Virtopsy: A Review on Non-Invasive Imaging Approach in Forensic Autopsy

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Abstract

Virtopsy, or virtual autopsy, is a major technological development in forensic science and has emerged as a practical alternative and supplement to conventional postmortem examinations in the digital era. It relies on advanced imaging methods, such as computed tomography (CT), magnetic resonance imaging (MRI), and other radiological tools, to examine the human body and assist in determining the cause of death. By avoiding surgical dissection, virtopsy can shorten the examination time and support a more precise, systematic, and non-invasive assessment of the deceased. This approach proved especially useful during the COVID-19 pandemic, when traditional autopsies carried a higher infection risk because of direct contact with the body. In such situations, virtopsy enables detailed postmortem evaluation while significantly reducing exposure to forensic staff. Although conventional autopsy is still regarded as a reliable and well-established procedure, the addition of modern imaging modalities through virtopsy offers improved visualization of internal structures and body cavities compared to conventional autopsy. The generated digital images and datasets can be stored, revisited, and presented as robust forensic evidence in legal proceedings. Overall, virtopsy functions as a promising adjunct to traditional autopsy, strengthening medico-legal examinations and supporting the integration of digital evidence within forensic practice.

Keywords – Virtopsy, Imaging techniques, Medico-legal evidence, Noninvasive.

1. Introduction

Forensic science is an interdisciplinary field that uses scientific methods and logic to answer legal questions in particular cases of physical injury, violence and unexplainable or suspicious death (9). The most important aspect of forensic medicine is autopsy, which is a systematic postmortem examination intended to explain the cause of death, manner of death (10) and

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circumstances of death. Traditional autopsy has always been gold standard in forensic pathology, but extremely invasive, permanent and commonly provokes ethical, cultural, religious, and occupational issues. (4)

The latest advancements in medical imaging and digital technology have led to the creation of a new non-invasive approach to postmortem examination called virtopsy (also known as virtual autopsy). Virtopsy uses radiological methods, including postmortem computed tomography (PMCT), postmortem magnetic resonance imaging (PMMRI), three-dimensional surface scanning, and computer-aided reconstruction, to evaluate the external and internal characteristics of the body without necessarily opening it (13). The mix provides the opportunity to visualize injuries and anatomical structures in detail and at the same time maintain the physical integrity of the remains.(8)

Some of the ethical and practical advantages of virtopsy are enhanced acceptability in the community with cultural or religious aversions toward dissection, enhanced occupational safety of forensic workers, and long-term digital security of medico-legal evidence. This was especially observed during the COVID-19 pandemic, when a direct contact with potentially infectious bodies had to be minimized. Virtopsy provides important diagnostic data in such environments reducting of biohazard exposure (5). Nonetheless, virtual autopsy will not be able to entirely supplant the traditional methods, particularly when histopathology or toxicology is needed. Rather, it must be viewed as a supplementary technique that, when used in conjunction with traditional autopsy, increases the accuracy of diagnoses, the strength of its evidence, and the ethical soundness of modern forensic practice.

1.1. Background of the study

Virtopsy or virtual autopsy is a technique of postmortem examination developed in the late 1990s as a safer and less invasive alternative to postmortem examination. Professors Richard Dirnhofer and Michael Thali of the University of Bern in Switzerland first proposed the idea in modern imaging could be used to minimize the amount of dissection (4). The method uses CT scans, MRI, and surface scanning to analyze the body in a detail without making physical contact.

Virtopsy has its origins in the use of X-rays by forensic biologists as a successor to the original use of X-rays to evaluate skeletal and cranial injuries in the 1970s (13). Cross-sectional imaging with the assistance of computer processing has transformed into three-dimensional visualization of internal organs, fractures,and patterns of injuries over the years (12). This has

given forensic experts the opportunity to record trauma more accurately and have a permanent digital record that they can revisit or revisit in court.

