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RESEARCH ARTICLE

Virtopsy: Experimental study of measurement tolerances in the pro-cessing and post-processing system of biomodels for forensic appli-cations.

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Abstract

Virtopsy, an innovative non-invasive post-mortem imaging technique, offers a new approach to forensic examination. Howe-ver, the accuracy of measurements obtained from 3D models reconstructed from CT scans is significantly influenced by the technical characteristics of the scanners employed. This study as-sessed the impact of two different-generation CT scanners on measurement variability, highlighting how each scanner introduces a "characteristic error". The results emphasize the need for standardized acquisi-tion protocols and the development of correction methods to ensure the reliability of digital evidence in forensic investigations. The ultimate goal is to promote the acceptance of virtopsy as a valid and reliable tool in forensic medicine.

Introduction

The post-mortem examination, a cornerstone of forensic investigations, has undergone a pro-found evolution in recent decades thanks to the integration of increasingly sophisticated tech-nologies. Among these, virtopsy has emerged as an innovative technique that, leveraging the po-tential of medical imaging, allows for a non-invasive and detailed analysis of the cadaver. [1]
While virtopsy's origins can be traced back to the early applications of radiological imaging in fo-rensics in the early 20th century [2], it was with the advent of multi-slice computed tomography (CT) and the subsequently magnetic resonance imaging (MRI) that virtopsy acquired its current characteristics, enabling a three-dimensional and highly detailed visualization of internal tissues. [3]
The evolution of CT scanners has led to a progressive increase in spatial and temporal resolution, allowing for the acquisition of increasingly sharp and detailed images. In parallel, the develop-ment of increasingly sophisticated three-dimensional reconstruction software has made it possi-ble to create extremely realistic virtual anatomical models, on which precise measurements and quantitative analyses can be performed. [4]
Despite these advancements, the accuracy of measurements obtained from 3D models can vary depending on the technical characteristics of the equipment used. This variability poses a signifi-cant challenge to the reliability of Virtopsy in forensic applications. For instance, an overestima-tion of bone fracture size could lead to misinterpretations of the force involved ina trauma, po-tentially influencing the reconstruction of a crime scene. Inaccurate measurements of projectile trajectory angles could lead to incorrect conclusions about the position of the shooter. Such dis-crepancies can lead to miscarriages of justice, either by wrongly implicating an individual or by failing to identify the actual perpetrator. In legal proceedings, where digital evidence from vir-topsy is increasingly presented, the reliability of these measurements is paramount. Inaccurate measurements can undermine the credibility of such evidence and compromise the integrity of the judicial process.
This study aimed to: 1) quantify the measurement variability introduced by two different CT scanners; 2) identify characteristic errors associated with each scanner; and 3) discuss the impli-cations for standardization in virtopsy. Study aims to evaluate the impact of these differences on measurement accuracy by analyzing the results obtained from two CT scanners of different gen-erations.
Virtopsy finds application in numerous contexts, including:

- Cases of violent death: It allows for the documentation and quantification of internal and external injuries, contributing to the reconstruction of the dynamics of the event by providing detailed information about the nature and extent of injuries without the need for invasive procedures.

- Mass disasters: It facilitates the identification of bodies and the assessment of the causes of death on a large scale by allowing for rapid and systematic scanning of numerous in-dividuals, aiding in disaster victim identification and cause of death determination.
- Cases of sudden death: It can provide useful information for differential diagnosis and the exclusion of criminal causes by revealing potential natural causes of death, such as cardiac anomalies or pulmonary embolisms, without requiring a traditional autopsy.
- Cases of suspicious death: It allows for the documentation of the state of the cadaver before any traditional autopsy, preserving potential evidence and allowing for a more informed decision regarding the necessity and extent of further invasive procedures.

Materials and Methods

Samples A single object with a regular shape (Truncated Octahedron Matrix) was chosen for this study (5). The object was created via 3D printing using polylactic acid (PLA) filament (Figure 1). The dimensions of the truncated octahedron can be seen in the first column of Table 1. A regular geometric shape was chosen to minimize the influence of complex surface morphologies on measurement variability. This simplified the analysis by isolating the impact of the CT scanners themselves, rather than the complexities of the object's shape. Furthermore, the regularity of the shape allowed for precise and reproducible measurements using traditional tools (caliper) for comparison.

of the sample with respect to the X-ray beam was ensured in both scans.

Equipment The CT scans were performed on two different devices:

- Siemens Somatom Definition Flash 128-slice at "Lorenzo BONOMO" Hospital in Andria.
- Toshiba 64-slice at the PTO in Trani.

