

Rechtsmedizin 2025 · 35:173–178
<https://doi.org/10.1007/s00194-025-00754-8>
 Accepted: 26 March 2025
 Published online: 6 April 2025
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Changes in the position of the abdominal organs of a corpse between postmortem computed tomography performed in the supine and sitting positions—A feasibility study

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Abstract

Postmortem computed tomography (PMCT) is an established technique that complements and guides conventional autopsies. Clinical computed tomography (CT) and postmortem CT (PMCT) are usually performed in a supine position. Car crashes, gunshot and stabbing incidents concerning forensic questions occur in different body positions and during movement. Whether and to what extent the anatomic topography of a corpse shifts due to supine positioning in postmortem CT is poorly understood. The positioning of anatomic structures between a standing or a sitting person and supine PMCT is especially important for the assessment of forensic and biomechanical questions. To investigate this effect, a male corpse of average height and weight was positioned on a radiolucent seat constructed from polystyrene panels. Afterwards, the corpse and the seat were positioned in a flat panel computed tomography used for industrial purposes. The generated data were compared with the dataset of the PMCT of this corpse performed in a (usual) supine position. Comparing the craniocaudal length from T1 to different organs, the largest increase (2.9 cm in distance) was found for the liver by scanning the corpse in a sitting position compared to the supine PMCT. Additionally, when the distance to the right kidney was measured, a clear increase in the measured distance of 2.4 cm was observed and smaller changes were observed on the organs of the left side of the body (0.3 cm when measuring to the left kidney). In this first comparison between a PMCT performed with the corpse in sitting and supine positions with the aim of detecting organ displacement, it was shown that there are clear displacements with an emphasis on the right organ side.

Keywords

PMCT · Organ shift · Sitting CT · Stab channel · Motor vehicle accident



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Introduction

Postmortem computed tomography (PMCT) is an established technique that complements and guides conventional autopsies [9–11]. Especially in trauma cases, such as traffic accidents, PMCT provides superior sensitivity compared to a conventional autopsy in detecting skeletal lesions,

which in turn are utilized for the purpose of the biomechanical reconstruction of accidents.

Clinical computed tomography (CT) and postmortem CT are usually performed in a supine position, mainly because of the needs of clinical medicine [3, 14] and the geometry of computer tomographs, whereas traffic accidents occur at all kinds



Fig. 1 ◀ **a, b** Corpse in a sitting position on the constructed styrofoam seat in front of the X-ray source on a rotating table (**b**) and with the flat panel unit behind (**a**)

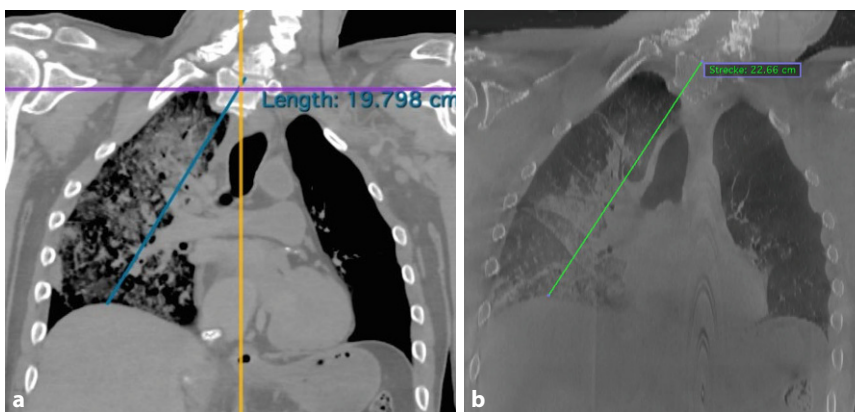


Fig. 2 ▲ **a** Multiplanar reconstruction (MPR) of the PMCT in a supine position and measurement of the length between the upper edge of the liver and T1 of 19.8 cm. **b** Multiplanar reconstruction (MPR) of the PMCT in a sitting position and measurement of the length between the upper edge of the liver and T1 of 22.7 cm

of positions, especially when passengers of vehicles are involved. Therefore, the topographic changes between the supine and prone positions in PMCT need to be taken into account and evaluated. The difference between a supine and prone position during a clinical examination has also already been demonstrated for clinical purposes, for example in ureterolithiasis [13].

There are studies assessing the movement of thoracic organs in living patients, e.g., during breathing [5, 15], between supine and prone positions [1, 8] or between sitting and lying in magnetic resonance imaging (MRI) [7, 17]. Whether and to what extent the anatomic topography shifts due to supine positioning in PMCT is poorly understood. This is especially important for the assessment of gunshot and

stab channels as well as for the simulation of traffic accidents.