The role of virtopsy was further enhanced during the COVID-19 pandemic as it minimized the chances of infection of medical and forensic personnel due to the minimal amount of direct contact with the dead. Overall, one can say that virtopsy is indicative of a more general idea of transferring forensic pathology to less risky, more objective and digitally aided approaches to the examination, yet is still co-located with the traditional autopsy to create a complete picture of the cause and manner of death.

1.2. Research problem

Traditional postmortem investigations still utilize conventional autopsy as the main technique of postmortem investigation. Nevertheless, it is intrusive, time-consuming and can be resisted by families or a communities based on religious, cultural or ethical reasons (9). Moreover, when handling open bodies ,forensic staff are exposed to biohazards and other work hazards and manual dissection may at times alter or destroy delicate evidence.

Virtopsy is a non-invasive alternative with a relatively lower risk owing to the high-quality imaging technology that can aid in the visualization of internal structures and injuries. Although it has several benefits, virtopsy has practical and technical issues, such as extreme cost of equipment, specialized training and infrastructure, and poor performance under certain soft-tissue assessments (10). The current research aims at to provide insight into the ability to incorporate virtopsy into conventional autopsy to enhance the accuracy and safety in forensics, and simultaneously highlight and discuss the current limitations of the technology.

1.3. Purpose of the study

The primary aim of this study was to assess the use of virtopsy as a supportive measure in forensic investigations as opposed to being a full substitute for traditional autopsy (4). This study analyzes its effectiveness, advantages and weaknesses in comparison to conventional postmortem techniques. The diagnostic value of PMCT and PMMRI is considered in the context of various medico-legal situations.

The other objective is to investigate ways in which the use of virtopsy alongside traditional autopsy methods can enrich accuracy, safety, documentation, and medico-legal effectiveness (12). Through a literature review, this study aims to demonstrate how a hybrid method

combining traditional dissection with current imaging can retain evidence, avoid any form of cultural or religious sensitivities, and enhance the quality of the investigation.

1.4. Relevance and value of the research

This paper highlights the growing importance of virtopsy as a recent advancement in forensic science. Compared to conventional autopsy, virtopsy employs a non-invasive imaging method to examine internal structures, which is highly beneficial when physical dissection is prohibited or unacceptable because of ethical, cultural, or religious reasons. The preservation of the body is usually followed by greater acceptance by family members and society. Meanwhile, high-resolution digital imaging enables objective recording of evidence, which is capable of storage, exchange, and reassessment, thus facilitating transparency and reproducibility of medico-legal practice.

The area of application in this study involves the use of virtopsy in a vast variety of forensic cases, including trauma examination, mechanical asphyxia, drowning, death by extreme temperatures, or illness. Its use in mass disasters and other large-scale health events is also factored in, where rapid and secure evaluation of several victims is required, and physical contact can be extremely biohazardous. Virtopsy allows virtual and remote consultations with specialists in other regions and leads to the standardization of digital processes. Virtopsy can be used as a complementary approach, instead of a stand-alone substitute, to enhance the quality of evidence and assist in the process of judicial procedures, even in regions with low forensic infrastructure development.

2. Brief explanation in terms of methodology

The systematic review method was applied in this study to understand the notion of virtopsy and its recent application in forensic research. The research work was not performed based on the original laboratory work or case work but rather on the vast review of literature on virtual autopsy that has been conducted previously. Four key academic publications were selected because they included much information concerning the historical evolution, technical context, and practical implementation of virtopsy in medico-legal practice.

Among the literature discussed and analyzed through a qualitative content analysis approach, review papers, case reports, and historical overviews are mentioned. A discussion of all the sources was conducted to analyze the application and outcomes of techniques such as PMCT and PMMRI and compare them to the results of classic autopsy (13) (4). This comparative

reading supported the definition of pros and cons and reliability issues related to virtopsy as a forensic instrument.

More emphasis was placed on the latest digital tools, such as three-dimensional reconstruction and finite element analysis (FEA), which are essential in trauma imaging and comprehending its characteristics. As no primary data sources were applied, all the findings were derived based on previous studies and the experience at hand.

