Computerized anthropometric analysis of the Man of the Turin Shroud

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ABSTRACT

For the development of the anthropometric analysis of the Man of the Shroud through vision systems an anthropometric research integrated with experimental researches was realised..

The images of the Man of the Shroud were acquired and numerically elaborated to point out the outlines of the two imprints (frontal and dorsal) and to carry out the measurements.

The dimensional results obtained were therefore corrected in consequence of the systematic effects found, like for instance those due to the cloth-body wrapping effect.

The height of the Man, 174±2 cm, was therefore measured with different techniques and the results obtained were compared with the anthropometric indices derived from bibliography.

From the comparison among the anthropometric indices characteristic of different human races and those of the Man of the Shroud it was shown that the Semitic race is the closest one to the Man's features.

1) INTRODUCTION

Numerous dimensional studies to gauge the height of the Man of the Shroud starting from the body image impressed on the linen were carried out.

Even if at first sight the task doesn't seem hard, it is necessary to overcome some difficulties: it must be observed that it is not enough to define two characteristic points such as the top of the head and the sole of the feet, and then to measure the distance between them. It must be considered that the cloth was wrapped around a man not lying completely flat, but rather with his legs flexed and his head bent forward.

The length of the body image must then be corrected, considering these effects and the fact that the cloth was not in contact with the whole body. For instance, the intensity variations of the image just next to the knee on the dorsal image and below the calves on the two imprints, frontal and dorsal, confirm the absence of such a contact.

Many scholars endeavoured to overcome such obstacles trying to make opportune corrections, considering also the possible presence of folds [1] on the sheet. However one got heterogeneous results that indicated a height variable from 162 to 187 cm!

Till now, the studies carried out have been based on more or less subjective hypotheses admitted also in consequence of the thesis that the various authors tried to show: some researchers favourable to the authenticity of the Shroud are inclined to provide the lowest values for the height, while those who are anti-authenticity are inclined to provide the highest values.

The authors who believe the Shroud is false claim that the Man of the Shroud, about 1.80 m height, was a giant compared to his contemporaries and therefore it wouldn't have been necessary for Judas to give him the famous kiss to point him out in the group. However from recent excavations made in Rishòn Letziòn [2] it is evident that many Canaanitic men were very tall: many of them reach 1.75 m.

A first attempt to study the height of Jesus Christ, likely drawn from the Shroud, dates back to the VI cent., by the Emperor Justinian (527-565): a height of about 180 cm resulted [3].

This attempt was followed by others through the centuries.

The measurement realized by Alfonso Paleotto coincides with this, even if he used the Bolognese foot as his unit of measurement; neither does Niceforo Callisto, who on the contrary used the spans, diverge much from such a measure.

Needless to note that such criteria are without doubt not very scrupulous in establishing the height of the Man of the Shroud.

A better accuracy and competence was showed by more recent studies, that draw also on more scientific knowledge, of the anthropometric and biotypological kind.

Among them, Luigi Gedda [4] communicated in 1939 the method he followed in his researches: he had a negative photograph taken, with the dimensions corresponding to the real ones of the cloth. From these images he got the anthropometric measures with two different methods: with the first one he measured the height of the face along the sagittal plane and from this dimension, with a mathematical calculus, he defined the other dimensions of the body; the latter method was to determine the height of the body on the well marked dorsal side, established at 185 cm, then he deducted about 2 cm, as the body was not lying perfectly flat, obtaining a height of 183 cm.

Giulio Ricci [5] carried out a very detailed analysis, but with some limitations due to a lack of accurate measurement systems and objectivity; he supposed that the sheet was softly placed on the body outline and that the body had not been laid out flat, both because of the position taken on the cross and because of rigor mortis; moreover, thanks to the blood traces and trickles, he was able to deduce the presence of folds on the sheet and the form this took on the body. Therefore the measurements realized directly on it and not corrected constitute only the linear development of the body outline. However he came to the conclusion that the height of the Man of the Shroud is 162.8 cm.

It is evident that the accuracy of the tenth of centimeter loses meaning if one notes that Ricci did various arbitrary corrections of about a centimeter.

2) RESEARCH METHOD

The dimensional analysis through vision systems was carried out according to the following scheme. First the outlines of the legs on the imprint of the sheet were determined, both on the frontal and on the dorsal images.

From them it was possible to define the characteristic anthropometric points and then calculate the relative tibio-femoral indices, defined by the percentage relation between the length of the tibia and that of the femur.

From the comparison between these two values with those characteristic of various races, through the use of relevant anthropometric tables, it was possible to determine the closest race; from this, the relative value of the radius-humeral index was then determined.

As is known, the radius-humeral index is not easy to determine on the Shroud imprint because of the burn marks caused by the Chambéry fire.

The preventive calculus of the tibio-femoral index was made for two reasons: a) to facilitate the reconstruction of the upper part of the body through the radius-humeral index that is strongly related to the first one and b) to determine the most probable race, the tibio-femoral index being the characteristic distinguisher of different peoples.

After reconstructing the outlines of the imprints, frontal and dorsal, we carried out a comparison among the two images to come, in an iterative way, for the reconstruction of the outlines.

