Lower-Abdominal Protrusion in Crucifixion and the Turin Shroud

A Critical Review of Thoracoabdominal Mechanics, Suspension Physiology, Postmortem Change, and Three-Dimensional Image Interpretation

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Abstract

A slight protrusion of the lower abdomen has long been described in the frontal body image of the Turin Shroud. Pierre Barbet interpreted this contour as a consequence of a thorax held in an extreme inspiratory configuration during crucifixion, with caudal displacement of the diaphragm and anterior displacement of abdominal contents. Frederick Zugibe, although rejecting Barbet's asphyxiation model, independently described a 'slight bulging of the abdomen' on the Shroud and documented predominantly abdominal, diaphragmatic breathing during experimental cross suspension. The observation has recently attracted renewed interest because three-dimensional intensity processing, including work by Thierry Castex, can make the lower-abdominal contour visually conspicuous. This paper asks a narrower scientific question: is visible lower-abdominal protrusion physiologically compatible with crucifixion or suspension, and, if so, by what mechanism? A targeted critical review was conducted through 8 August 2026 of crucifixion medicine, respiratory and suspension physiology, abdominal-wall and diaphragmatic mechanics, forensic postmortem change, and Shroud image-processing literature. The evidence does not support the claim that crucifixion is known to cause generalized acute enlargement of abdominal organs. A more defensible mechanism is mechanical: altered rib-cage recruitment and increased diaphragmatic contribution can descend the diaphragm; if anterior abdominal-wall tone is reduced or poorly coordinated, intra-abdominal contents redistribute caudoventrally and the lower abdomen can project forward without organomegaly or a large increase in abdominal contents. This mechanism is strongly demonstrated in independent CT, electromyographic, plethysmographic, and pressure studies of human abdominal distension, and is directionally consistent with Zugibe's cross-suspension observations and studies of unsupported arm elevation. However, this review identified no published crucifixion experiment that directly quantified lower-abdominal surface projection, and, if the image derives from a body wrapped after death, the relevant morphology is postmortem and predominantly supine rather than that of a living subject on a cross. Positional MRI and cadaver-orientation studies show that gravity can substantially alter diaphragmatic and visceral position when body orientation changes, making transfer from suspension to a supine burial configuration a critical unresolved step. Rigor mortis, cloth drape, body habitus, hand placement, image-formation physics, and intensity-to-height algorithms are therefore major confounders. The abdominal feature is best regarded as a testable forensic-anatomical hypothesis rather than an established diagnostic sign of crucifixion or an independent proof of Shroud authenticity. A preregistered experimental program combining ethical suspension studies, diaphragm ultrasound, abdominal-wall electromyography, optical surface scanning, and algorithm-sensitivity analysis of raw Shroud images is proposed.

Keywords: crucifixion; Turin Shroud; abdomen; abdominal protrusion; diaphragm; respiratory mechanics; suspension physiology; abdominophrenic dyssynergia; rigor mortis; three-dimensional imaging

1. Introduction

The frontal image of the Turin Shroud presents an adult male body with multiple features that have been interpreted in the medical and forensic literature as consequences of scourging, crucifixion, and death. Among the less frequently discussed observations is the contour of the lower abdomen. Pierre Barbet explicitly drew attention to a protruding hypogastrium, which he linked to his theory that crucifixion progressively fixed the thorax in an inspiratory position. Decades later, Frederick T. Zugibe - a forensic pathologist who strongly challenged Barbet's asphyxiation model - nevertheless described the Shroud as showing 'a slight bulging of the abdomen' (Zugibe 2005, p. 193). That agreement on the observation, combined with disagreement on mechanism, makes the feature scientifically interesting: it can be separated from the larger and much more contentious question of how crucifixion causes death.

The issue has resurfaced because image-intensity processing can render body contours in relief. The VP-8 work associated with Jackson and Jumper and later digital procedures, including Thierry Castex's color 3-D processing, translate variations in Shroud image intensity into a topographic display. In such renderings the lower abdomen may appear more prominent than in an ordinary positive photograph. The immediate temptation is to reason backward: if a crucified body should show abdominal swelling, and the Shroud appears to show it, the image has reproduced a medically obscure sign that a medieval artist would be

unlikely to know. That argument, however, contains several separate premises that must be tested rather than bundled together.

First, one must establish what the relevant anatomical feature actually is. 'Swollen abdomen,' 'protruding lower abdomen,' 'distended abdomen,' 'displaced viscera,' and 'enlarged organs' are not synonyms. True organomegaly means enlargement of one or more organs. Abdominal distension is an increase in abdominal girth or anterior projection and can occur without organ enlargement, without increased intestinal gas, and even without a large increase in total abdominal content. Second, one must distinguish physiology during life on a cross from morphology of a corpse after removal, transport, and supine burial. Third, a relief generated from image intensity is not a CT scan and must not be treated as a direct millimetric measurement of the underlying body. Finally, even if the contour is authentic and physiologically congruent, congruence is not uniqueness: an authenticity argument requires showing that plausible alternatives are substantially less likely.

This paper therefore addresses a deliberately narrow research question: can crucifixion or crucifixion-like suspension produce a visible lower-abdominal protrusion, and what mechanism is best supported by modern physiology? The goal is not to adjudicate the authenticity of the Turin Shroud or the precise cause of Jesus's death. Instead, the paper integrates four evidence streams that are usually discussed separately: (1) medical literature on crucifixion and experimental suspension; (2) laboratory studies of respiratory muscle recruitment and arm elevation; (3) modern imaging and electromyographic research on diaphragm-driven abdominal distension; and (4) forensic and image-processing constraints relevant to interpreting a postmortem Shroud image. The central thesis is that a mechanically produced abdominal protrusion is physiologically plausible and experimentally testable, whereas the stronger claim of acute generalized organ enlargement from crucifixion is not currently supported.

2. Methods and Scope of Review

A targeted critical narrative review was conducted, with the literature search updated through 8 August 2026. This was not designed as an exhaustive systematic review. The purpose was hypothesis evaluation rather than estimation of treatment effects, so a formal PRISMA meta-analysis was not appropriate. Searches were performed across PubMed/MEDLINE records, PubMed Central full texts, journal and publisher databases, institutional repositories, and citation chains from major reviews. Search concepts included combinations of crucifixion, cross suspension, suspension trauma, asphyxia, diaphragm, abdominal breathing, abdominal distension, abdominal protrusion, hypogastrium, respiratory mechanics, arm elevation, rib cage, intra-abdominal pressure, abdominal wall electromyography, rigor mortis, cadaveric spasm, postmortem CT, cadaver orientation, positional MRI, linen drape, fabric dynamics, Shroud of Turin, VP-8, three-dimensional imaging, image intensity, and Thierry Castex. Shroud-specific bibliographic resources were used primarily to locate older books and technical materials not indexed in PubMed; clinical or physiological claims were preferentially grounded in peer-reviewed medical literature.

Three source classes were distinguished. Direct evidence consisted of observations or experiments explicitly concerning crucifixion, simulated cross suspension, or the Shroud. Analogical physiological evidence consisted of human experiments that isolate one relevant component, such as unsupported arm elevation, passive suspension, diaphragmatic contraction, or abdominal-wall relaxation. Interpretive evidence consisted of Shroud image-processing studies and postmortem forensic literature that constrain how a visible contour can be interpreted. This hierarchy is important because a mechanism proven in a gastrointestinal laboratory is not thereby proven to occur during crucifixion; conversely, a qualitative observation in a crucifixion reenactment is strengthened if the same mechanical relationship is independently quantified with CT, electromyography, pressure measurement, and controlled intervention.

