th century, the TS was displayed only on rare occasions, making it difficult to study in detail. However, in 1898, when the lawyer and photographer Secondo Pia captured the first photographs of the Relic, which quickly spread worldwide and marked the beginning of scientific research onto the TS. To this date, it continues to challenge scientific understanding, as the formation of its body image remains unexplained and has never been successfully replicated despite numerous attempts. Given the religious significance of the TS and its profound implications, its authenticity was immediately questioned, prompting numerous investigations and scientific analyses. Forensic examinations [10] confirm the presence of liquid blood on the TS at the moment of wrapping a human body, with the absence of evidence of smearing, indicating the body was neither moved nor manipulated after bleeding onto the cloth. Additionally, the absence of putrefaction and the rigor mortis suggest an unusual phenomenon, leading researchers to explore the concept of matter transparency produced by an unknown energy-light [11] as a possible explanation for how the corpse disappeared from the TS without disturbing its wrapping configuration.

One of the most controversial aspects of its study centers on radiocarbon dating tests conducted in 1988, which dated the cloth's origin between 1260 and 1390 AD [12]-suggesting a medieval origin rather than a 1st century artifact. However, this conclusion has been widely disputed due to probable contamination, particularly from environmental factors which may have altered the test results [13-28]. Many scholars, finding the radiocarbon dating result unacceptable, made a variety of assumptions to explain the result, even going so far as to suggest possible fraud [29]. We must not forget that studies on Beta radioactivity and fluorescence in the TS bloodstains [30] suggest that the blood on the TS interacted with energy-light in unusual ways, indicating the possibility of an extraordinary event that affected the fabric. The selective radioactivity detected in some parts of the Relic [30] may have significantly altered the radiocarbon dating results and have proposed hypotheses linking this anomaly to the effects of neutron radiation [13,24]. Completely reversing the interpretation of the medieval result, some scholar even think that the 1988 radiocarbon result could perhaps be the first scientific clue that the TS witnessed a very peculiar and not fully explained phenomenon about 2,000 years ago, which could be linked to the effects of something beyond science and which some call the Resurrection of Jesus Christ [24,30,31]. Of course, the energy involved in the hypothetical matter transparency could also have influenced, through the neutron radiation, the transformation of the nitrogen and C^{13} isotope [13] contained in the flax into additional C^{14}, effectively rejuvenating the TS sample. The topic of the TS dating, which is metrologically very complex, will be

addressed in this paper in an attempt, through the information fusion of different types of data, to provide a plausible interpretation of all the results obtained which at first sight appear to be very contrasting each other.

Dating from Historical Evidence (2)

An important controversy that took place in the second half of the 14th century [6,8,27] between Geoffroy de Charney, the then owner of the Relic, the canons of Lirey, who received it for safekeeping, Pierre d'Arcis, the bishop of Troyes, King Charles VI of France, and the antipope Clement VII certifies that the TS was publicly exhibited in Lirey during that period. A document dated 1389 and written by Pierre d'Arcis states that the TS had been publicly exhibited approximately 34 years earlier, around 1355. In addition to these historically recognized documents, there are various alternative methods for determining the age of an archaeological find that are based on dating relative to other historical information. For example, an analysis of human DNA from dust vacuumed from the TS [31,32] showed that only 5.6% of the TS was contaminated by people of European origin, while 55.6% of the TS was contaminated by people of Middle Eastern origin and 38.7% by people of Indian origin. This analysis therefore does not propose dates for the TS but, combined with other historical information, shows that the TS was probably spun and perhaps even woven in India and then imported into the Middle East *via* the flourishing Silk Road around 2000 years ago. Only 5.6% of the TS was contaminated by Europeans, making it highly unlikely that this is a medieval European artefact, as many have supposed. While these methods do not provide an absolute dating for a find, they do clarify whether an artifact is older than a certain hypothesized period. Similar approaches can also be applied to the TS, as several historical artifacts share some characteristics typical of this Relic. This section presents some of this evidence including iconography and Byzantine coins.