Acquisition Protocol Different combinations of scan parameters were tested. The best results, in terms of image quality and minimizing artifacts, were obtained using the sequential technique with the following parameters:

- kVp: 80
- mA: 50
- Rotation time: 0.5 s
- Slice thickness: 0.5 mm

Reconstruction and Post-processing The acquired data was reconstructed using the proprietary software of the respective devices. Subsequently, the reconstructed volumes were imported into the 3D Slicer software for three-dimensional visualization (Figure 2).

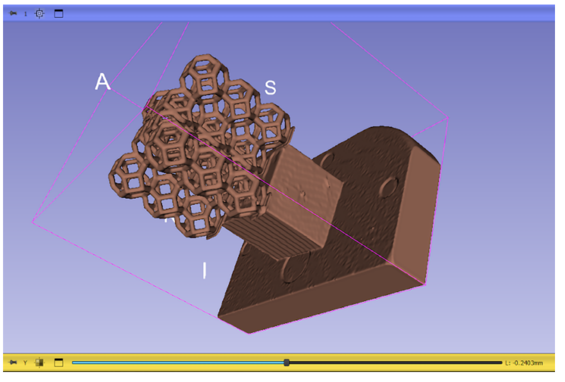
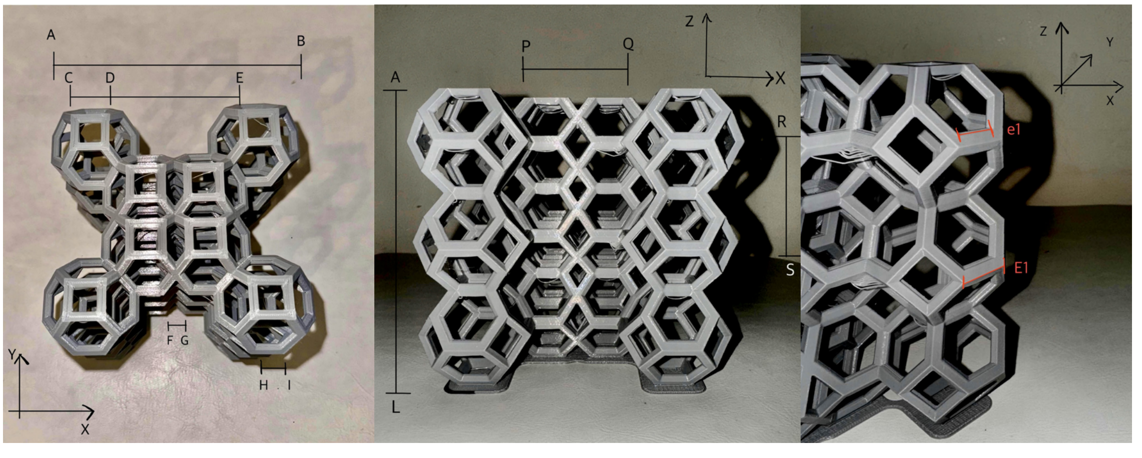


Figure 2. *Reconstruction on "3D Slicer"*



Figures 1, 2, and 3. *Starting object with the relative reference segments.*

Sample Positioning To ensure reproducibility of the acquisitions, the object was positioned inside the gantry of the two CT scanners using the centering lasers as a reference. In this way, the same orientation

Finally, the models were exported in STL format and processed with Autodesk Meshmixer for 3D printing preparation (Figure 3).

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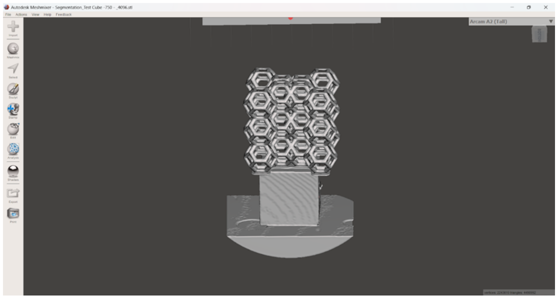


Figure 3. *Reconstruction on "Autodesk Meshmixer"*

In conclusion, the 3D printing process was initiated to obtain the two reconstructed models (Fig-ure 4).