Material and methods

After ethics committee approval, conventional PMCT in the supine body position of a male corpse with average body dimensions (length 180 cm, weight 78 kg, body mass index, BMI 24.1 kg/m²) was performed (64-row multidetector CT, helical pitch, voltage 120 kV, current 240 mAs, 0.625 collimation, pitch 1, layer thickness 1.25 mm) exactly 24 hours postmortem. The rigor mortis was at a detectable maximum.

To position the body, a radiolucent seat was constructed from four commercially available polystyrene panels, each measuring 100 × 10 × 50 cm. Styrofoam was chosen because of its material properties

as it is radiolucent and does not cause artifacts during imaging. The seating had a height of 43 cm, a depth of 30 cm and a width of 40 cm. The back of the seat was constructed with an inclination of 100° to facilitate positioning of the corpse. A back-rest inclination of 100–110° corresponds to an average car driver's seat [6]. After the fabrication of the seat, the corpse was fixed in the required position with metal-free tension belts (■ Fig. 1).

Afterwards, the corpse on the seat was positioned in a flat panel CT used for industrial purposes. The interval between the conventional supine (sup) PMCT and sitting (sit) PMCT was 17 hours. Tomographs were obtained with an X-ray tube with a power of 180 kV and 800 μA current at an exposure time per image of 250 ms. The entire trunk (thorax and abdomen) was scanned. This area is composed of seven scan planes in height and three scans in width. This resulted in 21 single scans with 1800 images each with a total scan time of approx. 155 min in fast scan mode.

The generated data were compared with the data of the PMCT performed in a supine position. The middle of the upper edge of the front edge of the 1st thoracic vertebra (T1) was defined as the reference point for the measurements. The distances to the upper edge (highest point) of the liver, the left diaphragmatic dome, the right and left kidneys and the splenic hilus were subsequently measured.

The DICOM dataset of the supine PMCT was reconstructed in a 3D-MPR (multiplanar reconstruction) in the OpenSource software "Horos" (free open-source code soft-