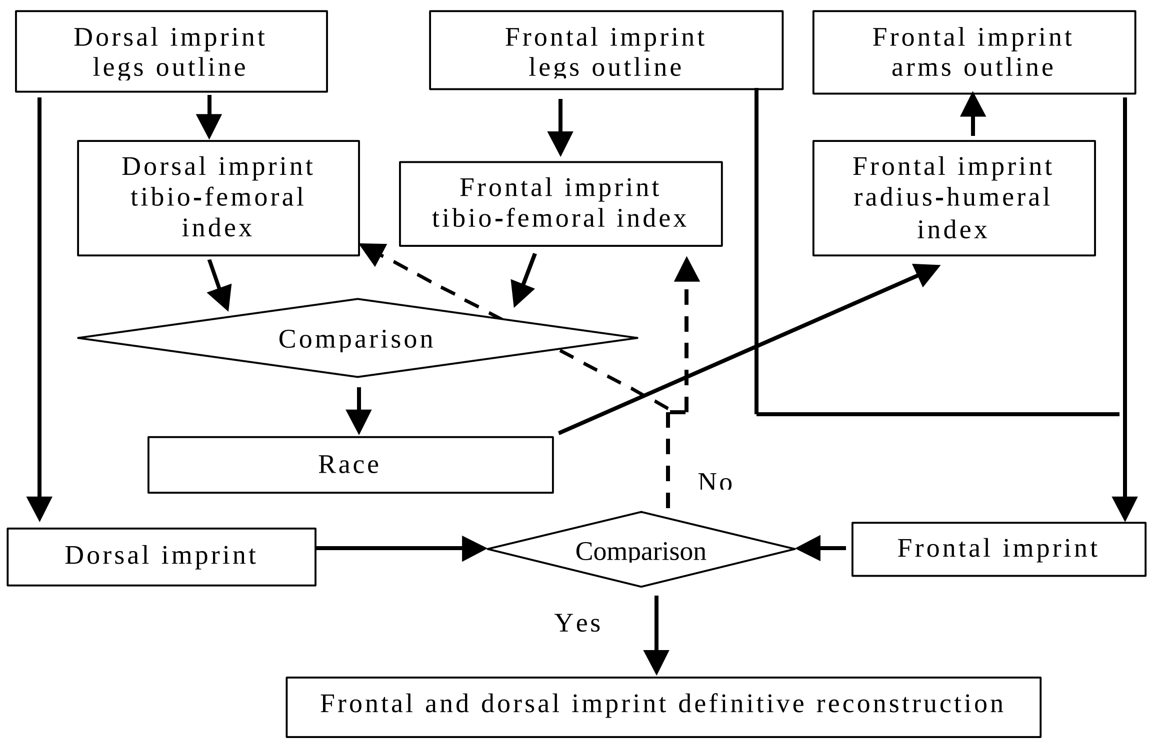


Figure 2.1[1]: Diagram of the method followed to carry out the computerized anthropometric analysis of the Man of the Shroud.

3) PARAMETERS CHARACTERISTIC OF THE POSITION OF THE MAN OF THE SHROUD

By carefully observing the legs on the dorsal image, the intensity variations depending on a touch-doesn't touch effect of the sheet are evident; such a situation is explainable if we suppose that the man has his lower limbs bent.

The inflexion [1] would be due to the position taken on the cross and therefore to rigor mortis; the assumption becomes probable if one thinks what the natural position of rest taken

[1] The numbering of the figures is related to the paragraphs in which they appear.

by a person lying down is. Moreover, such a position could also be the consequence of post-mortal stiffening.

The hypothesis is also supported by the non-flattening of some areas of the dorsal imprint, an effect that, because of gravity, should be present.

Figure 3.1 shows the hypothetical position of the Man of the Shroud depending on four angles that are the object of the following analysis.

The characteristic parameters of the position are:

- α: angle of the head in relation to the support surface;
- β: angle of the femur in relation to the support surface;
- γ: angle of the tibia in relation to the support surface;
- δ: angle of the straight line joining ankle-toe in relation to the support surface.

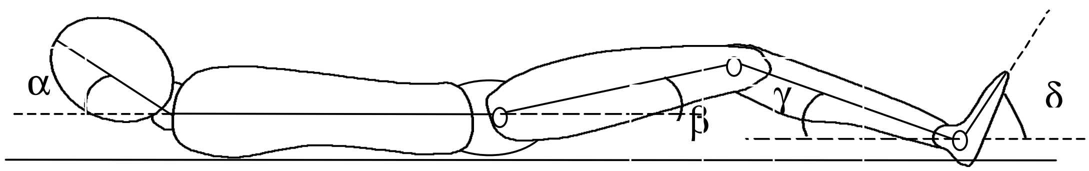


Fig. 3.1: Hypothetical position of the Man of the Shroud characterized by 4 parameters, the angles a, b, g, d, that respectively show the position of the head, the femur, the tibia and the foot.

Figure 3.2 shows that, just because of the inflexion of the lower limbs, the length of the leg measured on the frontal side is longer than that measured on the dorsal side.