Data analysis. To evaluate the accuracy of the measurements obtained with the two CT scanners, a comparative analysis was conducted on 3D and physical models. Linear measurements were performed on 3D models obtained from CT scans using the 3D Builder software. To ensure the objectivity of the analysis, the measurements were performed double-blind by two experts. (Ta-ble 1) The same measurements were replicated on the original physical models and those recon-structed using a caliper. (Table1)

Figure 4. *3D printed models.*

Table 1. *Collection of measurements with double-blind investigation on "3D Builder" software*

segments	ORIGINAL MODEL	RECONSTRUCTION A	RECONSTRUCTION B	RECONSTRUCTION A	RECONSTRUCTION B
		Refertatore 1		Refertatore 2	
	/	HU -800 +4096		HU -800 +4096	
AB	115,2	113,87	114,76	114,54	113,94
CD	17,2	16,94	16,58	17,57	16,55
DE	55,7	55,93	56,18	56,25	56,29
FG	6,9	8,84	9,35	6,96	7,09
HI	9.(	6,96	6,64	9.01	9,23
AL	107,1	108	106,49	105,82	103,62
PQ	33,2	31,76	35,44	34,17	33,31
RS	35.2	34,41	34,76	35,67	34,51
e1	10,5	8,79	7,82	8,25	8,94
E2	13,9	14,86	13,2	15,08	15,02

segments	ORIGINAL MODEL	3D PRINTED MODEL A	3D PRINTED MODEL B
		HU -800 +4096	
AB	115,2	116,1	116,1
CD	17,2	17,3	18,1
DE	55,7	57,4	56,3
FG	6,9	6,9	6,4
HI	9	9.2	9,3
AL	107,1	108,7	108,7
PQ	33,2	32,8	32,8
RS	35,2	34,9	35,1
e1	10,5	9,1	8,6
E2	13,9	14,8	14,3

Table 2. *Measurements collected with a vernier caliper.*

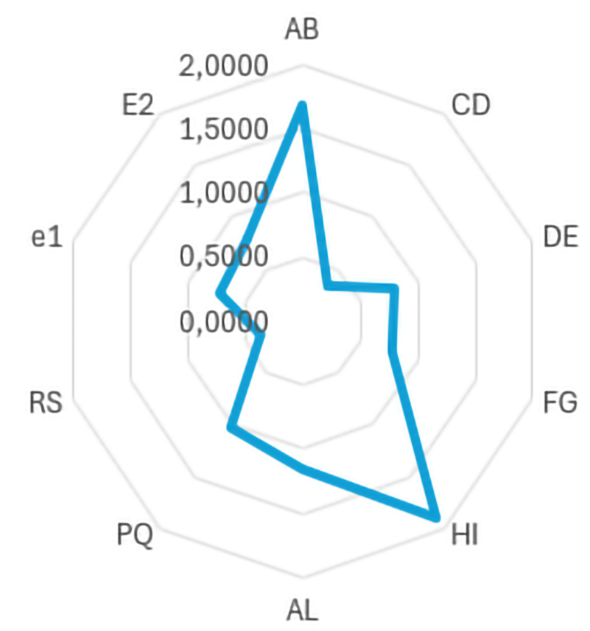
Statistical analysis: The collected data were analyzed using descriptive and inferential statistics to quantify the measurement error associated with each device and to evaluate the agreement between virtual and physical measurements. The statistical analysis was performed using Mi-crosoft Excel.

Results

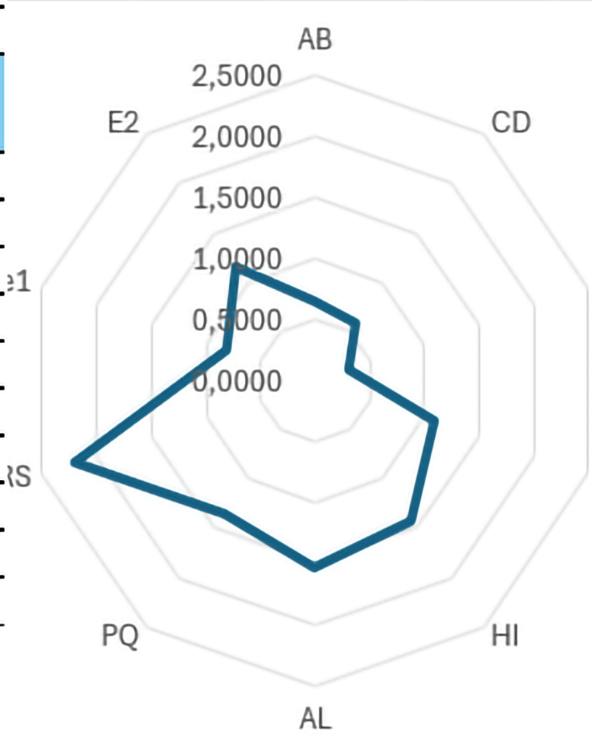
The data analysis revealed a significant variability in the obtained measurements, as demonstrat-ed by the values of the root mean square deviation. This indicator, which quantifies the disper-sion of data relative to the mean value, allows us to assess the reliability and precision of the measurements.
Table 3 and 4 present the mean measurements, standard deviations, confidence intervals, and the results of the statistical tests for each dimension measured. For example, measurements ob-tained from the Siemens scanner showed a mean difference of X mm compared to the physical model, while measurements from the Toshiba scanner showed a mean difference of Y mm.