Byzantine iconography (2.1)

The Gospels contain no descriptions of Jesus' physical appearance, but He is usually depicted as a slender man with long hair and a beard. However, the earliest depictions of Jesus show Him beardless and with short, often curly hair. A drastic change in the depiction of Jesus occurred in the mid-6th century, when the face of Jesus in Byzantine art was depicted very similarly to the face in the TS [6,8,27]. These traits show asymmetric features, and it is unthinkable that artists would have produced these imperfections in their representations of Jesus Christ Who was considered the most beautiful among men, unless they wanted to reproduce a prototype like that of the TS. These irregular features appear, for example, in two 6th century faces of Christ: The Christ Pantocrator icon from Saint Catherine's Monastery in Sinai and a silver vase of Emesa in Syria. Both images show Christ with a raised left eyebrow, large eyes, a long nose and pronounced cheekbones, a hairless area under a prominent lower lip, and asymmetric hair and beard. It is important to note that this new representation appeared in the East during the 6th century, coinciding with the time and place of the alleged rediscovery of the TS, identified with the Mandylion of Edessa.

Byzantine coins (2.2)

A strong clue that the TS was known in the Byzantine Empire at least as early as the 7th century AD concerns the numismatic analysis of coins depicting the face of Jesus Christ. In fact, starting in 692 AD, Emperor Justinian II began minting gold solidi bearing the face of Christ copied from the image on the TS. This is confirmed with a degree of certainty approaching 100%, both by a probabilistic analysis and by experimental studies carried out on reproductions of various faces [8]. Since then, apart from the interval during the iconoclastic periods, until the fall of Constantinople in 1204 the Byzantine emperors continued to mint gold, silver, and bronze coins bearing the face of Christ with distinctive features inspired by the image on the TS. After the fall of Constantinople, the TS disappeared from the Byzantine Empire, but it is interesting to note that for several centuries the Byzantines continued to mint coins bearing the face of Christ -although increasingly less similar to that of the TS, since they were obviously forced to copy from reproductions of the Relic. Fanti G [8] itself highlights both how the variety of faces minted during those centuries shows that the different engravers freely copied only some of the typical features of the TS face, and how it is very likely that some engravers took inspiration from copies of the TS-perhaps because they were far from the place where the Relic was displayed-since they produced faces less faithful to that of Christ of the TS. All this numismatic evidence confirms the presence of the TS in the Byzantine Empire at least from 692 AD until the fall of Constantinople in 1204 AD.

Hungarian pray manuscript (2.3)

The National library of budapest owns a medieval document, the Pray Codex, which was written in the Boldva Monastery in Hungary between 1192 and 1195 [27]. In this Manuscript, two illustrations can be seen showing the sepulcher of Jesus. The first scene depicts Jesus' body lying on the stone while being anointed by Nicodemus, Joseph of Arimathea and the evangelist John. The second shows Mary Magdalene, Salome, and Mary, mother of James, with an angel who informs them that Jesus is risen. Several points of congruence can be observed between the two scenes in the Pray Manuscript and the TS, demonstrating that the artist copied some details from the Relic, which was therefore already present at that time. Jesus is naked with His hands crossed over His pubis; the thumbs are not visible and the fingers are long and thin; a mark on the forehead appears to correspond precisely to the bloodstain in the shape of an inverted "3" on the TS; like the Relic, the cloth depicted also corresponds to twice the length of the body and has a herringbone pattern very similar; finally, four small "L-shaped" circles can also be observed in the design, like the "poker holes" visible on the TS.

Sudarium of oviedo (2.4)

The Sudarium of Oviedo, venerated as a relic from Jesus' burial, is a sheet measuring 53cm by 86cm believed to have been wrapped around Jesus' head after his death on the cross. It has been dated to 614 AD or before from historical records and radiocarbon dated three times from 642 to 869 AD, from 653 to 869 AD and from 660 to 890 at 95% confidence level [27]. The Sudarium does not bear an image but is stained with blood, likely from bodily fluids that issued from Jesus' mouth and nose. These stains show a remarkable correspondence with those on the TS, a finding supported by chemical and immunological analyses. All this historical evidence obviously contradicts the 1988 radiocarbon dating of the TS that will be discussed later.