Older crucifixion sources require special caution. LeBec, Hynek, Mödder, and Barbet were historically influential, but their arguments often combined anatomical observation, wartime wrist-hanging torture, limited experiments, and extrapolation to Roman crucifixion. Modern reviews have emphasized that crucifixion methods varied and that the exact mechanism of death cannot be inferred confidently from a single reconstructed posture (Maslen and Mitchell 2006; van Wingerden 2020; McGovern, Kaminskas, and Fernandes 2023). Accordingly, this paper treats the older work as hypothesis-generating unless later experiments independently confirm the relevant component. Bibliographic metadata were cross-checked against PubMed/PubMed Central records, publisher pages (including Applied Optics/Optica, Wiley, Elsevier/Gastroenterology, Springer, and the American Physiological Society), and institutional bibliographic records available online as of 8 August 2026. Direct online searches identified no peer-reviewed crucifixion study in which abdominal girth or lower-abdominal surface projection was a measured outcome.

3. The Abdominal Observation on the Turin Shroud

3.1 Barbet: protruding hypogastrium within an asphyxia model

Barbet's interpretation is the clearest historical statement connecting the Shroud's abdominal contour to crucifixion physiology. In A Doctor at Calvary he described an elevated and expanded thoracic frame, a depressed epigastric region, and a lower abdomen that appeared to protrude. His explanation was that the diaphragm, constrained by the configuration of the thorax, was displaced toward the abdominal contents. This was embedded in his broader claim that crucified victims died through progressive asphyxia and muscular tetanization. The anatomical observation and the causal theory should not be treated as inseparable. A protruding lower abdomen could be real even if Barbet's proposed terminal respiratory mechanism is partly or wholly incorrect.

The terminology matters. Barbet referred to the hypogastrium - the lower central abdomen - rather than describing generalized swelling of the entire abdomen or enlargement of specific organs. His description therefore fits a contour-change hypothesis at least as well as an organomegaly hypothesis. Modern abdominal physiology, discussed below, shows that the lower abdominal wall can move anteriorly because the diaphragm and abdominal wall redistribute existing contents; no enlarged liver, spleen, bowel, or other organ is required.

3.2 Zugibe: independent description despite rejection of Barbet

Zugibe provides unusually valuable evidence because he dissented from Barbet on major physiological questions. In his forensic description of the Shroud he noted a 'slight bulging of the abdomen' while cataloguing scourge marks, shoulder asymmetry, limb position, and other body features (Zugibe 2005, p. 193). This observation cannot reasonably be dismissed as merely a restatement of Barbet's asphyxia theory, because Zugibe devoted extensive experimental work to challenging that theory. He found that healthy volunteers suspended in a cross-like position had a chest that appeared relatively fixed and soon adopted obvious abdominal or diaphragmatic breathing, yet they maintained oxygen saturation and did not develop the respiratory distress predicted by the classical asphyxia model.

In Zugibe's experiments, increased respiratory rate became visible after several minutes and breathing shifted toward an abdominal pattern. Subjects also shifted posture and arched their bodies to relieve pain and muscle cramping. These findings are highly relevant to the present question. They support the proposition that cross suspension can redistribute ventilatory work toward the diaphragm, but they do not support the stronger proposition that such redistribution necessarily causes fatal asphyxia. In other words, the respiratory-mechanical premise of an abdominal-contour hypothesis has better experimental support than Barbet's terminal-cause-of-death inference.

3.3 Three-dimensional processing and the Castex montage

The supplied Castex montage makes the lower-abdominal region visually conspicuous by displaying multiple intensity-processed views and a side-profile relief. Castex is a geophysical engineer specializing in seismic processing and 3-D imaging. CIELT describes his procedure as applying image filtering and equalization to color photographs, separating and processing RGB components, suppressing weave-related periodic structure, and then converting pixel amplitudes into calculated 'heights.' From 2011 onward he worked principally with Gian Carlo Durante's 2002 color photographs, later combining multiple photographic sources. These procedures can be useful for feature visualization, but their outputs must be interpreted as model-derived relief, not direct topography measured from the corpse.

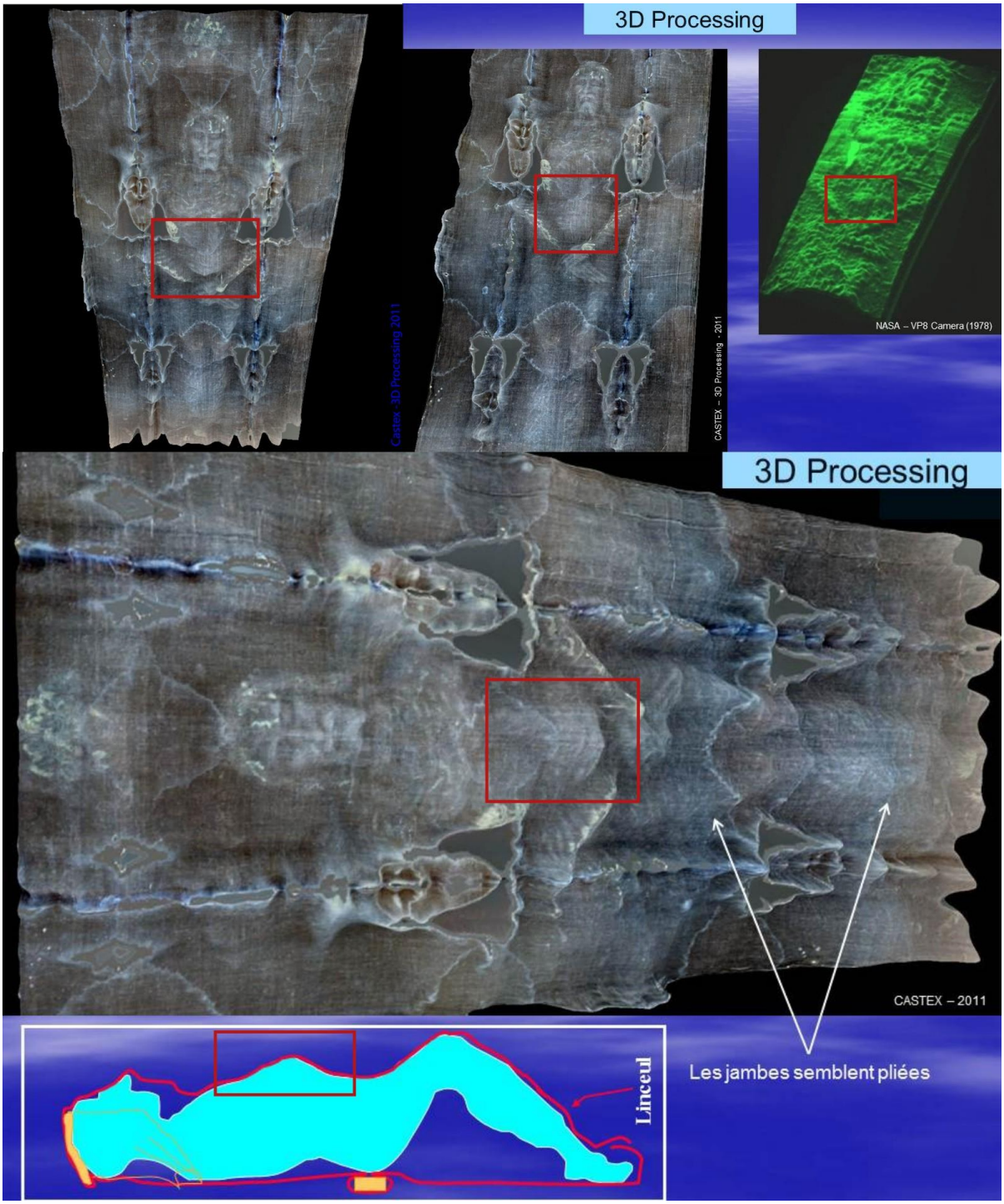


Figure 1. Composite of Thierry Castex-style 3-D processing supplied by the author. Red rectangles identify the lower-abdominal region in several processed views. The montage also includes a side-profile relief and a VP-8 comparison. Because Castex's method maps processed image amplitudes to calculated height, the apparent relief is illustrative of image-intensity structure and must not be treated as a CT-derived measurement of abdominal projection.