Tables 3 and 4. *Root Mean Square Deviation of the two reconstruction models and reference graphs.*

RECONSTRUCTED MODEL A	
SEGMENTS	Root Mean Square Deviation
AB	1,6746
CD	0,3422
DE	0,8049
FG	0,7864
HI	1,8909
AL	1,1481
PQ	1,0224
RS	0,3704
e1	0,7198
E2	0,7930



RECONSTRUCTED MODEL B	
SEGMENTS	Root Mean Square Deviation
AB	0,6609
CD	0,5870
DE	0,2981
FG	1,0932
HI	1,4183
AL	1,5302
PQ	1,3586
RS	2,1999
e1	0,8222
E2	1,1629



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Discussion

The results of this study highlight how the accuracy of measurements obtained from 3D models used in virtual autopsies is significantly influenced by the intrinsic characteristics of the CT scanners employed. Each scanner exhibits a "characteristic error" that can introduce varia-tions in the dimensions and shapes of the reconstructed models, underscoring the importance of accurately characterizing each individual device. For example, the observed X mm difference in “AB” segment obtained from the Siemens scanner compared to the physical model could be crit-ical in determining the actual size in that axis during reconstruction of events. This highlights the need for caution when interpreting Virtopsy data obtained from different CT scanners. Similar-ly, the Y mm difference observed with the Toshiba scanner in “RS” segment could have implica-tions for the same reason.

This study has several limitations. First, we used a single object with a regular geometry. Future studies should investigate the performance of a wider range of CT scanners and evaluate the impact of object shape and material composition on measurement accuracy. Second, we only evaluated two CT scanners. While these scanners represent different generations of technology, the findings may emphasize the importance of considering the technological peculiarities of each CT scanner when interpreting forensic data and open up new perspectives for the development of more rigorous quality standards in this field. The integration of this knowledge into legal sys-tems represents a complex but necessary challenge to ensure the acceptance of digital evidence obtained through virtual autopsies in court

To ensure the reliability of digital evidence and its admissibility in legal proceedings, it is es-sential to define rigorous protocols for data acquisition, reconstruction, and measurement, in order to minimize inter-observer and inter-equipment variability. The development of mathe-matical models capable of correcting the distortions introduced by individual scanners repre-sents a crucial challenge for the future of virtual autopsies.

References

1. *Hayakawa M, Yamamoto S, Motani H, Yajima D, Sato Y, Iwase H. Does imaging technology overcome problems of conventional post-mortem examination? A trial of computed tomography imaging for postmortem examination. Int J Legal Med. 2006 Jan;120(1):24-6. doi: 10.1007/s00414-005-0038-x. Epub 2005 Oct 12. PMID: 16220318.*
2. *Krantz P, Holtås S. Postmortem computed tomography in a diving fatality. J Comput Assist Tomogr. 1983 Feb;7(1):132-4. doi: 10.1097/00004728-198302000-00024. PMID: 6826832.*
3. *Badam RK, Sownetha T, Babu DBG, Waghray S, Reddy L, Garlapati K, Chavva S. Virtopsy: Touch-free autopsy. J Forensic Dent Sci. 2017 Jan-Apr;9(1):42. doi: 10.4103/jfo.jfds_7_16. PMID: 28584475; PMCID: PMC5450483.*
4. *Fedorov A., Beichel R., Kalpathy-Cramer J., Finet J., Fillion-Robin JC., Pujol S., Bauer C., Jennings D., Fennessy FM, Sonka M., Buatti J., Aylward SR, Miller JV, Pieper S., Kikinis R. 3D Slicer as an image processing platform for quantitative imaging network. Magnetic reso-nance imaging. November 2012;30(9):1323-41. PMID: 22770690. PMCID: PMC3466397.*
5. *Truncated Octahedron Matrix by Toddard is licensed under the Creative Commons – Attribution license. https://www.thingiverse.com/thing:2383494*

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