In fact bending a limb, the center of rotation being just next to the knee, one will have a lengthening of the front leg and a shortening of the back one.

Analogous considerations must be made for the position of the feet.

The Man of the Shroud has his feet bent forward and this is very important for the measurement; in fact as shown in Figure 3.3, the position of the heel changes considerably if measured with a “hammer” or outstretched foot.

The heel itself being a fundamental reference point for the length of the tibia, it becomes necessary to value this effect too.

For these reasons, it became necessary to make corrections to the results of the measurements realized for the systematic effects, due to the inclination of the legs and the feet; they are valuable in a first approximation in:

$L = a (\beta + \gamma)$ for the frontal imprint;

$L_1 = c (\beta + \gamma)$ for the dorsal imprint; and

$B \delta$ that represents the retroversion of the heel due to a forward rotation of the foot.

The length of the leg measured on the frontal imprint G_f is given by:

$$G_f = F + T + L; \qquad (3.1)$$

the length of the leg measured on the dorsal imprint G_d is given by:

$$G_d = F + T - L_1 - \delta\ \beta; \qquad (3.2)$$

the effective length G of the Man of the Shroud's leg is instead:

$$G = F + T \qquad (3.3)$$

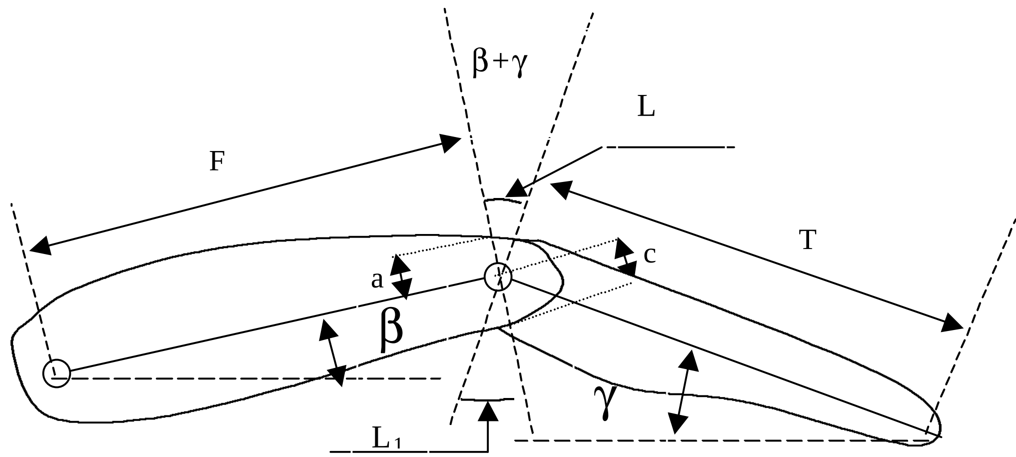


Fig.3.2: The length of the frontal and dorsal body imprint of the Man of the Shroud's legs is different and depends on the product of the angle g for the distances a or c.