Source note. The montage was supplied by the author and incorporates 3-D image-processing outputs attributed to Thierry Castex. CIELT describes Castex's workflow as using filtered RGB image amplitudes, including work based on Gian Carlo Durante's 2002 photographs, followed by conversion of processed amplitudes into calculated heights. Reproduction permission should be confirmed with the relevant rights holder before journal publication.

This distinction is not a semantic technicality. Jackson, Jumper, and Ercoline (1984) reported a relationship between frontal image intensity and a body-shape/cloth-distance model, but they also emphasized lateral distortions associated with draping cloth and did not establish a universal rule by which any single pixel intensity equals anatomical height. Castex's filtering, dynamic equalization, deconvolution, and low-/high-frequency recombination further alter the signal before height conversion. A prominence that remains stable across independent photographs and across reasonable processing parameters is more persuasive than a prominence that appears only after one filter choice. Therefore, a quantitative abdominal claim should begin with raw or minimally processed intensity data and then test robustness across algorithms.

4. Historical Development of the Crucifixion-Asphyxia Model

4.1 LeBec, Hynek, Mödder, and the transition from theory to experiment

A.A. LeBec's 1925 physiological account is an important starting point because it explicitly proposed that elevated arms impaired respiration and displaced abdominal viscera. LeBec argued that the position immobilized the ribs, made expiration difficult, disturbed the abdominal viscera, and progressively compromised circulation and gas exchange. His description was mechanistically ambitious but not based on a controlled crucifixion experiment. Later writers frequently cited it as if the chain of events were established rather than hypothesized.

Rudolf W. Hynek connected the theory to observations of extreme suspension torture in which a subject's upper limbs were elevated and body weight was largely borne through the arms. He also reported radiographic observations that arm elevation and suspension altered diaphragmatic position. Hermann Mödder then performed a more concrete experiment in medical students suspended by bands around the wrists with the hands approximately one meter apart. As summarized by McGovern and colleagues, vital capacity fell markedly over the first several minutes, respiration became predominantly diaphragmatic, and cardiovascular and neurological effects developed. These experiments establish that severe wrist-hanging can profoundly alter respiratory mechanics. They do not establish that a Roman crucifixion posture with arms closer to horizontal, variable foot support, movement, pain, blood loss, and trauma produces the same trajectory.

This gap between wrist hanging and crucifixion is central. In modern clinical physiology, arm position changes ventilatory muscle recruitment because muscles of the shoulder girdle serve both postural and respiratory functions. But the effect is graded, not binary. The angle of the arms, degree of external support, foot loading, trunk inclination, and ability to shift position all change respiratory demand. A theory derived from near-vertical wrist suspension cannot be mechanically transplanted to every form of crucifixion without measuring these variables.

4.2 Barbet and the fixed-inspiration interpretation

Barbet synthesized LeBec, Hynek, and Mödder into the most influential medical narrative of crucifixion asphyxia. He argued that a sagging victim progressively lost the ability to expire, became fixed in an inspiratory position, and repeatedly pushed upward through the feet to obtain respiratory relief. The Shroud's thoracic and abdominal morphology was then read as the residue of this process: expanded upper chest, epigastric depression, and protruding lower abdomen. The interpretation had considerable explanatory appeal because it linked posture, blood-flow angles, respiratory mechanics, and image morphology into one scheme.

The weakness is that several links were inferred rather than directly measured. Barbet did not quantify abdominal surface displacement during suspension, and the classic experiments that showed severe ventilatory compromise used configurations not equivalent to cross suspension. Moreover, his final-state argument assumes that the posture at the last breath remained anatomically preserved through death, removal from the cross, and burial. That assumption intersects with rigor mortis and primary flaccidity and requires independent forensic justification.

4.3 Edwards and later medical reviews

Edwards, Gabel, and Hosmer's widely cited 1986 JAMA article reinforced a multifactorial model in which scourging caused substantial blood loss and crucifixion interfered with normal respiration, with hypovolemic shock and exhaustion-asphyxia contributing to death. Retief and Cilliers (2003) likewise emphasized multifactorial pathology but regarded progressive asphyxia as a major element. By contrast, Maslen and Mitchell (2006), after reviewing more than forty medical sources and the limited historical and experimental evidence, concluded that the evidence was insufficient to state exactly how Roman crucifixion victims died and that different methods and postures could produce different mechanisms.

The debate continues. Habermas, Kopel, and Shaw (2021) surveyed medical opinions and found asphyxia or asphyxia-dominant theories numerically common. McGovern, Kaminskas, and Fernandes (2023) challenged the inference that prevalence of an opinion equals evidential consensus, tracing the suffocation model back to a small cluster of mutually dependent sources and emphasizing that realistic cross-suspension experiments did not reproduce progressive hypoxemia. The present paper does not need to resolve this dispute. For abdominal morphology, the key point is narrower: altered diaphragm recruitment can occur even when oxygenation is preserved. Thus, the abdominal hypothesis need not stand or fall with suffocation as the cause of death.

5. What Experimental Cross Suspension Actually Shows

5.1 Zugibe experiments

Zugibe's volunteer studies are the most directly relevant experimental material because the subjects were positioned on a cross rather than simply hung from vertically elevated wrists. His apparatus permitted physiologic monitoring while healthy volunteers were suspended with wrist support and varying foot conditions. He observed marked cramping of the calf and thigh muscles, twitching, changes in posture, sweating, and substantial discomfort. With respect to breathing, the chest appeared relatively fixed and abdominal breathing became obvious after about four minutes, while respiratory rate increased to roughly two to three times normal. Subjects described the chest as somewhat rigid and their breathing as abdominal, with relatively short inspirations and longer expirations. Importantly, blood oxygen content did not fall; it often remained constant or rose slightly, consistent with hyperventilation rather than progressive suffocation.

This is a crucial discriminant. A fixed-looking chest plus diaphragm-dominant breathing is compatible with a mechanical shift in thoracoabdominal motion, but it is not equivalent to a lung fixed at maximal inspiration. The diaphragm can become the predominant pressure generator precisely because rib-cage inspiratory muscles are constrained by upper-limb posture. When the diaphragm contracts, it descends and raises abdominal pressure; if the abdominal wall yields, that pressure is expressed as anterior abdominal displacement. Thus Zugibe's data supply a direct bridge from crucifixion posture to the modern physiology of visible abdominal protrusion, even though his experiments undermine Barbet's particular asphyxia endpoint.