Pre-1988 Dating: Alleged Radiocarbon Test (3)

While many scholars, especially those belonging to the "Shroud of Turin Research Project" (STuRP), were pressuring the Competent Authorities to perform a radiocarbon test to determine a probable age of the TS, it appears that an unofficial test was conducted on a thread taken from the Relic. Kowalski M [27] on pages 140-143 reports the results of an alleged unofficial radiocarbon test performed in 1982 in the Livermore Laboratory of California by Dr. George Rossman, a mineralogist at the California Institute of Technology (Caltech). From the same Ref. we read: "Adler had told Rossman that he believed there was starch present on one end of the thread and so Rossman had cut the thread in half and dated each portion separately. He found that one end dated to 200 AD whilst the other gave a result of 1200 AD." The same Kowalski M [27] reports that in a telephone call with Sue Benford, Rossman declared that he was the one who had performed the test.

1988 Radiocarbon Test (4)

Rivers of words have been written regarding the 1988 radiocarbon dating [12-29], and for more information, we refer to specific texts such as Kowalski M [27]. Even before the test was carried out, proposed in detail by members of the STuRP but then excluded from the analyses, several controversies arose, which multiplied at least tenfold after the controversial result. The age of the TS was officially determined [12] to be between 1260 and 1390 with a 95% confidence level. However, several statistical, methodological, and metrological errors were identified. From a statistical standpoint [17] states: " The twelve results from the 1988 radio carbon dating of the Shroud of Turin show surprising heterogeneity. … We establish the existence of a trend in the results." In addition to this, the assigned uncertainty appears underestimated. From a methodological perspective, it does not seem correct to assume a priori that a linen sheet of approximately 5m², which has undergone various vicissitudes and fires, is uniform in terms of C^{14} isotope content, and consequently to extract only one sample of a few cm², moreover from a corner likely more contaminated than the rest of the fabric. From a metrological point of view, an in-depth analysis of the possible systematic effects (bias) that could have influenced the dating result by even millennia was not performed. As predicted by Ref. [13] and then at least partially confirmed by Fanti G [10,11,24,30], the beta-type radiation found in the cited references, which is still very evident after centuries if not millennia, demonstrates the lightness of the laboratories, but especially of the person in charge of the analyses, M. Tite (official, scientific coordinator of the analyses and keeper of the research at British

Museum of London), with whom the radiocarbon tests were conducted. This will be more widely discussed later in the Comments (6.4).

Post-1988 Datings (5)

After the shocking result of the 1988 dating - shocking because it turned out to be the only scientific evidence against the authenticity of the TS, contrasted with hundreds of pieces of evidence in favor [3-5] - and given the impossibility of officially repeating the radiocarbon test as it is not permitted by the Competent Authorities, an intense scientific research effort was launched. This research aimed to provide alternative dating for the TS - albeit unofficial - that could offer a further indication of the Relic's most probable age. The repetition of the radiocarbon dating and the development of possible alternative dating methods were made even more difficult by the rarity and the extremely limited quantity of fabric samples from the TS available to scholars. This constraint forced researchers to design and develop alternative dating methods based even on single fragments of linen fiber. Presented below are the results obtained independently by various researchers who managed to develop alternative methods capable of providing useful information.

Rogers' vanillin test (5.1)

Ray Rogers conducted an analysis of the lignin content in the growth nodes of the TS fibers, based on the premise that lignin gradually loses its vanillin over time. A chemical test for its presence could have provided some clues about the TS age and is advantageous because it is non-destructive and requires only a single flax fiber. In this way, Rogers was the first to verify the reliability of the 1988 radiocarbon dating of the TS [15]. However, the amount of vanillin present in flax also depends on temperature, meaning the number of years required for vanillin to completely disappear from flax fibers varies significantly. Aware of the influence of temperature, he first calibrated this alternative dating method, determining that to lose 95% of its vanillin, flax stored:

- at 25°C would take 1319 years;
- at 23°C, 1845 years;
- at 20°C, 3095 years [27].