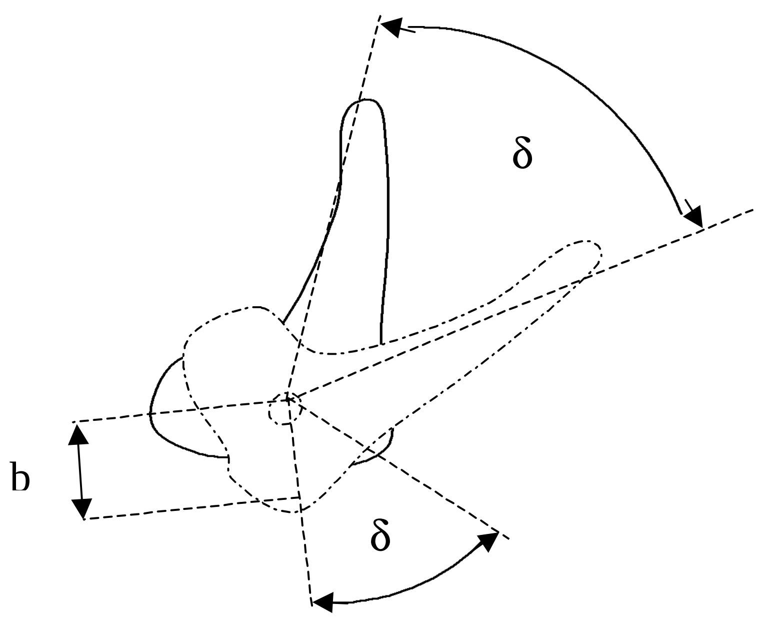


Fig.3.3: Position of the heel in connection with the angle of the foot

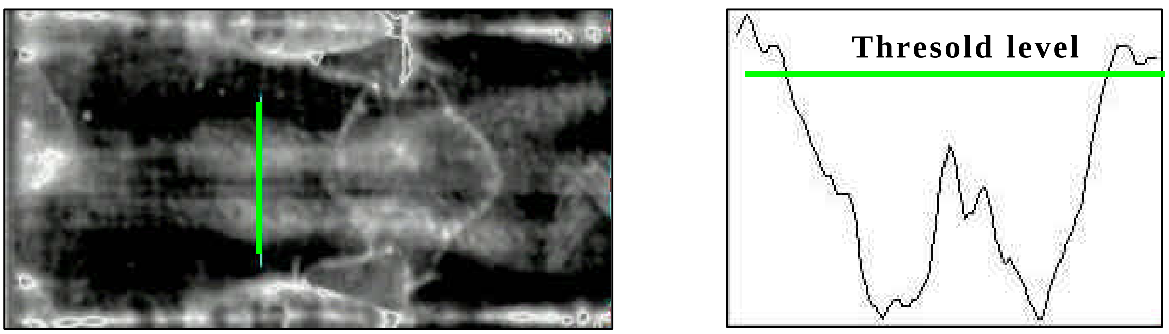
4) COMPUTERIZED ANTHROPOMETRIC ANALYSIS

4a) Determination of the outlines

For the determination of the Shroud imprint outlines we used a B/W digitized image, in negative with 512x512 pixels and 256 different grey levels.

The technique to point out the outlines used different elaborations, among them a preliminary filtering of the image, a determination of the threshold on the basis of pre-established grey levels and an adjustment of the outline through suitable spatial filters.

The local analysis of the grey levels carried out in a tenth of image portions allowed us to choose the most appropriate threshold level. For instance, as for the lower limbs (Fig. 4.1a), a transversal segment is traced along which the outline of the grey levels is studied; then an opportune value like threshold is determined (Fig. 4.1b) through which the software traced the outlines (Fig. 4.2).



a) b)

Fig.4.1: a) In the portion of the Shroud frontal image, corresponding to the lower limbs, a segment is traced along which the different grey level values are shown in b).

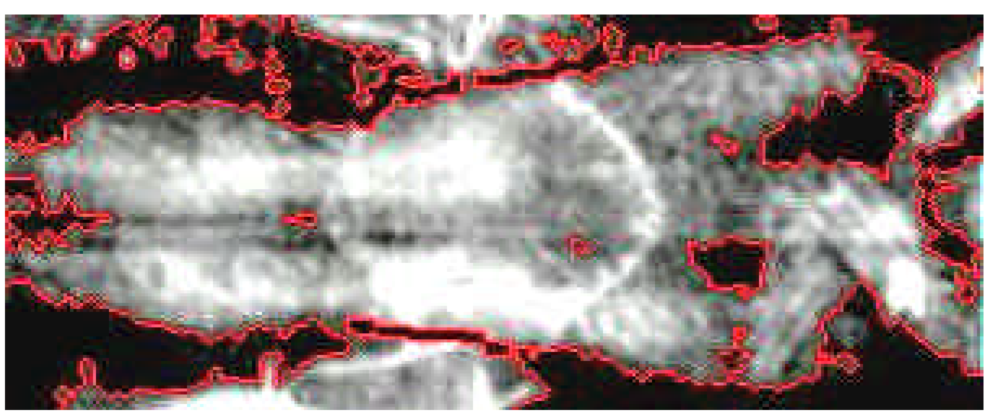


Fig.4.2: Example of determination of Figure 4.1 body image outlines during a phase of intermediate elaboration, before the spatial filtering.

4b) Comparison between frontal and dorsal imprint

After having reconstructed the two imprints and determined the outlines, an overlay comparison is carried out, shown in Figure 4.3.

The first remarkable result obtained was to note that the two imprints are anatomically superimposable.

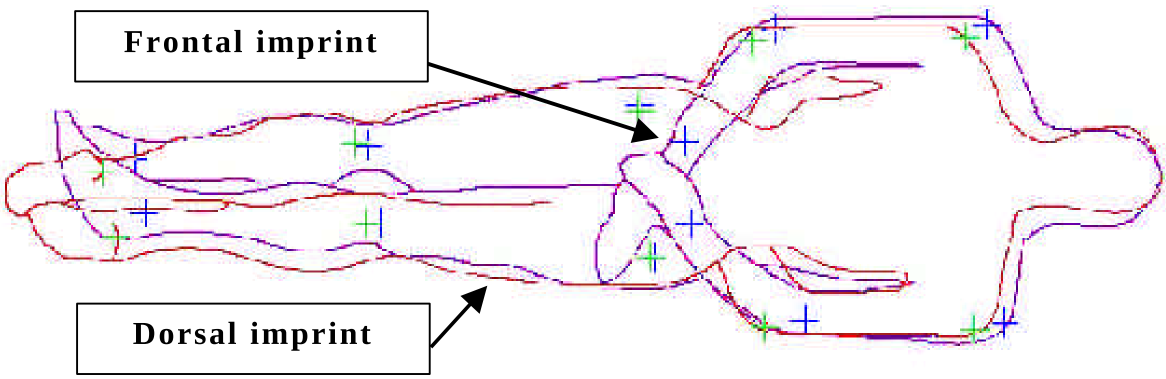


Fig. 4.3: Overlay of the frontal and dorsal imprint: the two imprints are anatomically compatible. Moreover in the Figure the anthropometric points of greatest interest are shown.