5.2 Ball and the limits of short experimental exposures

David Ball published crucifixion reconstructions in 1989 and later spirometric studies in 2008. His work is useful because it attempted to measure pulmonary function rather than infer it from appearance. However, as later reviewers note, volunteer experiments necessarily involve short durations, healthy subjects, straps rather than nails, controlled temperatures, absence of scourging and hemorrhage, and immediate termination when risk develops. They are therefore better at falsifying claims about immediate unavoidable respiratory failure than at reproducing the terminal physiology of a severely injured person after hours on a cross.

This asymmetry should inform interpretation. If healthy cross-suspended subjects rapidly adopt diaphragm-dominant breathing, that observation is relevant because it appears despite the model's mildness. If those same subjects do not develop fatal hypoxemia, one cannot conclude that a scourged, dehydrated, shocked victim would remain physiologically stable for hours. The safe conclusion is that altered respiratory recruitment is experimentally demonstrated; the time course to death is not.

5.3 Passive suspension and circulatory redistribution

Modern suspension-syndrome research provides a second, imperfect analogy. In randomized and ultrasound studies, passive harness suspension produces rapid lower-limb venous pooling, sluggish venous flow, and in some subjects presyncope. Rauch and colleagues found near-syncope in approximately 30% of suspension tests, with a late vagally mediated fall in heart rate and blood pressure in susceptible participants. These studies support the general proposition that prolonged vertical suspension redistributes blood volume and can destabilize circulation. They do not demonstrate abdominal swelling, and the harness posture differs greatly from crucifixion. They are therefore best treated as context for circulatory stress, not as evidence that the Shroud's abdomen records venous congestion.

The splanchnic circulation is a large capacitance bed and responds dynamically to hypovolemia, posture, autonomic activation, and respiration. Human experimental blood loss reduces splanchnic flow, and animal hemorrhage studies demonstrate mobilization of blood from abdominal reservoirs such as spleen, liver, and intestine. These responses argue against the simplistic assertion that hypovolemic shock should acutely enlarge the abdominal organs as a class. Depending on organ and hemodynamic state, volume may decrease, redistribute, or - in some shock states - become congested. No crucifixion-specific literature establishes generalized organomegaly as the cause of a protruding lower abdomen.

6. Modern Thoracoabdominal Physiology: How a Belly Can Protrude Without Enlarged Organs

6.1 The abdomen as a mechanically coupled pressure-volume compartment

The abdominal cavity behaves approximately as a hydraulically coupled compartment bounded superiorly by the diaphragm and anterolaterally by compliant muscular walls. Tzelepis and colleagues measured pressure

at multiple colonic sites during inspiration and expulsive maneuvers and found pressure changes to be nearly homogeneous along cephalocaudal and side-to-side axes, supporting a hydraulic model of abdominal mechanics. The practical implication is straightforward: when the diaphragm descends, it does not need to 'enlarge' the viscera to make the abdomen project forward. It adds downward pressure and displacement to a largely incompressible content volume. Where the boundary is most compliant, the wall moves.

The anterior abdominal wall is not passive. Rectus abdominis, obliques, transversus abdominis, intercostals, and diaphragm form a coordinated system that changes with posture, breathing, speech, exertion, and loading. In normal accommodation to an increase in gut volume, the diaphragm can relax while the anterior wall increases tone, limiting protrusion. Reverse that pattern - diaphragm contraction with anterior wall relaxation - and the same or nearly the same abdominal content can produce a conspicuous increase in girth.

6.2 Direct demonstration of diaphragm-driven pseudo-distension

The clearest experimental precedent predates the modern gastrointestinal literature. Tyrer, Murphy, and Emmerson (1958) studied two patients with dramatic non-gaseous abdominal distension and four healthy men able to reproduce the phenomenon voluntarily. They concluded that substantial diaphragmatic descent caused by sustained active contraction was the principal factor. The maneuver produced marked increases in abdominal girth and intra-abdominal pressure even without exaggerated lumbar lordosis. Although the clinical context was entirely unrelated to crucifixion, it directly proves the mechanical proposition needed here: active diaphragmatic descent can create a visibly enlarged abdomen without acute organ growth.

That result also clarifies the terminology. If a suspended victim uses the diaphragm more forcefully because rib-cage recruitment is constrained, and if abdominal-wall tone is reduced by exhaustion, pain, injury, neurological stress, or posture, the expected visible change is a redistribution of contour. Calling it 'swelling' is understandable at the level of appearance, but the more precise term is lower-abdominal protrusion or distension.

6.3 CT and EMG evidence for caudoventral redistribution

Accarino and colleagues (2009) used paired CT studies to quantify abdominal morphology during severe bloating. In patients with functional intestinal disorders, total abdominal content volume increased only modestly, yet the anterior abdominal wall moved forward by about 14 mm and the diaphragm descended by about 12 mm. The investigators described the process as caudoventral redistribution of contents. This is highly relevant as a physical analogy because it separates visible projection from increased contents. A change of more than one centimeter in surface contour can arise predominantly through internal redistribution and muscular coordination.

Subsequent studies identified the neuromuscular pattern. Villoria et al. (2011) induced standardized colonic gas loads while recording diaphragm and abdominal-wall electromyography. Compared with healthy controls, symptomatic subjects developed greater distension associated with paradoxical diaphragm contraction and relaxation of the internal oblique. Barba et al. (2015) extended the work using CT and EMG during spontaneous episodes in 45 patients. Distension involved diaphragm descent, altered intercostal recruitment, and anterior wall protrusion; biofeedback that reversed the abnormal muscle pattern reduced distension. A randomized placebo-controlled trial in 2017 and a newer thoracoabdominal-motion-guided randomized trial in 2024 showed that retraining the muscular pattern can substantially reduce visible distension. These interventions provide causal evidence: changing muscle recruitment changes abdominal contour.

A pooled objective evaluation of 139 patients by Barba et al. (2023) further strengthens the mechanism. Abdominal girth increased in 138 of 139 during symptomatic episodes. In the great majority, changes in intestinal gas were too small to account for the contour change. Diaphragm contraction was detected in nearly all subjects with valid diaphragm EMG, diaphragm descent was common on CT, and anterior abdominal-wall activity decreased in most subjects. Again, the clinical disorder is not a model of crucifixion; the value lies in demonstrating the anatomy and physics of visible protrusion.

6.4 Arm elevation shifts work toward the diaphragm

Upper-limb posture supplies an independent link to crucifixion. Several shoulder-girdle and thoracic muscles contribute both to arm positioning and to ventilation. During unsupported arm activity, part of this musculature is diverted to stabilize the upper limbs, changing the distribution of respiratory work. Celli, Criner, and Rassulo (1988) found that unsupported arm exercise in healthy subjects shifted dynamic ventilatory work toward the diaphragm and abdominal expiratory muscles. Couser, Martinez, and Celli (1992) then showed in 22 healthy subjects that simple arm elevation increased ventilation, tidal volume, oxygen

consumption, and heart rate. In the pressure-measured subgroup, end-inspiratory gastric and transdiaphragmatic pressures increased significantly, indicating greater diaphragmatic contribution.

These experiments involved arms elevated to shoulder level rather than nailed to a patibulum, and the subjects were seated and uninjured. Nevertheless, they demonstrate a general biomechanical principle: changing upper-limb support changes respiratory-muscle recruitment. Combined with Zugibe's observation of abdominal breathing during cross suspension, the evidence supports a coherent chain from upper-limb fixation to greater diaphragmatic work. The remaining unmeasured link is whether that change is large enough, and sufficiently sustained, to produce a measurable lower-abdominal projection in a crucifixion-like posture.