3. Literature Review

3.1. Review of previous studies

The development of virtopsy and the increased application of imaging in forensic practice have been influenced by many researchers.(4)Dirnhofer et al were one of the first to document the use of computed tomography in postmortem examination when they computed tomography to look at gunshot wounds to the head. This initial effort proved that cross-sectional imaging could show ballistic damage that cannot be easily identified by mere surface inspection.

The term virtopsy was coined later by Thali et al. (13), who proposed the practical application of multi-slice CT (MSCT) and MRI in postmortem studies. Their analysis of nearly 40 cases treated imaging findings in a comparative manner with traditional autopsy data. They demonstrated that fractures and some soft-tissue injuries were especially well identified using virtopsy. Dirnhofer et al. (4) also highlighted the benefits of the minimally invasive postmortem techniques particularly where full autopsy was not acceptable.

Bolliger et al. (1) presented reviews of different virtopsy projects and outlined how virtual autopsy creates a connection between radiology and forensic medicine enhancing documentation and analysis by providing digital records. Later articles, including that of Zou et al. (15), provide a summary of the use of virtopsy in various cases, including blunt and sharp injuries, asphyxial deaths, and disease-related deaths. Injury mechanisms were also discussed in these studies using FEA. Kumar (9) stated that virtopsy was suggested as a complement and not a complete substitution for the traditional autopsy.

3.2. Available theories and important findings

Virtopsy is constructed on well-grounded principles of diagnostic imaging. CT is considered very useful in investigating bones, fractures, and gas distribution in the body; thus, it is particularly useful in cases of trauma, gunshot, and blast-related deaths. In contrast, MRI

provides better imaging of soft tissues and can be used to detect hemorrhages, organ trauma, and musculoskeletal injuries. According to many studies, a high level of concordance has been observed between the results of virtopsy and those of conventional autopsy, especially skeletal results, with reported accuracy ranging between 80 and 90 percent. Simultaneously, restrictions have also been mentioned, such as the inability of imaging to visualize color changes, odors, or microscopic changes that pathologists assess regularly in an average autopsy.

PMCT has occasionally identified missed or only partially appreciated fractures in trauma cases during conventional autopsy, particularly in multifaceted craniofacial or vertebral injuries. Virtopsy can show fluid in the airways and paranasal sinuses, which can support a diagnosis of drowning in suspected drowning cases. Using finite element models, including the Total Human Model for Safety (THUMS), falls, impacts, and ballistic events are simulated to assist investigators in understanding the forces at work and the subsequent patterns of injury. Virtopsy received additional support during the COVID-19 pandemic as a response to reducing physical contact with infectious bodies and allowing essential diagnostic data to be obtained.

3.3. Research gaps identified

Nevertheless, even with such significant advances, the literature on virtopsy has some gaps. The primary difficulty lies in the fact that in advanced cases of decomposition or mummification, it is always challenging to distinguish between antemortem injuries and postmortem alterations. Due to body damage, artifacts in imaging grow, and soft tissues become more challenging to interpret, thus causing less diagnostic certainty.

Accessibility is another important issue. State-of-the-art imaging equipment, such as CT and MRI, involves significant investments in money, specialized equipment, and staff. Such demands inhibit extensive use in most underdeveloped or resource-constrained environments. Moreover, how virtopsy can be integrated into various religious, cultural, and ethical standards is also relatively under-discussed, particularly in countries where traditional approaches to autopsy are already controversial.

Issues concerning long-term storage, data integrity, and the legal admissibility of digital evidence from virtopsy are also not completely resolved. Cybersecurity, the potential for imaginary manipulation, and the risk of digital forgery are some of the issues that beg the question of how courts should assess and certify imaging datasets. Moreover, comparative studies on virtopsy and conventional autopsy are relatively few and do not investigate specific groups of people, including children, the elderly, or patients with specific diseases. Lastly,

although FEA is currently used to simulate cranial injuries, its application to non-cranial injuries (thoracic or abdominal injury) is currently under-explored, suggesting that more biomechanical studies are required in this direction.