The numerical valuation of the mean tibio-femoral index allowed us to verify that the one calculated (83.5 %) is compatible with the mean ones quoted in bibliography [6,7,8,9].

The larger width of the frontal imprint compared to the dorsal one is due to the position of the sheet: lying on the support surface, under the body, and lying on the Man of the Shroud outline in the upperside; the linear development of this one led to a greater deformation of the frontal imprint.

<u>5) UNCERTAINTY ANALYSIS</u>

The analysis that follows refers to the ISO Guide for the expression of the measurement uncertainty [10].

a) Uncertainty of the vision system

A vision system [11] generally consists of a shooting surface on which one places the object, a lighting system, a camera with CCD sensor and a system of data acquisition and elaboration.

The images acquired by the camera are forwarded to a computer where, through the applicative software, they are elaborated.

The assignment of the measurement uncertainty is not easy because it depends on the measurement method and the procedure followed, on the particular definition of the image and the different parameters of the measurement chain composing the vision system; the most important uncertainty sources are:

- the resolution of the image;
- the environmental conditions in which the image was acquired;
- the image digitization;
- the complanarity between the surface where the segment to measure is and that of the optic sensor;
- the background noise;
- the proceeding chosen to point out the outlines, for instance connected to the choice of the threshold value of the grey level.

Once the size of the single components have been valued, the uncertainty must be propagated to the result assuming a covering factor equal to 2, corresponding to a confidence degree of 95%.

The uncertainty of dimensional measurement we obtained with the vision system adopted is of some millimeters. It turns out to be negligible compared to the uncertainty of a centimeter attributed to the measurement of the outlines and of the anthropometric points on the analyzed sheet photograph.

b) Systematic effects

All those effects that influence the dimensional measurement must be considered to correct the final measurement result.

All the systematic effects were considered negligible except the following ones:

1) Linear development of head roundness

The sheet could have followed head roundness; in such a case, then, what it is measured is no more the real nape-vertex distance, but it is the one taken along the cranium outline. Such correction considers also the presence of the hair.

- Dorsal imprint correction: -3% $\pm$ 1%[2].

2) Effect of the forward bending of the head (parameter α)

It is not easy to define from the body image how much the head is bent forward; experimentally the two extreme situations (α=0 e α= max) have been taken into account.

- Frontal and dorsal imprint correction: +3 $\pm$ 3 cm[2].

3) Lengthening of the linen due to mechanical stress

It is considered that in time the linen could have lengthened following the application of mechanical tensions. The assignment of the uncertainty does not exclude the hypothesis of lengthening absence.

- Frontal and dorsal imprint correction: -2% $\pm$ 2%.

4) Lengthening of the cloth due to the linear development of the frontal outline on which it is placed

The cloth wrapped the body of a man and it is extremely improbable that it was perfectly stretched out.

- Frontal imprint correction: -7,5% $\pm$ 2%[2].

[2] Measurement carried out by the authors on physical samples.

5) Lengthening due to the linear development of the back outline of the legs with which it was in contact

While it is probable that the sheet in the back area was stretched out on the support surface of the Man, so much cannot be claimed for the legs.

It has been supposed that the sheet could in such a way be brought closer to the back of the legs by a possible side bandaging (bandages), without which it would have remained on the support surface.

- Dorsal imprint correction: $-1\% \pm 1\%$[2] .

6) Presence of possible folds on the sheet

Because of the lacking of reliable data, the following correction is assumed (Ricci's [1] evaluation of about 17 cm seems excessive):

- Frontal and dorsal imprint correction: $-2\% \pm 2\%$.

7) Probable "S" bending of the backbone

The possible effect due to the bending seems to have had some influence and because of the lack of data the following correction was used:

- Frontal and dorsal imprint correction: $+1 \pm 1$ cm.

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8) Compression of the intervertebral discs in a standing person

It results from bibliographic data [12] that a man lying down is about 2 cm longer compared to the standing position because of compression of the cartilages in the standing position; this effect is concentrated above all along the backbone:

- Frontal and dorsal imprint correction: $-2{,}0 \pm 0{,}5$ cm.

9) Shrinkage of a linen sheet after the washing

It is known that a linen sheet when washed undergoes considerable shrinkage and it is not easy to know which treatments the sheet under discussion underwent before the wrapping of the Man of the Shroud.

However historical references relative to the "linen cooking" (washing and natural drying in the sun before the use of the sheet) [13] are favorable to the hypothesis according to which the sheet would have been washed before the wrapping of the corpse.

- Frontal and dorsal imprint correction: 0 cm.

6) DISCUSSION OF RESULTS

6a) Anthropometric results

Through analyses with vision systems the measurements on the image of the Turin Shroud digitized with 512x512 pixels were carried out.

The study started with the valuation of the tibio-femoral index that, in anthropometry, is one of the most important parameters. Before proceeding with the calculus, it was necessary to turn the heel-knee distance measured on the Shroud photograph into corresponding length of the tibia; to do this some considerations were necessary.