6.5 Generalizability of the analogical physiology

The gastrointestinal distension literature should not be treated as a clinical model of crucifixion. Many participants were patients with disorders of gut-brain interaction, and several cohorts were predominantly female. The inference used here is narrower and mechanical rather than diagnostic: active diaphragmatic descent raises abdominal pressure and displaces largely incompressible contents, while the degree and direction of visible wall motion depend on abdominal-wall recruitment and compliance. That relation is demonstrated not only in symptomatic patients but also in healthy volunteers capable of voluntary pseudo-distension, in pressure-transmission studies, and in independent respiratory experiments involving arm elevation. The convergence therefore supports a general human thoracoabdominal mechanism rather than transfer of a gastrointestinal disorder to a crucified subject.

What cannot be generalized from those studies is equally important. They do not establish the magnitude, frequency, or persistence of lower-abdominal projection in a severely traumatized male suspended for hours, nor do they establish the neuromuscular state at death. The analogical literature therefore establishes biomechanical plausibility and a directionally coherent mechanism; crucifixion-specific incidence and effect size remain empirical questions for the proposed suspension study.

7. A Mechanistic Model for Lower-Abdominal Protrusion During Crucifixion

The literature supports a more conservative mechanism than the common internet claim that 'crucifixion enlarges the organs.' A proposed sequence is as follows. First, upper-limb fixation and body loading alter the contribution of rib-cage and shoulder-girdle muscles to ventilation. Second, respiratory work shifts toward the diaphragm. Third, repeated forceful diaphragmatic contractions cause greater caudal excursion and raise intra-abdominal pressure. Fourth, prolonged pain, fatigue, trauma, posture, and variable neurological drive may reduce or dyscoordinate tonic contraction of the anterior abdominal wall. Fifth, the largely incompressible abdominal contents redistribute caudoventrally, increasing projection of the hypogastric/lower abdominal wall. Sixth, if this altered contour persists at or near death and is preserved sufficiently through removal and burial, the supine corpse may retain some corresponding morphology.

Each link has a different evidence level. Increased diaphragmatic contribution with arm elevation has controlled human data. Diaphragm-dominant breathing during cross suspension has direct observational data from Zugibe. Diaphragm descent plus wall relaxation producing visible distension has robust CT, EMG, pressure, and intervention evidence in other human contexts. The persistence of such a contour through death and burial has not been directly demonstrated. The model is therefore biologically coherent but incompletely validated.

The model also predicts regional rather than generalized swelling. A downward and anterior redistribution of contents should preferentially affect the lower anterior abdomen while the epigastrium may become relatively flattened or concave depending on rib-cage and diaphragmatic configuration. This regional pattern resembles the language used by Barbet and is more specific than saying the 'belly is swollen.' It is also testable with surface scanning and diaphragm imaging.

7.1 Evidence hierarchy

Table 1. Evidence streams relevant to the abdominal-contour hypothesis. The central methodological point is that the strongest evidence for the physical mechanism comes from independent physiology, while direct crucifixion studies have not yet measured the proposed morphological endpoint.

Evidence stream	Representative studies	What it supports	What it does not establish
Direct Shroud observation	Barbet 1953/1963; Zugibe 2005	Lower abdomen has been described as protruding or slightly bulging by medically oriented investigators.	Cause of the contour; magnitude in millimeters; authenticity.
Cross-suspension physiology	Zugibe 2005; Ball 2008	Relative chest fixation, early diaphragm-dominant/abdominal breathing, postural shifting.	Inevitable asphyxia; direct measurement of abdominal projection.

Evidence stream	Representative studies	What it supports	What it does not establish
Arm-elevation physiology	Celli et al. 1988; Couser et al. 1992	Upper-limb loading can increase diaphragmatic contribution and ventilatory demand.	Magnitude under crucifixion trauma and multi-hour exposure.
Abdominal mechanics	Tyrer et al. 1958; Accarino et al. 2009; Villoria et al. 2011; Barba et al. 2015, 2023, 2024	Diaphragm contraction/descent plus abdominal-wall relaxation can visibly increase girth without organ enlargement.	That crucifixion necessarily produces the same neuromuscular state.
Suspension hemodynamics	Rauch et al. 2019, 2020	Passive suspension can cause rapid venous pooling and circulatory instability.	Abdominal organ enlargement or Shroud contour.
3-D image analysis	Jackson et al. 1984; Castex/CIELT; Moraes 2026 and commentary	Shroud intensity contains structure that can be converted into relief under specified assumptions.	Direct anatomical topography independent of the chosen mapping/processing model.
Posture and cadaver orientation	Beillas et al. 2009; Howes et al. 2013; Takazakura et al. 2004	Changing the gravity vector can substantially alter diaphragm and abdominal-organ position; postmortem tissues remain highly orientation-sensitive.	That a suspension-derived abdominal contour survives the specific transition to supine burial.
Postmortem forensics	Bedford and Tsokos 2013; Pirch et al. 2013; Krompecher 1981	Rigor timing is variable; instantaneous rigor/cadaveric spasm is controversial.	Automatic preservation of the final respiratory posture at the moment of death.

8. Why “Enlarged Organs” Is Not the Best-Supported Explanation

The literature search conducted for this review identified no controlled crucifixion study showing that crucifixion acutely enlarges the abdominal organs in a manner expected to create visible lower-abdominal bulging. The claim is therefore too strong. Organ enlargement has specific pathophysiological meanings. Acute hepatic congestion can enlarge the liver in right-sided heart failure or venous obstruction; splenic volume can change rapidly because the spleen is a blood reservoir; bowel loops can distend with gas or fluid; the bladder can enlarge with urine; and intraperitoneal fluid can distend the abdomen. None of those phenomena can simply be inferred from the fact of crucifixion.

The hemodynamics of severe trauma and hemorrhage actually complicate the enlargement idea. During acute hypovolemia, sympathetic activation tends to preserve central perfusion by reducing flow to several splanchnic territories and mobilizing venous reservoir volume. In healthy volunteers, removal of approximately 900 mL of blood reduced cardiac output and splanchnic and renal flow. Animal studies show substantial blood mobilization from spleen, liver, and intestine during hemorrhage. These responses do not exclude localized congestion in a particular terminal state, but they contradict a generic expectation that blood loss should make the abdominal viscera collectively larger.

8.1 Selective visceral volume changes: possible but non-specific

Rejecting generalized organomegaly does not mean that every abdominal organ must retain an unchanged volume during terminal trauma. The liver can enlarge acutely in particular states of venous congestion; splenic volume is labile because the spleen is a contractile blood reservoir; bowel can dilate with gas or fluid; and the urinary bladder can enlarge with retention. Such processes are physiologically conceivable, but each requires its own antecedent mechanism and cannot be inferred merely from suspension or crucifixion.

They also have weak anatomical specificity for the feature under review. Hepatic congestion primarily affects the right upper abdomen, splenic volume change the left upper quadrant, and bowel or bladder distension would generate different distributions depending on the involved structure. Any of these could contribute to overall abdominal contour in an individual case, but none presently predicts the combination most relevant to Barbet's description: relative epigastric depression with a central lower-abdominal or hypogastric prominence. Selective visceral change should therefore remain in the differential diagnosis rather than serve as the default explanation.