Therefore, if the TS age had been between 1260 and 1390 AD, as indicated by the 1988 radiocarbon result, it should have contained a non-negligible amount of vanillin. Rogers concluded that the linen of the Relic must be much older than the declared date because all the fibers he collected from the TS in 1978 did not show presence of vanillin. The hypothesis that temperature during the Chambéry fire could have had an influence was also deemed unsustainable by Rogers, as the linen's exposure for such a short time with respect of centuries could not decisively account for the absence of vanillin found.

Alternative multi-parametric mechanical dating (5.2)

In 2009, the Author began to consider some alternative dating methods that could verify the results of the 1988 radiocarbon dating and focused on the analysis of mechanical parameters that could be useful for this purpose [18]. In particular, he considered the breaking strength, the elastic or Young's modulus, and the structural damping or loss factor. Based on the premise that flax fibers degrade over time, this degradation also affects their physical characteristics. The long molecular chains of cellulose slowly fragment into smaller pieces, and the cellulose structure gradually becomes less crystalline and more amorphous. As a result, the molecular chains in flax fibers become more mobile with age, altering certain mechanical properties such as strength and elasticity. Not finding many existing studies on the linen fibers ageing, also due to the difficulty of performing mechanical analyses on single fibers, the Author initially limited himself to trying to determine a possible correlation between the breaking strength of ancient linen fibers and their age. He found Dr. Ingo Burgert of the Max-Planck-Institute of Colloids and Interfaces, Department of Biomaterials in Potsdam, Germany, very willing to perform preliminary tests on ancient fibers, consisting in firmly clamping both ends of a fiber and pulling it until the fiber broke under the applied force [18]. The first results in 2010 were very encouraging, in the sense that a correlation between the sample's age and the breaking strength-which visibly decreased with age-was immediately evident. Unfortunately, however, the analyses could not be completed because the testing machine at the Max-Planck-Institute was not able to measure the breaking strength of fibers older than about ten centuries with sufficient accuracy. Consequently, after further unsuccessful research, the Author decided to design and build, with his thesis students, a machine suitable for the tests necessary to perform a mechanical analysis of the TS linen fibers for dating purposes [33].The specifications for the microcycle tensile machine were very demanding because it had to measure forces with a resolution of 2 micronewton (μN) and elongation with a resolution of 0.1 micrometer (μm) in order to plot stress-strain curves for the fiber. Of course, to obtain sufficiently reliable results [18,34], it was not only necessary to build a machine for the cyclic traction of individual flax fibers with the stringent specifications reported in [18], but also to calibrate both the machine and the method using a series of proper ancient fibers. The mechanical parameters considered were five: breaking strength σ_r, Young modulus E_1 of the last part of the increasing loading cycles, Young modulus E_2 of the first part of the decreasing loading cycles, loss factor η_1 of the last complete loading cycle representing the dissipated energy and loss factor η_2 of the inverse direction of the cycles.

In 2013 the first multi-parametric mechanical dating was reported preliminarily and anonymously in [35] (that is, without declaring the sample's provenance as a precaution, as explained in Fanti G [36] which also details the reasons). It reports: "As an example, the method has been applied to six fibers picked up from an ancient textile of unknown age and the resulting values are: $y_{\sigma r}$ = 577 AD; y_{Ef} = 14 AD; y_{Ei} = 456 AD; $y_{\eta d}$ = −510 AD; $y_{\eta i}$ = 564 AD, which give the following dates: ym1 = 220 AD; ym2 = 372 AD. The (standard) uncertainty … is … about 200 years …".

Fanti G [36], confirming in 2023 the results of Refs. [33, 35], proposed the following relationships between age and five mechanical properties of ancient flax textiles:
σ_r = 139.1 e0.000968 A, ±336 years, P=0.94,
E_1 = 6.222 e0.0007094 A, ±418 years, P=0.92,
E_2 = 8.176e0.0006059 A, ±537 years, P=0.91,
η_1 = 7.538−0.001372 A, ±193 years, P=0.96,
η_2 = 4.260−0.001146 A, ±385 years, P=0.90,

… The loss factor is defined as: $\eta = D/2\pi U$ where D is dissipated energy and U is stored energy during a whole cycle."