So as not to make the treatment dull, the measurement uncertainties are assigned to the final result.

In the case of the dorsal image the foot is bent, therefore the heel made a rotation backwards: for a foot bent 25°, the heel undergoes a displacement of 4.4 cm.

Assuming the legs were bent at an angle of 20°, the lengthening of the leg image due to the contact of the sheet with the knee results of 2.1 cm.

The distance between heel and malleolus of a standing person is valued at 9 cm.

In this way it was possible to trace the length of the tibia L_t equal to:

$$L_t = (45.2 + 4.4 + 2.1 - 9 =)\ 42.7 \text{ cm.}$$

In confirmation of the result obtained, the same value was obtained measuring the frontal imprint.

An analogous proceeding for the measurement of the femur was adopted and the result was 51 cm.

The values of the tibio-femoral index obtained for the Man of the Shroud are reported in table 6.1.

Measurements on the Man of the Shroud	Frontal imprint	Dorsal imprint
Tibia length [cm]	42.7	42.7
Femur length [cm]	50.9	51.0
Tibio-femoral index [%]	**83.9**	**83.7**

Table 6.1: Tibio-femoral indices measured through vision system.

Then the dimensional values characteristic of the Man of the Shroud were measured and therefore the corresponding anthropometric indices were calculated.

First, the results relative to the frontal image with those relative to the dorsal image were compared and, once the complete compatibility of every value had been verified, the corresponding mean values were calculated. The main results are reported in table 6.2.

Tibio-femoral index	**83 ± 3%**
Radius-humeral index	**75 ± 3%**
Facial index	**106 ± 25%**
Nasal index	**60 ± 8%**
Height	**173 ± 4 cm**

Table 6.2: Dimensional results of the Man of the Shroud obtained through vision system.

To verify the result, the height of the Man of the Shroud was also calculated through an anthropometric table of correlation among the height and the lengths of the humerus, radius, femur and tibia relative to adult and white males.

Table 6.3 was used in the following way: once entered with the measured lengths of tibia and femur (bold), the relative uncertainty fields were also shown (double line). From these the value of the height was obtained, assigning an uncertainty equal to the common uncertainty field of the relative tibia and femur length (broken lines).

The height obtained is 174 ± 2.5 cm, a value completely compatible with the one obtained through direct measurement with vision systems.

Therefore an average weighing was carried out as a function of the uncertainty between the height obtained from the anthropometric table and that calculated with direct measurements.

Then the height of the Man of the Shroud turns out to be 174 ± 2 cm.

The results are reported in table 6.4.

	Height [cm]	Humerus [cm]	Radius [cm]	Femur [cm]	Tibia [cm]
	169.7	34.0	25.2	46.7	38.3
174 ±2.5cm	171.6	34.4	25.5	47.5	38.9
	173.0	34.8	25.8	**48.2**	39.4
	175.4	35.2	26.1	49.0	40.0
	176.7	35.6	26.4	49.7	**40.5**
	178.5	36.0	26.7	50.4	41.0
	181.2	36.4	27.0	51.2	41.5
	183.0	36.8	27.3	51.9	42.0
	184.8	.....	.....	52.4	.....
	185.6	.....	.....	.....	42.6
	193.0	.....	.....	.....	44.3

Table 6.3: The anthropometric table of correlation among the height and the lengths of humerus, radius, femur and tibia, relative to adult and white males, was used to obtain the height of the Man of the Shroud in a different way.

Tibia mean length [cm]	Femur mean length [cm]	Height (calculated from table 6.2) [cm]	Mean height measured [cm]	**Weighed mean height [cm]**
40 ± 2	48 ± 1	174 ± 2.5	173 ± 4	**174 ± 2**

Table 6.4: Dimensional results characteristic of the Man of the Shroud, directly measured and obtained from the weighing average (as a function of the uncertainty) among the vision system data and those foreseen by anthropometric tables.

6b) Hypothesis on the race of the Man of the Shroud

The anthropometric indices of the Man of the Shroud and the mean ones relative to different present ethnic groups were compared. Obviously the results, reported in table 6.5, are to be used only for a broad comparison because it was not possible to verify that the indices attributed to a certain race remained constant with the passing of the centuries.

It must be noted that the Man of the Shroud's features are very similar to those relative to the Mediterranean race (bold), even if analogies with other races cannot be excluded.

Particularly, the tibio-femoral index of the Man of the Shroud turned out to be 83.8%. If the data is compared with the indices typical of different races, it is evident that the value is very close to that of the Semitic race, characterised by an index of 83.66%.

This analysis cannot show that the Man of the Shroud was certainly Jewish because of the uncertainty of the data obtained (in the order of some percentage point) and because the data obtained by bibliographic research is not completely exhaustive, but it is certainly significant that an anthropometric analysis carried out with the greatest possible objectivity could have led to such an extraordinary result.