Ascites is likewise a poor default explanation. Zugibe specifically considered and rejected a hypothesis in which abdominal effusion accounted for the 'blood and water' phenomenon, noting that it did not fit the wound and abdominal configuration. More generally, clinically important free intraperitoneal fluid does not usually arise within a few hours merely from suspension. Severe trauma could cause internal bleeding, but an intraperitoneal hemorrhage large enough to alter contour would require injuries not independently established by the Shroud image.

Postmortem gas is another differential diagnosis but is temporally problematic for a burial shortly after death. Putrefaction eventually produces marked gaseous bloating and can even mimic abnormal body rigidity, but forensic decomposition literature places this in a later decompositional process rather than an immediate consequence of death. Early postmortem CT can show gas and transudates within hours under some conditions, yet the gross bloated stage is distinct from the early fresh postmortem interval. A Shroud scenario

involving removal and burial within hours therefore should not invoke putrefactive abdominal bloating without additional evidence.

The parsimonious terminology for the feature under review is consequently 'lower-abdominal protrusion' or 'visible lower-abdominal distension.' This describes what is at issue without presupposing the internal cause. The mechanistic hypothesis then becomes a question of diaphragmatic displacement, wall tone, posture, and content redistribution rather than speculative organ pathology.

9. Postmortem Transition: The Critical Missing Link

9.1 A Shroud image is postmortem evidence

Any crucifixion physiology hypothesis faces a temporal discontinuity. Respiratory mechanics operate while the victim is alive. The Shroud, if it wrapped a corpse, records the body after death, removal from the cross, transport, manipulation, and placement supine. A contour generated actively by diaphragmatic contraction during life might diminish when muscle tone ceases. Therefore, the phrase 'frozen in maximal inspiration' cannot be accepted without examining the postmortem behavior of skeletal muscle and the diaphragm.

Ordinary death is followed by primary muscular flaccidity and later rigor mortis as ATP depletion locks actin-myosin interactions. Rigor does not normally preserve every active contraction from the final instant of life. Its onset and progression depend strongly on temperature, exertion, metabolic state, muscle type, and other conditions. Experimental animal work demonstrates that full rigor may develop over hours and that temperature markedly shifts the time course. Extreme exertion before death can plausibly accelerate postmortem biochemical depletion, but that does not prove instantaneous whole-body fixation in a respiratory pose.

9.2 Cadaveric spasm is controversial

The forensic concept of cadaveric spasm or instantaneous rigor has historically been invoked to explain bodies apparently retaining an action at death. Modern forensic literature is divided and often skeptical. Bedford and Tsokos (2013) argued that cadaveric spasm is a myth. Pirch, Schulz, and Klintschar (2013) analyzed an unusual upright corpse and concluded that the position was mechanically stable without instantaneous rigor; their report emphasizes that apparent preservation of posture can be misleading. Other authors continue to defend rare cases, and a 2025 drowning case revived the debate. The responsible conclusion is not that instantaneous fixation is impossible, but that it is too controversial to carry a major Shroud argument without additional evidence.

For the abdominal hypothesis, the consequence is substantial. The most defensible version does not require the exact respiratory phase of the final breath to be frozen. A lower-abdominal contour could instead reflect a combination of baseline body habitus, prolonged pre-death loading, residual postural configuration, early rigor developing after the body was repositioned, and the way linen draped over the supine abdomen. But because these factors are not yet separated quantitatively, the appearance cannot be used as a simple timestamped snapshot of physiology at death.

9.3 Gravitational reconfiguration from suspension to supine burial

The postmortem problem is not limited to loss of muscle tone. It also involves a major change in the direction of gravity relative to the body. During suspension, the torso is predominantly upright or oblique and gravity acts along the long axis, favoring caudal loading of mobile abdominal contents. In a supine burial configuration, the same gravitational vector acts primarily posteriorly relative to the anterior abdominal wall. Positional MRI in living subjects confirms that this is not a trivial geometric change: Beillas, Lafon, and Smith (2009) found that the supine posture displaced solid abdominal organs by as much as 39 mm in their nine-subject dataset, and Takazakura et al. (2004) demonstrated significant posture-dependent differences in diaphragmatic excursion between sitting and supine positions.

Cadaver data make the problem still more explicit. Howes, Hardy, and Beillas (2013) instrumented two unembalmed postmortem human surrogates and quantified abdominal-organ position under different orientations. Their upright-to-inverted comparison was a 180-degree rather than a crucifixion-to-supine transition, so it is not a direct model of burial. Nevertheless, it demonstrated pronounced gravity sensitivity after death: diaphragm-marker displacement ranged from 99 to 121 mm and liver-marker displacement from 71 to 192 mm between orientations. The authors attributed the exaggerated positional dependence in part to postmortem loss of active musculature. These measurements show that a corpse cannot be assumed to retain the visceral geometry of the position in which death occurred.

Early postmortem imaging likewise documents rapid internal change. In a CT-autopsy comparison of 30 cadavers, Charlier et al. (2012) found normal abdominal postmortem modifications related to livor mortis and putrefactive change within hours. That study did not quantify anterior abdominal surface projection and therefore cannot determine whether a crucifixion-derived contour would persist, but it reinforces the principle that the early corpse is mechanically and radiologically dynamic rather than a frozen copy of the living body.

The diaphragm itself should therefore not be conceptualized as a piston that simply remains fixed in its last active position. Its dome geometry depends on lung volume, abdominal pressure, thoracic configuration, muscle activation, and the gravitational loading of the viscera. Once active contraction ceases, a caudally displaced inspiratory configuration has no demonstrated mechanism that would preserve it unchanged through removal, handling, and supine placement. A viable Shroud hypothesis must instead show either that a regional contour survives these changes, that passive supine redistribution recreates a similar contour, or that early rigor develops after repositioning in a geometry that retains the relevant surface relationship. Those alternatives are experimentally distinguishable.

10. Interpreting Three-Dimensional Shroud Relief

10.1 What Jackson, Jumper, and Ercoline established

Jackson, Jumper, and Ercoline's 1984 Applied Optics study remains the key peer-reviewed technical reference for the relationship between Shroud intensity and three-dimensional body geometry. They reported that the frontal image was consistent with a naturally draping cloth over a body shape in the sense that image shading could be represented by a global mapping of cloth-body distance. They also tested several image-formation classes and discussed characteristic distortions expected from draping. Whatever one concludes about mechanism, this work shows why Shroud intensity cannot be treated as ordinary photographic shading.

At the same time, the study does not justify treating every intensity-derived relief as a unique reconstruction of the corpse. The mapping depends on assumptions about image formation and cloth geometry. Lateral distortions, cloth contact, pressure independence, and discontinuities all matter. A lower-abdominal 'hill' in a VP-8 or modern rendering may correspond to a genuine regional intensity structure while still differing in height and shape from the anatomical abdominal wall.

10.2 Castex processing: strength and limitation

Castex's approach uses modern signal-processing tools familiar from geophysical imaging. CIELT describes suppression of the herringbone weave by filtering, dynamic equalization of bands and streaks, spectral deconvolution to recover high-frequency detail, processing of RGB components, and subsequent conversion of filtered low-frequency amplitude into calculated height with a high-frequency color texture superimposed. The approach is valuable for revealing subtle image structure across large areas of the cloth and for comparing frontal and dorsal data. It also introduces a chain of processing operations, each with parameters that can affect local contrast and therefore the apparent relief.