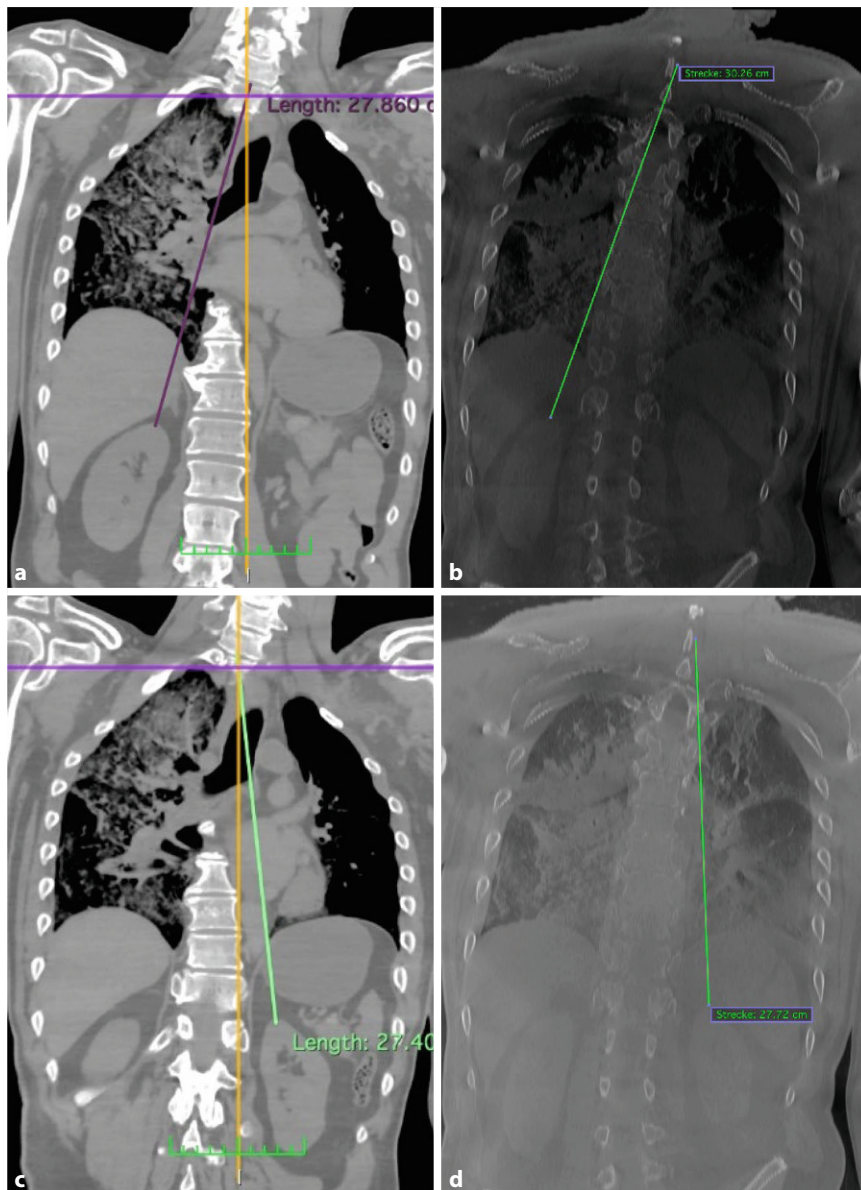


Fig. 3 ▲ **a** MPR of the PMCT in a supine position and measurement of the length between the upper edge of the right kidney and T1 of 27.9 cm. **b** MPR of the PMCT in a sitting position and measurement of the length between the upper edge of the right kidney and T1 of 30.3 cm. **c** MPR of the PMCT in a supine position and measurement of the length between the upper edge of the left kidney and T1 of 27.4 cm. **d** MPR of the PMCT in a sitting position and measurement of the length between the upper edge of the left kidney and T1 of 27.7 cm

ware (FOSS) program, distributed free of charge under the LGPL license at Horosproject.org and sponsored by Nimble Co LLC d/b/a Purview in Annapolis, MD, USA). The extremely large dataset of the sitPMCT of approx. 52 GB was processed with another appropriate computer with sufficient random access memory (RAM=working memory). The software “Materialise Mimics” was used for this large dataset. Furthermore, the determination of the fixed point

and measuring distances was influenced by the different layer thicknesses between supPMCT (1.25 mm) and sitPMCT (overlapping single scans with a flat panel detector).

Results

The datasets of the supPMCT and sitPMCT were processed by two different forensic specialists and forensic biomechanics. The

largest increase in distance was found between the fixed point of T1 and the upper edge of the liver. In the supine position (supPMCTA), the distance was 19.8 cm, and in the sitting position (sitPMCT), the distance was 22.7 cm. Therefore, the change in position resulted in an increase in distance of 2.9 cm (see ■ Fig. 2a, b) from the supine position to the sitting position. Additionally, when the right kidney was measured, an increase in the measured distance of 2.4 cm was observed (■ Fig. 3a, b; ■ Table 1).

Smaller changes were observed on the left side of the body. The spleen moved 0.7 cm downward between the supPMCT and the sitPMCT (see ■ Table 1) and the left kidney was seated 0.3 cm more distally than it was in the supine position (■ Fig. 3c, d). Here, a distance of 27.4 cm was measured between the fixed point at T1 and the upper edge of the left kidney in the supPMCT image and 27.7 cm in the sitPMCT image. On the other hand, no change could be discerned when the distance from the first thoracic vertebra to the left diaphragmatic dome was measured at 22.5 cm in both, the supPMCT and the sitPMCT.

It has to be noted that the rigor mortis was broken in the large joints of the extremities when the corpse was placed on the polystyrene chair. All the results can be seen in ■ Table 1.

Discussion

In a flat panel CT the entire volume of an object is examined by X-raying it from all sides. The X-ray source emits a cone beam, which is detected with a flat panel detector. This allows a volume model to be generated directly. However, this is technically complex and expensive. This device is normally used for testing material properties [12]. Due to the horizontal beam path and the open device structure, this device offers enough space to position a corpse in a sitting position. A lying scan was not possible. As a result, a conventional PMCT was performed in a clinical CT scanner. This involves moving an electromotive table, on which the patient or the object to be examined lies, through the gantry [18]. The radiation source rotates around the body, whereas with flat-panel

Table 1 Overview of the measured distances between the upper anterior edge of the T1 vertebral body and the upper edge of the organ or the splenic hilus

Organ	supPMCT	sitPMCT	Difference Δ (supPMCT to sitPMCT)	Measurement increase from supPMCT to sitPMCT?
Liver	19.8 cm	22.7 cm	+2.9 cm	Yes
Spleen	28.4 cm	29.1 cm	+0.7 cm	Yes
Right kidney	27.9 cm	30.3 cm	+2.4 cm	Yes
Left kidney	27.4 cm	27.7 cm	+0.3 cm	Yes
Left diaphragm	22.5 cm	22.5 cm	0.0 cm	No

CT the body rotates on a turntable and the radiation channel remains fixed.

It was not possible to carry out both scans in one device for spatial reasons within the design.