	Height [cm]	Tibio-femoral index [%]	Radius-humeral index [%]	Facial index [%]	Nasal index [%]
Italy	166.0	/	/	/	67-72
France	/	82.5	/	/	/
Middle Europe	165.5	/	/	86-90	67-72
North Europe	**173.0**	/	/	>90	67-72
Eastern Europe	167.0	/	/	86-90	67-72
Ancient Mediterraneans	/	80.5	/	/	/
Modern Mediterraneans	/	82.8	/	/	/
Mediterranean Africa	**170.5**	/	/	89.2	71.4
Russia	165.5	/	/	86-90	79.9
Semites	/	**83.7**	/	/	/
India	165.9	/	/	86-90	79.9
Turkey	167.5	/	/	86.5	62.9
Arabia	165.5	82.1	**75**	85.1	68.3
Middle East	165.0	/	/	88.9	**61.4**
Black Race	/	84.9	/	/	/
Man of the Shroud	174±2	83±3			60±8

Table 6.5: Heights and mean anthropometric indices relative to different modern ethnic groups and relative to the Man of the Shroud.

6c) Characteristic parameters

Another alternative technique was used for the determination of the Man of the Shroud’s height; the two imprints, frontal and dorsal , were compared. A diagram of the height of the two imprints to favour of the angles ($\beta+\gamma$) and δ (see Figure 3.2, 3.3) of legs and feet was made assuming the dimensional equality among the limbs of the two images.

The value of the height was obtained as the intersection among the relative curves; it resulted equal to:

height of 173.3 cm

that corresponds to the following values of the angles:

angle of the knee = $(\beta+\gamma) = 24°$
angle of the foot = $\delta = 25°$.

Note how these values are completely compatible with those already obtained with the previous techniques.

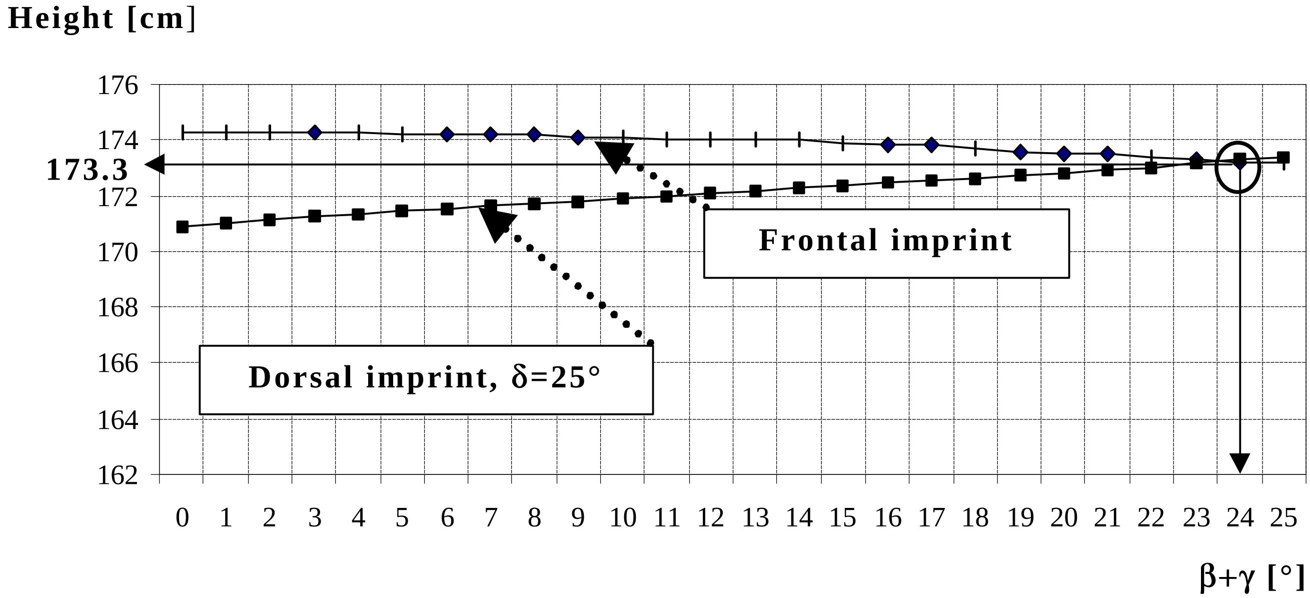

Figure 6.1: Diagram of the height measured in the two imprints, frontal and dorsal as a function of the angles (b+g) and d (see Figure 3.2, 3.3) of the legs and the feet assuming the dimensional equality between the limbs of the two images.

6d) Tibio-femoral index: evidence of authenticity

For a comparison a dimensional analysis of the lower limbs of three copies of the Shroud was carried out:

a) the one attributed to Dürer in 1516;

b) the one owned by the Monastero delle Cappuccine in Turin, dated 1644; [14]

c) the one realized in 1643 and owned by the countess Alessandra Lovera di Maria [14],

adopting the same standards of measurement used for the Turin Shroud.

In every copy of the Shroud, even a keen eye can perceive few real anatomic particulars, but the computerized dimensional analysis showed that the tibio-femoral indices are absolutely incompatible with that of the Man of the Shroud and the mean anthropometric one. The results are reported in Table 6.6.