Basing on [18], it adds: "A least squares multi linear regression was then applied to the measured mechanical data estimating an age of 260 A.D. with an uncertainty of ±274 years." Confirming the dating of the TS to the first century AD through the mechanical multi-parametric method.

Alternative FT-IR chemical dating (5.3)

A Nicolet 5700 type FT-IR instrument was used to measure the intensity of the absorbance spectra produced by suitable linen samples of various known ages. Based on degradation results reported in the literature, numerous ratios of the intensity peaks of the measured spectra [37] that showed an evident correlation of the intensities with the age of the analyzed sample were examined. The band integrals most sensitive to age were those located in the 2600-3080 cm^{-1} and 3070-3600 cm^{-1} ranges, while those in the 800-1180 cm^{-1} and 1500-1760 cm^{-1} ranges showed an opposite trend. According to [18], two ratios, R1 and R2, of the peak area integrals for each sample were evaluated from the spectra, and these showed a close correspondence with the ages of the analyzed samples. The following relationships were therefore defined:

$$D = 1730 + 1809 \log_e R1$$
$$D = 1706 + 2397 \log_e R2$$

where D is the date of the linen sample, and Pearson coefficients of 0.90 and 0.95 respectively, confirming the accuracy of these formulas (considering that a value of 0.7 of this Pearson coefficient is evidence of a strong correlation between a formula and its corresponding measurements). Having established that heat accelerates the deterioration of cellulose, the possible effect of the 1532 Chambéry fire on the TS sample was taken into account by increasing the two intensity ratio values, R1 and R2, by 18%. These values, corrected for the presumed effect of the fire, produced dating results of 200 BC and 297 BC respectively, giving an average value of 250 BC ± 400 years with a 95% confidence level [18]. This corresponds to more than a millennium before the result produced by the 1988 radiocarbon dating test, but it includes the era when Jesus lived in Palestine.

Alternative Raman chemical dating (5.4)

The dating method for linen fabrics based on Raman analysis initially considered five band intensities [37] but later used only the following two because they proved to be more significant. The band intensity related to the symmetric COC stretching mode of the glyosidic bond at 1097 cm^{-1} allows to obtain information about the degradation of linen over time; conversely, the hydrogen-bonded C-OH band at 3251 cm^{-1} is relatively stable over time.

The RCOC/OH ratio of the peak amplitudes was therefore measured for each sample in the corresponding spectra:
$R_R = (I_{1097} / I_{3251})$

where I is the measured Raman intensity subtracted from its baseline, as a function of the wavenumber n in cm^{-1}. One issue with this Raman method is fluorescence, which can be minimized through appropriate processing but not eliminated. It therefore affects the measurement of peak amplitudes in the obtained spectra because it depends directly on the characteristics of the individual linen sample. Eleven analyzed linen samples produced varying amounts of fluorescence, and each was classified as either high or low fluorescence.

The plots obtained for both sample groups revealed a close match with the first-order exponential decay curve predicted for cellulose degradation. This Raman method yielded two different dating equations:

D = 7498 + 4871 loge R; for high-fluorescence samples
D = 2451 + 2299 loge R; for low-fluorescence samples

with relatively high Pearson correlation coefficients of 0.947 and 0.907 for the high and low fluorescence equations respectively, confirming a close fit. Contrary to the FT-IR dating method, the effect of heat was considered smaller than the assigned uncertainty and was therefore neglected. Since the Raman spectra for the TS showed intermediate fluorescence values, an intermediate date relative to the two defined equations was calculated, yielding a value of 30 AD ± 400 years at the 95% confidence level [18]. Once again, a different method for dating linen has produced a result that contradicts the radiocarbon dating measurement.