Organs in living humans shift during breathing and between different body positions. Many (clinical) studies, mainly for radiotherapy, have focused not only on the effect of a breathing cycle but also on organ changes between the supine and prone positions [7, 8, 15, 16, 19, 21]. In addition to the lungs, the liver is especially affected by position changes [4]. This information is important for clinical radiologists. However, in postmortem CT the effect of breathing is irrelevant. There are conditions that are not necessarily comparable to those of radiological imaging in living patients. Body changes such as rigor mortis and putrefaction, must be considered instead.

Furthermore, additional circumstances such as the onset or release of rigor mortis, particularly internal rigor mortis of the diaphragm and external rigor mortis of the trunk muscles as well as the position of the corpse when rigor mortis occurs, could also influence the measurement results.

In order to evaluate whether and to what extent these postmortem changes affect the intra-abdominal position of the organs, we carried out a feasibility study, initially with a corpse.

In our postmortem study an increase in the craniocaudal distance was observed in almost all organs measured when the corpse was placed in a sitting position after being measured via supine PMCT. Only the left diaphragm dome remained unchanged in its location in relation to the measured distance. In particular, the right-sided organs, liver and right kidney were

clearly affected by a change in position of +2.9 cm (liver) and +2.4 cm (right kidney) in a sitting position compared with the supPMCT. It seems likely that this is caused by the downward pull of the liver, which weighed 1455 g in this case and on average approximately 1600 g [2]. As the right kidney also shows a similar extension of the measuring distance between the fixed point at T1 and the upper edge of the kidney, this could indicate that the change in position of the liver also influences the right kidney, although it appears to be well protected by a fat capsule. In the present case the fat capsule was average strongly developed seen during autopsy.

The data published by Hayes et al. 2013 [7] were recorded on a (living) volunteer. In their study, the same organs were assessed, also in a lying and sitting position but via MRI. This research seems to be a suitable comparison to our results. They measured a craniocaudal increase in the liver of +1.95 cm from the supine position to the sitting position, which is less than our result. There was also a change in the position of the right kidney of +1.70 cm after the volunteers' position changed from (lying) MRI to upright MRI. In comparison, the direction of the organ shift seems similar for the right-sided organs. In our study, the organs of the left side of the body (spleen and left kidney) were clearly less displaced (+0.3 cm left kidney; +0.7 cm spleen) in the caudal direction after sitting up. Compared with the results of Hayes et al. [7] these results differ significantly as the organs of the left side of the body in the living individuals in their study wandered towards the cranium and not in the caudal direction after they sat up. In our case, rigor mortis was fully developed in the large and small joints. This can have

a significant influence on the extent of the change in position. Due to the rigidity of the diaphragm, movement of the organs can be considerably restricted, in contrast to a living person.

It seems that postmortem changes in the body have a large influence on the outcome of this experiment. The consequences of not observing organ position changes on PMCT could be significant. In forensic cases of stab wounds, for example, the question of the length of the stabbing canal is regularly part of the forensic medical report in court. This assessment is important to include or exclude a possible weapon presented during a trial. However, if the stab canal is misinterpreted due to organ displacement in the case of a condition after organ penetration, this can have serious consequences. The extent to which the change in position of the organs is (predominantly) influenced by gravity and the influence of postmortem changes such as rigor mortis, is not yet known. It is also possible that the effects are mutually amplifying.

Dynamic conditions prevail both in traffic accidents, with or without the use of seat belts, and in gunshot and stabbing injuries. These are influenced both by the movement of the person and by the kinetic energy of the object (car, motorcycle, projectile, knife, or sharp object).

It is thus clear that this research approach can have direct relevance to everyday forensic medicine. However, further studies with corpses of different sizes, statures, rigor mortis and decomposition status need to be conducted to comprehensively shed light on the issue of postmortem organ displacement between seated and supine positions of the corpse. This issue could of course also affect bodies in a standing position, as gravity also acts on the abdominal organs in this case. It is unclear whether there is a difference between the sitting and standing position with respect to this topic.

Until a study is carried out with different corpses, this study can be taken as an indication of the corresponding changes.

Limitations

First, the 3D-MPR (multiplanar reconstruction) in the OpenSource program Horos was used to create a congruence for the supPMCT. Particular difficulties included finding not only the agreed fixed points on the organs but also the previously defined fixed points in the middle of the front of the upper edge of the first thoracic vertebra. Therefore, the measurements are not completely precise, when a CT-graphic measuring point is not an absolute fixed point, such as the upper pole of the kidney.