Note how the tibio-femoral indices of the copies, that are among the most significant from the anthropometric point of view, are not only high compared to the mean one, but would mean a tibia length longer than the femur one.

From this comparison results that in 1600 the anatomic knowledge and the techniques of drawing were still too lacking in reproducing such a complete and detailed image like the one on the Turin Shroud.

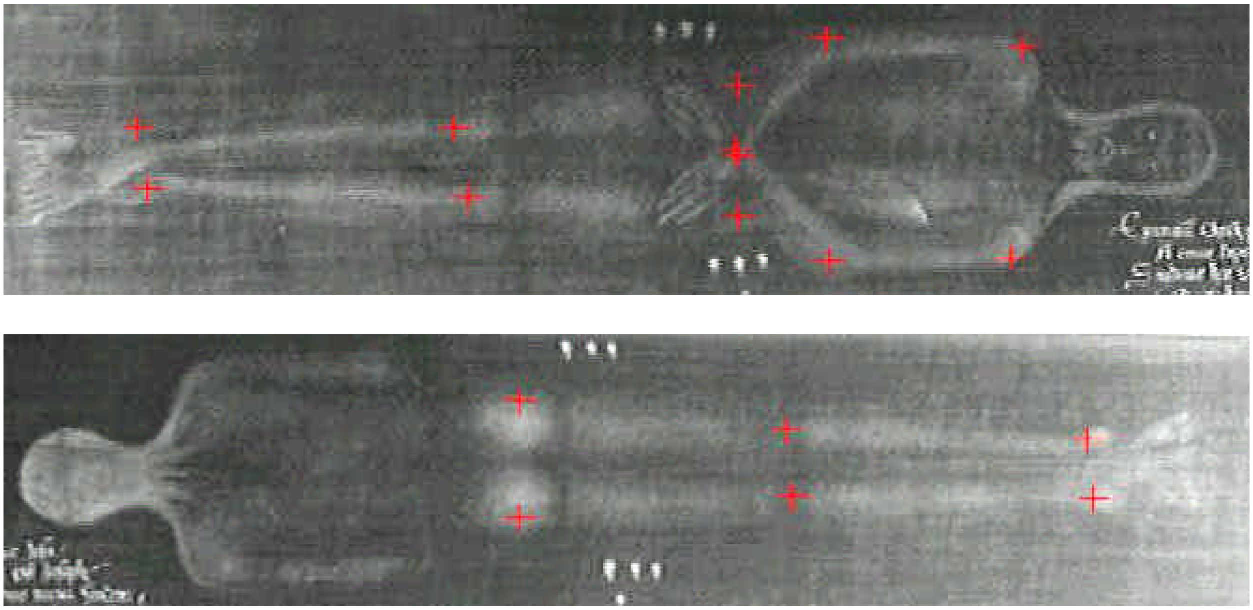

Figure 6.2: Copy of the Shroud attributed to Dürer (negative)

	Tibio-femoral index [%] = (Tibia length*100) / (Femur length)
Dürer's copy of 1516	115±5
Copy of 1643	105±5
Copy of 1644	103±5
Man of the Shroud	83±3
Anthropometric mean	82.3

Table 6.6: Tibio-femoral indices of copies body images, compared with the Man of the Shroud's index and the mean anthropometric index.

7) CONCLUSIONS

An anthropometric analysis of the Man of the Shroud was carried out making comparisons with bibliographic data and experimental research.

The images were acquired and elaborated to point out the outlines of the two imprints and to carry out the measurements corrected following the systematic effects found, like for instance those due to the cloth-body wrapping effect.

The height of the Man of the Shroud was obtained both directly measuring with digital techniques and comparing the most significant anthropometric indices with bibliographic data, and imposing the same kinematic conditions (angles of the knees and feet) in the frontal and dorsal imprint.

From the comparison among the anthropometric indices characteristic of different human races with those of the Man of the Shroud it was possible to point out that the Semitic race is the closest one to the characteristics obtained.

The tibio-femoral index, one of the most significant, calculated for the Man of the Shroud (equal to 83% ±3%) is completely compatible with the mean one quoted in bibliography (equal to 82.3%), the tibio-femoral index measured on three different copies of the Shroud (respectively equal to 115%, 105%, 103% ±4%) showed the incompatibility of the images painted by artists who at that time did not have enough anatomic knowledge.

The height of the Man of the Shroud turned out to be 174±2 cm, the rotation angle of the knee ($\beta+\gamma$) equal to 24±2° and the rotation angle of the foot δ equal to 25±2°.

The frontal and dorsal imprints of the Man of the Shroud are anatomically superimposable.

ACKNOWLEDGMENTS

The authors thank Simona Rastelli who translated into English the original Italian version, Mark Guscin who revised the translation and Maurizio Marinelli who arranged the slides for the presentation.

For Italian academic purposes only, the authors individual contributions to this work are specified as follows: G. Fanti (50%) was the investigator of the paper and the research co-ordinator; E. Marinelli (25%) provided the bibliographic sources, revised and presented the work; A. Cagnazzo (25%) under the guidance of G. Fanti compiled the paper and carried out the measurements and the numerical elaborations.

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