4. Objectives of the study

This study aimed to follow the history of the development of the concept of virtopsy and outline the most important imaging technologies and digital tools used to facilitate the use of this non-invasive method in forensic investigations.

- This study aimed to examine the practical application of virtopsy in different medico-legal conditions, such as traumatic injuries, mechanical asphyxia, drowning, temperature-related deaths (hypothermia and hyperthermia), and disease-related deaths.
- To contrast virtopsy and traditional autopsy based on their weaknesses and strengths in terms of diagnostic accuracy, legal acknowledgment, ethical issues, and medico-legal precedence.
- To determine gaps in research in the field of virtopsy and suggest further approaches, such as the more comprehensive use of modern technologies, such as finite element analysis (FEA), to reconstruct injuries more accurately.

To determine the significance of virtopsy in public health emergencies, such as the COVID-19 pandemic, in mitigating biohazard risks to forensic practitioners without undermining the credibility of medico-legal evidence.

5. Tools and Techniques:

1. A systematic review of previous studies based on content analysis was conducted to identify common themes, such as the benefits, limitations, and practical uses of virtopsy.
2. Postmortem computed tomography is one of the main methods for visualizing skeletal structures and gas patterns, and it can be of great importance in cases of trauma and asphyxia.
3. Postmortem magnetic resonance imaging was tested because of its capability to provide detailed images of soft tissues, which are very useful in determining muscle injuries, bleeding, and damage to internal organs.

4. Three-dimensional photogrammetry is a non-contact technique for recording outside injuries and body surfaces in detail.
5. The idea of finiteness in element analysis was developed as a high-level computational method to model injury mechanisms and investigate the way forces act on the body in the case of various traumas.

6. Results

1. PMCT showed high sensitivity, where all craniofacial fractures of the reviewed materials were detected on PMCT, but only approximately half of them were detected on conventional autopsy. This observation shows the enhanced ability of imaging in complicated skeletal injury evaluation.
2. Thoracic injury was common in case of falls where high-impact energy was used, making it common in fatalities. The fractures and internal injuries that PMCT might identify and diagnose could not be detected or underestimated with the help of the regular autopsy.
3. In asphyxia cases, PMMRI demonstrated good agreement to autopsy especially in detecting blood loss in the neck muscles in strangle cases or other compressive force cases.
4. In drowning deaths, PMCT repeatedly exhibited typical accumulation of fluid in the sinuses and airways, which favors its application in identification of changes associated with drowning.
5. Thermal injury analysis showed that PMCT is capable of differentiating heat-induced bone damage and traumatic fracture and therefore helps to avoid misinterpretation. It also showed average internal changes in fatalities due to exposure to severe cold.
6. In fatalities caused by disease, the PMMRI proved accurate in the detection of myocardial damage whereas CT angiography was effective in the visualization of inflammatory changes of abdominal organs as is the case with acute pancreatitis.

6.1. Relevance of the Results

The results have shown that virtopsy can be of great assistance to the traditional autopsy and not as a full replacement of autopsy. It has one outstanding benefit in that the body is maintained in its physical state, which can be very important in situations where the acceptability of dissection is restricted by cultural, religious, or family issues. The computer-derived images and reconstructions provided by CT, MRI and other similar methods can be safely held and

subsequently produced in a courtroom as objective, repeatable proof, and thus, enhance transparency in forensic practice.

Virtopsy has also found application in biohazards especially in the COVID 19 pandemic where minimizing physical contact with cadavers was not only a significant safety protocol. Finally, integrating the multidisciplinary approach with radiology, forensic medicine, and digital technologies, virtopsy advances diagnostic precision, but only in the cases of trauma and complicated pathology. Put together, the findings also indicate that virtopsy can play a significant role in advancing global activities of standardized and modernized forensic processes.