Alternative X-Ray dating (5.5)

Utilizing the properties of X-rays, a team led by Liberator De Caro (IC-CNR, Bari, Italy) [25] analyzed the state of degradation of the cellulose composing the linen fibers of a fragment of thread from the TS using Wide-Angle X-ray Scattering (WAXS) technique. This non-destructive method is based on the following principle. The cellulose in linen is a crystalline material made up of long chains of molecules which, over time, break due to environmental factors such as heat and humidity. This process of progressive disorder causes the crystalline regions to become progressively smaller and less ordered, thus transforming them into amorphous regions. By irradiating the sample with X-rays, a diffraction pattern directly correlated to the degree of crystallinity of the linen's structure is obtained. The WAXS technique measures the degree of crystallinity of the cellulose and from this deduces how many centuries ago the flax plant produced the polymer chains under examination. For dating the sample, the hypothesis was made that the degradation rate of cellulose is relatively constant over time. By measuring the current degree of crystallinity of a sample and knowing the degradation rate, it is therefore possible to estimate its age.

For the calibration of the new dating method, the team analyzed with WAXS seven linen samples of known age, from 3000 BC to 2000 AD, provided by the Author linking the degree of crystallinity to the fabric's age. The team then analyzed a small piece of thread from the TS and measured its degree of crystallinity. After applying a correction to the obtained values based on assumptions of exposure to ambient temperatures consistent with the historical journey of the Relic [26], it achieved a dating to the first century AD with an uncertainty of a few centuries, thus placing again the TS in an era compatible with tradition but clearly incompatible with the radiocarbon date of 1988.

Comments on Ts Dating (6)

The preceding Sections 2 (Historical Evidence), 3 (Alleged Radiocarbon Test), 4 (1988 Radiocarbon Test), and 5 (Post-1988 Datings) have yielded many and widely divergent and conflicting results regarding the dating of the TS, which require both general comments and detailed ones.

General comments (6.1)

Figure 2 summarizes all these results, highlighting the mutual incompatibility of the result of Section 2.4 which yielded a range (red) between 614 and 890 AD with two results from Section 3, which provided quite doubtful dates of 200 and 1200 AD, and all the results from Section 4, which yielded a range (blue) between 1260 AD and 1390 AD.

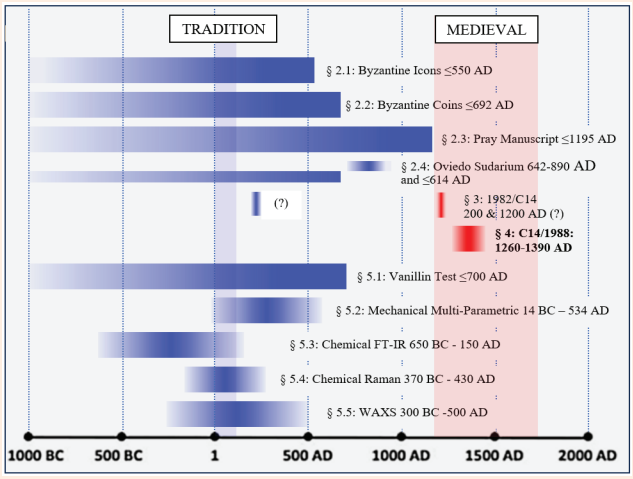

Figure 2: Summary of results concerning the dating of the TS. The horizontal bars, composed of colors with varying intensities proportional to the hypothetical probabilities of finding the result in that area, show the eleven results obtained with the different methods described in the respective sections. Some results of Sections 3 and 4 are not compatible with all the other 10 results of Sections 2 and 5 which instead are all compatible each other. These various inconsistencies highlighted by the results achieved make more detailed investigations necessary, discussing both the various outcomes and the methods by which they were obtained. From a general standpoint, it must also be emphasized that various results carry different weights and levels of importance, which cannot be overlooked in the present evaluation. The results from Section 2 derive from historical information, while the others come from more or less reliable scientific analyses. For example, the results from Section 3 are poorly documented, whereas those from Section 4 come from three of the world's most renowned laboratories. The results from Section 5, on the other hand, are all consistent with each other but originate from innovative investigative methods still under confirmation. In the following sections, these groups will be analyzed in greater detail, to attempt an interpretation for the most probable age of the TS.