It should be also taken into consideration that the datasets of the supPMCT and sitPMCT were processed by two different staff members. This was caused mainly by the extremely large dataset of the sitPMCT image and the computer needed, which was not accessible to us. Furthermore, the determination of the fixed point and the measuring distances was influenced by the different layer thicknesses between supPMCT (1.25 mm) and sitPMCT (overlapping single scans with a flat panel detector). It is difficult to estimate the user-related measurement inaccuracy, which is probably in the range of a very few millimeters.

The influence of strapping the corpse onto the styrofoam seat, created to ensure a continuously upright body position during the scanning time of approximately 2.5 hours, is unknown. This could also have an influence on the measured lengths.

Another limitation is the corpse itself. The corpse was without any signs of putrefaction but gas and hypostasis could have an unknown effect on the body. In the present case, a male corpse of average length and weight was measured. However, different person-specific body characteristics, such as body and abdominal fat or surgery, scars and adhesions in the chest and abdominal areas, could affect changes in suspected organ movements and measured distances. In traffic medicine, car crashes and computer simulations are often performed for an average European male [20]. The corpse used in this experiment was also a male with average attributes. However, it should be noted that this corpse represents only a small part of the population, especially women and children are not represented. Espe-

cially in children the position might be even more crucial.

Conclusion

In this first comparison between a PMCT performed with the corpse in a sitting and a supine position with the aim of detecting organ displacement, it was shown that there are clear displacements with an emphasis on the organs of the right body side. The organs on the left side of the body showed no or only relatively small extensions in the measurement path. Overall, however, many other influences on the corpse as well as on the measurement data and distances must be investigated to be able to make a reliable statement regarding the influence of the position of the corpse during postmortem imaging on shifts in the internal organs. Therefore, further research is needed regarding the influence of rigor mortis, joint position, body size and weight on the shifts in organs between the sitting and supine positions.

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Funding. Open Access funding enabled and organized by Projekt DEAL.

Data availability. The dataset will be made available on request.

Declarations

Conflict of interest. G.M. Bruch, J. Mühlbauer, N. Pfeiffer, M. Mayerhöfer, M. Graw and F.T. Fischer declare that they have no competing interests.

For this article no studies with human participants or animals were performed by any of the authors. All studies mentioned were in accordance with the ethical standards indicated in each case.

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Lageänderungen der Bauchorgane einer Leiche in der postmortalen Computertomographie zwischen liegender und sitzender Position – Eine Machbarkeitsstudie

Die postmortale Computertomographie (PMCT) ist eine etablierte Technik, welche die konventionelle Obduktion ergänzt und begleitet. Die klinische Computertomographie (CT) und die PMCT werden in der Regel in Rückenlage durchgeführt. Autounfälle, Schuss- und Stichverletzungen, die forensische Fragen aufwerfen, ereignen sich in verschiedenen Körperpositionen und während Bewegungen. Ob und inwieweit sich die anatomische Topografie eines Leichnams durch die Rückenlage bei der PMCT verschiebt, ist kaum bekannt. Die Position anatomischer Strukturen zwischen einer stehenden oder sitzenden Person und der PMCT in Rückenlage ist besonders wichtig für die Beurteilung forensischer und biomechanischer Fragestellungen. Um diesen Effekt zu untersuchen, wurde eine männliche Leiche von durchschnittlicher Größe und Gewicht auf einem röntgendurchlässigen Sitz aus Polystyrolplatten positioniert. Anschließend wurde die Leiche auf dem Sitz in einem Flachbild-Computertomographen positioniert, der für industrielle Zwecke verwendet wird. Die erzeugten Daten wurden mit dem Datensatz der PMCT dieser Leiche in (üblicher) Rückenlage verglichen. Beim Vergleich der kranial-kaudalen Länge von BWK1 zu den verschiedenen Organen wurde die größte Organverschiebung (2,9 cm) bei der Leber festgestellt, wenn die Leiche im Sitzen gescannt wurde, verglichen mit der PMCT in Rückenlage. Des Weiteren wurde bei der Messung der rechten Niere eine deutliche Zunahme des gemessenen Abstands von 2,4 cm festgestellt, während bei den Organen der linken Körperhälfte geringere Veränderungen (0,3 cm bei der Messung zur linken Niere) zu beobachten waren. In diesem ersten Vergleich zwischen einer in sitzender und liegender Position durchgeführten postmortalen CT mit dem Ziel, Organverschiebungen festzustellen, wurde gezeigt, dass es deutliche Verschiebungen mit Schwerpunkt auf der rechten Organseite gibt.

Schlüsselwörter

PMCT · Organverschiebung · CT sitzend · Stichkanal · Kraftfahrzeugunfall