7. Conclusion

The non-invasive aspect of forensic science has become a major field with the development of virtopsy. It has been demonstrated to be very effective in detecting fractures, gas patterns, and certain internal pathologies, with reported detection rates of approximately 80 to 100 percent in key areas of forensic importance. The review confirms that virtopsy addresses the primary aims of research by enabling the supplementation of traditional autopsies, decreasing the use of invasive procedures, and improving evidence documentation and interpretation.

In addition to its diagnostic use, virtopsy facilitates safer medico-legal examination through the reduction of the risk of infection, observation of cultural sensitivity, and strengthening the position of digital forensic evidence in courts of law. Virtopsy enhances the existing state of forensic investigations by providing scientific accuracy and advancing ethical and technological standards to achieve justice in a meaningful way.

8. Limitations of the study

- The paper is founded purely on some already published review articles and secondary sources and does not include some new case studies or original experimental data.
- Other modern imaging modalities like PMCT and PMMRI have large financial and technical demands and very few skilled personnel which limits their adoption in low-resource or developing countries.
- Also imaging quality can be impaired by artifacts in situations of advanced decomposition, which reduces diagnostic accuracy. Because virtopsy relies on the

digital data, the issue of image manipulation, cybersecurity, and data authenticity still exists.

- On the one hand, the literature review was limited to English-language sources, which implies that the literature might have overlooked possibly significant results of non-English or local research.
- Virtopsy has shortcomings as far as identifying changes at a microscopic or cellular level or eliminating a histopathological examination, unless used together with a specific biopsy or sampling.

9. Future scope of virtopsy

Virtopsy and traditional autopsy in various age groups, such as pediatric and geriatric, should be compared in longitudinal and large studies; this would help soften the diagnostic criteria and enhance the reliability of results.

- In the future, the field of use of artificial intelligence (AI) and machine learning can be extended to advance virtopsy, automating detection of injuries, minimizing artifacts, and interpreting PMCT and PMMRI images.
- The use of FEA would be applied to more complicated trauma cases such as vehicle-pedestrian accidents and multiple impact events using realistic computer models.
- Big multi-centre, multi-country research studies are required in order to test the performance and utility of the virtopsy in case of the mass disasters, pandemics, and the biohazards where the normal autopsies might be challenging or unsafe to carry out.
- In this regard, it is evident that there is a need to come up with internationally recognized protocols and standards on how to handle, store and present digital virtopsy records in a manner that such evidence is able to attain uniform legal credibility and admissibility.

10. Practical uses of virtopsy

- Very fast 3-dimensional imaging could capture the information about gunshot, sharp-force, and blunt-force trauma, and save it as digital data to be used in court, eliminating the necessity to exhumate them later. This was particularly helpful during the COVID-19 pandemic, where municipal governments attempted to restrict contact but at the same time record injuries in detail.

- PMCT captures skeletal and soft-tissue injuries in precise visualization assisting in determining intricate fracture patterns and interior trauma associated with accidents, falls, or gunfire. Using the data of PMCT and FEA jointly, the investigators can recreate what occurred during the fall or crash with several victims involved and analyze the forces behind the gunshot wounds.
- PMMRI assists in postmortem diagnosis of diseases by recognizing the abnormalities in the soft tissues such as myocardial infarction, vascular lesion, and internal hemorrhages that could explain the cause of death.
- Alternatively, Virtopsy is in many ways more culturally and ethically acceptable than invasive methods, as it means that the deceased can be examined without making physical contact, in situations where standard autopsy is restricted or tabooed.
- Mobile imaging units can be used in mass disasters and emergencies in the field of public health to scan many victims quickly, ensuring the identification process and cause-of-death, and minimizing the risk of biological exposure to employees.
- The virtopsy assists forensic odontology by providing 3D photogrammetry and digital imaging in recording the structure of the teeth and bite marks without touching the body thus enhancing accuracy in victim identification and bite-mark comparison.
- Sharing the digital datasets: This can also encourage education, training, and collaboration between the forensic professionals by allowing them to consult remotely, and can assist in bringing more standardized practices together with tele-forensic networks.

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