Comments on the 1982/ C^{14} test (6.2)

Section 3 is anomalous for several reasons. Firstly, it refers to unofficial results reported only verbally among scholars and is therefore not very reliable scientifically. It was conducted during a period when the radiocarbon dating method was still under significant development, and the origin of the dated sample is not well-defined. According to some historical reconstructions, the sample tests might derive from the so-called Raes' sample, which is notoriously known to have been found more contaminated than other areas of the TS fabric. As added by Gerardo Ballabio of Shroud Science 1, it was not specified whether the piece of thread cut into two parts that was dated had been cleaned prior to testing, and this amount of material would be much less than that considered the minimum necessary to obtain a reliable dating. Moreover, if starch had been added to the fabric during the manufacturing process, it would be the same age as the linen, and therefore its influence on dating would be negligible; if the starch had been added in the Middle Ages, to significantly alter the dating, the TS sample would have to be composed of about 80% starch and 20% linen, which is clearly absurd. In reference to the alleged presence of starch on half of the thread tested, the chemist Stan Nickle of Shroud Science 1, responded to the Author's inquiry by saying that the retting process for linen can leave some natural starch in the flax fibers, and starch can also be added to fabrics, both to smooth and stiffen the linen. In any case, starch is not very durable; it is subject to hydrolysis and decomposition over time and is unlikely to be converted into something less susceptible to acid attack. Lugol's iodine solution is the common and definitive test for starch; the blue-black color is highly specific and results from the amylose structure in the starch reacting with the iodine. The Author performed the Lugol's test on a linen fiber taken from an area of the TS very close to the sample used

for the 1988/C^{14} dating, and obtained a clearly negative result, indicating the absence of starch in the fiber. Consequently, these results (200 AD and 1200 AD) are considered as an additional piece of historical information but of little significance for the purpose of the scientific results analysis.

Comments on the results of the Oviedo sudarium (6.3)

The finding from Section 2.4, regarding the Sudarium of Oviedo, is not a direct measurement of the TS. It is merely a comparison with another archaeological textile supposedly contemporaneous to the TS and is therefore not scientifically very significant for the purpose of dating the Relic. From a historical perspective, it is established that this textile was known as early as 614 AD, while various radiocarbon datings assign it a time interval between 642 and 890 AD at a 95% confidence level. It is not clear, however, whether this textile may have undergone different environmental contaminations over time compared to those suffered by the TS, which could therefore have altered the result differently, making it incompatible with many other findings described here. Consequently, this information is also considered to be of little significance for the purpose of dating the TS.

Comments on the 1988/C^{14} test (6.4)

As already noted in Section 4, the result indicating a medieval dating of the TS has been heavily criticized. Indeed, the Author has also verified some procedural irregularities and some inaccuracies in the statistical analysis published in [12], but believes that by assigning a broader statistical uncertainty, the determined C^{14}/C^{12} isotopic ratio can be acceptable. We will not delve here into the various accusations made by several scholars, even of foul play, and instead we attempt to analyze the result from a more objective standpoint. One cannot overlook the previously highlighted lightness of the laboratories, which did not check the possible radioactivity of the linen sample. Such radioactivity could have in fact significantly increased the measured isotopic ratio, introducing a bias on the order of several centuries. This is due to at the time neglected and now detected presence of the selective β ionizing nuclear radiation [30] that would have converted nitrogen present in the linen fibers of the TS into C^{14}, thus making the analyzed samples appear younger. The radioactive blood of the TS confirms its anomaly compared to common human blood, additionally exhibiting a reddish fluorescence [30], typical of radioactive material, that was also detected in the Gilbert & Gilbert spectra in 1978 [38]. The relative scarcity of nitrogen found in the blood of the TS [24] also confirms this supposed transformation of nitrogen into additional C^{14} already foreseen by T.J. Phillips [13] in 1989. Likewise, G.B. Rinaudo [39,40], who proposed that the body image was formed by neutron radiation, also hypothesized that this radiation would have produced a significant bias in the radiocarbon dating of the TS. Finally, it must not be forgotten that the Holy Fire of Jerusalem [41], which recurs every year on Orthodox Holy Saturday, is not scientifically explainable, because it is cold. However, it may be considered linked to the presence of excited electrons, likely caused by neutron radiation emitted from beneath Jerusalem itself. Since the Holy Fire is a symbol of the Resurrection [41] and it appears to be closely connected with the formation of the body image of the TS, furthermore, given that T.J. Phillips has hypothesized that the 1988/C^{14} dating result may have been altered due to a neutron source, a possible correlation between these events certainly cannot be overlooked. A very recent paper [42] confirms the doubts posed on the result of the 1988 radiocarbon test and tries to explain this error with a neutron radiation that probably was "a singular and extraordinary event".