For the abdominal question, the correct scientific use of Castex's output is hypothesis generation. The red-boxed region in Figure 1 identifies an area that should be measured in the underlying images. A robust result would demonstrate the same relative prominence in independent photographs, before and after periodic-weave suppression, across multiple reasonable equalization and deconvolution settings, and using algorithms not based on Castex's specific pipeline. Without such a sensitivity analysis, the relief cannot serve as a direct anatomical measurement.

10.3 Linen drape, bridging, and apparent abdominal relief

A burial cloth is a flexible mechanical surface, not a transparent shell that reproduces every depression and prominence of the skin beneath it. Between regions of contact, linen can bridge unsupported spans; local curvature depends on bending stiffness, in-plane tension, weave orientation, friction, gravity, folds, and the geometry of nearby contact points. Consequently, the surface profile of the cloth over the abdomen can differ from the actual profile of the abdominal wall even before any image-formation process is considered.

This is particularly relevant to the lower abdomen because the Shroud frontal image places the forearms and hands across the lower torso and pelvic region. Depending on the actual three-dimensional arrangement, those structures could support, tension, or redirect the linen and alter the transition between epigastrium, hypogastrium, and pelvis. A cloth-generated convexity need not imply an equally convex skin surface, just as a true body convexity need not be reproduced with its original amplitude on the cloth.

The point is already implicit in the Shroud image-geometry literature. Jackson, Jumper, and Ercoline modeled image intensity in relation to cloth-body distance and discussed distortions associated with draping. Moraes (2026) went further by explicitly simulating fabric dynamics and contact patterns; the interpretation of his low-relief comparison has been challenged by Casabianca, Marinelli, and Piana, but the methodological dispute does not remove the basic requirement to model fabric-body geometry. For the abdominal hypothesis, therefore, textile transfer is an independent stage of the causal chain and must be tested rather than treated as a negligible overlay.

10.4 The current digital-image debate

The need for caution is underscored by current peer-reviewed debate. Moraes (2026) used digital human models, fabric simulation, and contact-area mapping and concluded that a low-relief representation better reproduced certain Shroud contours than direct wrapping around a full 3-D body. Casabianca, Marinelli, and Piana (2026) published a commentary arguing that the reconstruction omitted important features and did not substantiate the low-relief conclusion; Moraes replied that his study was methodological and focused on projection deformation. The exchange is useful here because it shows that image geometry remains contested even with modern 3-D tools. A paper about one anatomical contour should therefore report the contour conditionally, not use 3-D visualization as if the image-formation problem were already solved.

11. Differential Explanations for the Apparent Abdominal Contour

A strong forensic interpretation must compare alternatives. At least seven explanations are compatible with some degree of lower-abdominal prominence. First, normal body habitus can produce a convex hypogastrium, particularly when the abdominal wall is relaxed supine. Second, prolonged diaphragm-dominant breathing before death may redistribute contents caudoventrally. Third, upper-limb suspension and trunk sag can alter spinal curvature and abdominal wall geometry. Fourth, hand and forearm placement over the pelvis can change local linen drape and visual boundaries. Fifth, postmortem muscle flaccidity followed by rigor can reshape the torso after removal from the cross. Sixth, cloth-body distance and draping can encode a contour that differs from the true body surface. Seventh, intensity filtering and height conversion can amplify a low-frequency regional gradient.

Additional pathological explanations - ascites, internal hemorrhage, acute bowel distension, bladder distension, organ congestion, and early decomposition - are possible in principle but require positive evidence. Their mere medical possibility does not make them good explanations. The most valuable next step is not to choose a favorite mechanism by visual inspection but to quantify the feature and compare explicit predictions of these alternatives.

12. Does the Abdominal Feature Strengthen an Authenticity Argument?

The abdominal observation is potentially interesting in authenticity discussions because it is not a conventional iconographic emphasis. Barbet's rhetorical point was that a forger who intentionally encoded subtle crucifixion physiology would require unusual anatomical knowledge. That argument becomes stronger if the feature is (a) objectively present in minimally processed data, (b) quantitatively predicted by crucifixion physiology, (c) uncommon in ordinary supine bodies and medieval artistic representations, and (d) difficult to produce accidentally through cloth drape or the image-forming method. At present, those conditions have not all been demonstrated.

In particular, one should avoid a knowledge-only fallacy. The evidential question is not simply whether a medieval maker possessed an explicit theory of diaphragmatic mechanics. A person can reproduce an anatomical appearance without understanding its cause. A hypothetical maker could copy a living model, a corpse, an earlier representation, or a physical imprinting process; alternatively, cloth drape or image formation could generate a contour that no maker consciously designed. Thus the relevant comparison is between complete generative pathways, not between modern physiology and medieval textbook knowledge.

The iconographic premise also requires measurement rather than impression. This review did not perform a quantified survey of medieval crucifixion images, effigies, burial representations, or other supine figures, so it cannot establish how rare the relevant abdominal configuration actually was. A stronger historical test would preregister anatomical landmarks and a lower-abdominal/epigastric profile metric, score a temporally defined corpus blind to provenance, and compare the distribution with the Shroud. Such a study would distinguish genuine morphological rarity from selective attention to a feature after it has already been noticed on the Shroud.

For the abdominal feature to become materially probative, the target should also be more specific than generic convexity. The strongest candidate would be a compound quantitative signature: the relative amplitude and position of epigastric depression, hypogastric projection, adjacent thoracic contour, and pelvic transition, shown to be stable across minimally processed Shroud photographs. That measured signature would then need to occur more frequently under realistic suspension-to-postmortem-to-linen experiments than in ordinary supine controls, artistic low-relief controls, and alternative cloth-drape conditions. Only such differential likelihood would support the claim that the feature carries independent evidential weight.

The appropriate evidential language is therefore conditional. The lower-abdominal contour is compatible with a genuinely suspended/crucified body and has a plausible mechanistic explanation that was not obvious in medieval anatomical theory. It is not, by itself, a diagnostic marker of crucifixion or an independent proof of antiquity. Its value lies in the fact that the hypothesis can now be tested with methods unavailable to Barbet and Zugibe.

13. Proposed Experimental Program

13.1 Study A: quantify the Shroud feature before interpreting it

The first study should be purely image-analytic. A preregistered region of interest should extend from the xiphoid/epigastric region to the pubic area, with lateral boundaries defined by reproducible torso landmarks. Measurements should be performed on the best available independent photographic datasets, including images with different acquisition histories. The primary endpoint should be a lower-abdominal projection index defined from raw or minimally processed image intensity relative to adjacent epigastric and pelvic reference regions. Because the absolute intensity-to-distance law is uncertain, the primary analysis should emphasize within-image normalized profiles rather than assert millimeter body height.

The same images should then be processed through several families of methods: a Jackson-style global distance mapping, a Castex-style filtered/equalized intensity-to-height mapping, generic shape-from-intensity approaches, and control transformations with deliberately varied filter settings. The analysis should report whether the location and relative amplitude of the abdominal prominence remain stable. A feature that disappears when a narrow Fourier notch, equalization window, or low-frequency cutoff is changed is not a robust anatomical signal.

Controls should include ordinary photographs, bas-relief images, anatomically realistic 3-D human models, and linen draped over bodies or mannequins. The goal is not to prove one image-formation mechanism but to determine how frequently a comparable lower-abdominal relief can arise from ordinary shading, contact, drape, low relief, and algorithmic processing. This directly addresses specificity.