Comments on the post-1988 datings

Since Section 2 (Dating from Historical Evidence) provides information that is completely incompatible with the results of Section 4 (1988 Radiocarbon Dating), several scholars in the following years have developed various alternative dating techniques based on both the chemical-physical and mechanical properties of the TS linen. It is interesting to note that all the results reported in Section 5 (Post-1988 Datings) are compatible with those of Section 2, pointing to a first-century AD date, which is thus also consistent with tradition.

Obviously, these new methods developed after 1988 result will need to undergo more detailed verification in the near future, both from a metrological standpoint and regarding the actual dependence on possible systematic effects such as the temperature and humidity of the environment in which the samples were stored. For example, according to the Author, a bias of a few centuries might emerge in some parameters of the mechanical dating of the TS. In particular, the long-term preservation of the TS, considered religiously an object to be preserved with the utmost care-and therefore better than the preservation of common archaeological finds-could cause an adjustment of the mean dating related to the breaking strength from 400 AD to perhaps the first century AD. Finally, it is significant that beyond the compatibility already observed for these mechanical and chemical results, their mathematical average yields a result of 86 AD +/- 206 [18] compatible with the period in which Jesus Christ lived in Palestine.

Conclusive Remarks

The age of the TS has been debated for several decades, also because the result can influence religious aspects. Indeed, if the Relic were dated to the first century AD, this would confirm not only the historical existence of Jesus Christ but would also validate everything written about Him in the Bible, especially concerning His Passion, Death on the cross, and Resurrection. If, on the other hand, it were dated to the Middle Ages, it would indicate that the TS is not contemporaneous with Jesus Christ and is therefore an artifact, even if produced in a way that remains scientifically unexplainable in the 21st century. Hence, there is great interest among many people, even outside the scientific community, in knowing the age of the TS. Consequently, it is understandable why various datings of the Relic have been carried out, even using alternative and, in some cases, completely innovative methods. Following the comments of Section 6 on the various results obtained regarding the dating of Christianity's most important Relic, it is noted that, at first glance, these results appear to be significantly discordant and highlight the considerable difficulty in obtaining the sought information. Aside from some questionable results like those in Sections 2.4 and 3, the evident incompatibility stems from the data in Section 4, which assigns a result differing by several centuries. Regarding this, however, apart from the lightness identified in the laboratories that produced this incompatible result in 1988, it must not be forgotten that, for example, the Beta Analytic laboratory in Miami, Florida (USA) "does not undertake the dating of textiles unless they are part of a multidisciplinary scholarly process" [43] because it has repeatedly found that textile samples can lead to non-negligible biases. In seeking a solution to reconcile all the apparently heterogeneous dating results for the TS, one could reconsider the results of Section 4 by taking into account the hypothetical effect of selective radioactivity on the Relic. Such radioactivity could have converted nitrogen (as well as C^{13}) present in the linen into additional C^{14}, thereby altering the measured isotopic ratio in a non-negligible way. Obviously, at this point, a new experimental verification would be appropriate, but only after having gained a better understanding of the formation of the body image, which itself might have produced a non-negligible bias due to the associated radiation involved.

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