13.2 Study B: ethical crucifixion-position suspension physiology

A second study can test the physiological mechanism without nailing or injuring subjects. Healthy adult volunteers could undergo short, carefully monitored suspension/postural trials using padded wrist/forearm supports and adjustable foot loading. A randomized crossover design would compare arms near horizontal, moderately elevated, and more elevated; feet fully supporting, partially supporting, and minimally supporting; and neutral versus sagging trunk configurations. Exposures should remain brief, with conservative termination criteria and independent medical oversight.

The primary morphological endpoint should be change in anterior lower-abdominal surface projection measured by 3-D optical scanning or validated markerless photogrammetry. Secondary endpoints should include diaphragm excursion by ultrasound, rib-cage and abdominal motion by respiratory inductance plethysmography, surface EMG of rectus and oblique muscles, intercostal EMG, spirometry before and immediately after exposure, oxygen saturation, end-tidal CO_2, heart rate, and blood pressure. Where ethically justified, noninvasive estimates of inspiratory pressure or gastric pressure surrogates could be included. The key predicted correlation is that increased diaphragmatic excursion and reduced anterior-wall activity should track increased lower-abdominal projection.

This design would answer a question that, among the classic crucifixion studies identified in this review, was not directly measured. It would also distinguish two competing models. A Barbet-style maximal-inspiration model predicts a particular combination of thoracic expansion, epigastric depression, and hypogastric projection that worsens with loading. A simpler diaphragm-dominant breathing model predicts abdominal projection without requiring progressive hypoxemia or complete thoracic fixation. Continuous oxygenation and capnography could discriminate these mechanisms in real time.

13.3 Study C: postmortem and cloth-drape transfer

A third stage must address the gap between living posture and a burial cloth. Anatomical mannequins with deformable abdominal compartments, high-fidelity cadaver models, or ethically available postmortem donors could be positioned first in experimentally defined suspension-derived geometries and then supine under linen. Optical scans of the body before and after repositioning, together with cloth-surface photogrammetry, would quantify how much lower-abdominal shape survives the transition and how much additional contour is introduced by fabric bridging and hand placement. The textile arm of the experiment should vary and report linen bending stiffness, in-plane pre-tension, weave orientation, surface friction, moisture condition, fold geometry, and hand/forearm support, because each can alter the relationship between skin topography and cloth topography. If cadaveric work is not feasible, finite-element modeling of the diaphragm-abdominal-wall system and cloth drape can be validated first against living-subject surface scans.

The crucial outcome is not whether a model 'looks like the Shroud' to an observer. It is whether prespecified, numerical abdominal and epigastric profiles converge on the same relationship seen in the Shroud across independent datasets. This avoids circular reconstruction.

13.4 Falsifiable predictions

The hypothesis would gain support if four predictions are met: (1) a statistically stable lower-abdominal intensity prominence exists across independent Shroud photographs and preprocessing choices; (2) suspension conditions that increase diaphragmatic contribution produce a reproducible increase in lower-abdominal projection in living subjects; (3) the measured change covaries with diaphragm excursion and inverse abdominal-wall tone rather than with gas or organ volume; and (4) enough of the contour persists, or is recreated by supine cloth drape, to reproduce the Shroud's regional profile. It would be weakened if the prominence is algorithm-dependent, if realistic suspension does not alter abdominal projection, if the direction of displacement is opposite the Shroud profile, or if ordinary cloth drape generates the same feature at high frequency in controls.

14. Limitations

The direct literature is sparse. No surviving Roman medical dataset records abdominal morphology of crucified victims, and archaeological remains cannot preserve soft-tissue contours. Modern reenactments are necessarily short and humane, use straps instead of nails, and involve healthy volunteers without scourging, dehydration, blood loss, fear, and prolonged pain. Analogies from functional abdominal distension demonstrate a mechanical possibility rather than a crucifixion-specific disease process. The gastrointestinal studies often involve women and patients with disorders of gut-brain interaction, whereas the Shroud image depicts an adult male; however, the relevant finding - that diaphragm descent and wall relaxation can redistribute contents and increase girth - is a general biomechanical principle, not a diagnosis-specific claim.

The Shroud itself poses independent uncertainties. Its chronology, image-formation mechanism, cloth-body configuration, and some anatomical interpretations remain disputed. Three-dimensional renderings depend on assumptions that are not universally accepted. The Castex montage examined here is a processed representation rather than raw instrumental topography. The present paper therefore cannot establish the absolute magnitude of abdominal protrusion on the Shroud.

Finally, the postmortem transition is underdetermined. The literature does not demonstrate that a crucified person's active respiratory contour would be preserved unchanged after death. Positional MRI and cadaver-orientation data further show that a change in the gravity vector can materially alter visceral and diaphragmatic geometry. Rigor mortis may begin earlier after severe exertion, but instantaneous preservation of the final breathing phase is not established. This limitation prevents the abdominal contour from being used as a straightforward diagnostic fingerprint of terminal asphyxia.

15. Conclusions

The literature supports a narrower and more scientifically defensible claim than the popular statement that crucifixion causes enlarged abdominal organs. Pierre Barbet described a protruding lower abdomen on the Turin Shroud and explained it through his fixed-inspiration asphyxia model. Frederick Zugibe, while rejecting that model, independently described a slight bulging of the abdomen and directly observed that cross-suspended volunteers shifted rapidly toward abdominal, diaphragmatic breathing while their chests appeared relatively fixed. Controlled studies of arm elevation independently show increased diaphragmatic contribution when upper-limb posture recruits shoulder and thoracic musculature.

The strongest mechanistic evidence comes from modern thoracoabdominal physiology. Sustained diaphragmatic contraction can cause visible pseudo-distension; CT studies show that diaphragmatic descent can drive caudoventral redistribution of abdominal contents with more than a centimeter of anterior wall protrusion despite little increase in total content; EMG studies identify the combination of diaphragm contraction and abdominal-wall relaxation; and randomized biofeedback trials show that changing this muscular pattern changes abdominal girth. This provides a robust physiological basis for the proposition that visible abdominal protrusion need not imply gas accumulation, ascites, or organomegaly.

Applying that mechanism to crucifixion is plausible but not yet demonstrated. This review identified no crucifixion experiment that directly measured lower-abdominal surface displacement. If the Shroud image derives from contact or spatial relation with a corpse, the relevant morphology is that of a postmortem body in a predominantly supine burial configuration; the transition from active respiratory mechanics to postmortem morphology therefore introduces major uncertainty. Positional MRI and postmortem cadaver experiments show that changing orientation can substantially redistribute the diaphragm and abdominal organs, so the suspended geometry cannot be assumed to survive the transition to supine burial. Rigor mortis does not automatically preserve the final respiratory pose, and instantaneous rigor remains controversial. In addition, intensity-derived 3-D Shroud relief is model-dependent and must be validated against minimally processed photographs.

Accordingly, the abdominal feature should be treated as a promising, falsifiable forensic-anatomical hypothesis. It may ultimately add to a cumulative argument about the Shroud if it proves robust, quantitatively concordant with realistic suspension physiology, and uncommon in appropriate controls. At present, the scientifically strongest statement is that the apparent lower-abdominal protrusion is compatible with a mechanically stressed, diaphragm-dominant thoracoabdominal state such as can arise in suspension, but it is neither an established consequence unique to crucifixion nor, by itself, sufficient to justify an inference that a hypothetical medieval image-maker deliberately encoded advanced knowledge of suspension physiology.

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