Indian Journal of Forensic Medicine and Pathology
Volume 14 Number 2, April - June 2021 (Special Issue)
DOI: http://dx.doi.org/10.21088/ijfmp.0974.3383.14221.24

REVIEW ARTICLE

Virtopsy in Covid-19 and Its Application in Forensic Science: A Review

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ABSTRACT

The outset of the year 2020 witnessed the outbreak of an epidemic known as CoVid-19 or novel coronavirus pandemic. Since then, the number of confirmed cases of this infection had increased rapidly all over the world. Autopsy provides relevant knowledge about the identification and determination of the cause of death in forensic medicine. Different non-invasive and minimally invasive approaches over the traditional autopsy are introduced into forensic science to deal with challenges presented by COVID-19 pandemic where performing invasive autopsy is not feasible. Virtopsy is a multi-disciplinary science. 'Virtopsy' or Virtual Autopsy aims at new imaging techniques in forensic pathology to facilitate the present postmortem examination. It offers advantages over invasive 'body opening' autopsy. Virtopsy consists of body volume documentation, optical scanning with imaging techniques such as Magnetic resonance imaging (MRI), computed tomography (CT) scan coupled with minimally invasive approaches such as postmortem biopsies. The importance of Virtopsy is noteworthy in post mortem examination of COVID-19 patients. Virtopsy has a broad spectrum of uses in forensic medicine, forensic odontology, firearm injury and road traffic injury etc. Hence, it can be used either independently or as an alternative to conventional autopsy. The present study highlights the importance of Virtopsy in postmortem examination and its contribution in forensic science. It also provides scope for future research in the subdisciplines of forensic science.

KEYWORDS | covid-19, virtopsy, minimal invasive autopsy, mri, ct scan

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INTRODUCTION

The severe acute respiratory syndrome SARS-2 (SARS-CoV-2) is a respiratory distress syndrome. It affects the functioning of other vital organs in cases. The first case of this epidemic was reported at Wuhan, the People's Republic of China, in the year 2019.[1–3] Older people with other diseases are more prone to this infection. Till 3rd April 2021, out of 129,902,402 confirmed cases worldwide, 12,392,260 cases with 164,110 deaths were reported in India only.[4] In Forensic medicine, postmortem examinations provide the required information regarding the exact cause and mechanism of death. An autopsy has been of great importance.[5] The word "autopsy" from the Greek words 'autos' and 'opsomei' meaning 'to see with one's eye'.[6] Under such circumstances, the contagious nature of COVID-19, forensic pathologists need to face numerous challenges of protecting themselves to analyzing the organs accurately while performing traditional body opening invasive autopsy.[7] Hence, there is a need to look for an alternative to conventional invasive autopsy to examine the dead accurately and effectively. Virtopsy is marked as one of the effective techniques to reduce the chance of infection to the practitioners. It also advances the radiological techniques

How to cite this article
Samiksha Chauhan. Virtopsy in Covid-19 and Its Application in Forensic Science: A Review. Indian J Forensic Med Pathol. 2021;14(2 Special):181-187.

in forensic science.[8] As the name suggests, Virtopsy is the combination of two words: virtual (obtained from the Latin language 'Virtus' meaning 'efficient, good') and autopsy eliminating the term 'autos' (self).[9] Virtopsy generally is composed of 3-D (three dimensional) body volume analysis by non-invasive techniques such as Multi-slice Computed Tomography (MSCT), Magnetic Resonance Imaging (MRI) and 3-D Photogrammetry and optical surface scanning strengthened by minimally invasive techniques.[10] Minimal invasive autopsy is the procedure that includes imaging techniques augmented with postmortem biopsies[11]. Virtobot is one of the newest robotics systems which are capable of performing body scanning and image-guided post mortem biopsies.[12] Virtopsy presents wide spectrum of applications in Forensic science. The imaging techniques help in postmortem examination in cases of hanging, drowning, shooting etc.[13] The present study illustrates the importance of imaging techniques such as CT, MRI and minimally invasive autopsy for future implications. But these imaging techniques are still not utilized today due to inadequate knowledge and expenses. The present study supports Virtopsy as an alternative to conventional invasive autopsy especially for COVID-19 patients and highlights its importance in Forensic Science.

METHODS

3-D Imaging Techniques:

X-ray is one of the oldest human imaging systems developed so far. Soon after its discovery in 1895, scientists have started using X-rays to produce postmortem images. Since then, various imaging modalities exist today.[14] Computed Tomography is a fast-imaging technique based on the attenuation of X-ray. It includes a rotating source of X-ray and detector that produce 3-D tomographic images using the algorithm. The cross-sectional images are detailed and sliced so that examiner can observe the internal organs thoroughly. It performed well in trauma cases.[15,16] It is one of the most widely used approaches in forensic radiology for post mortem examination.

Unlike CT, Magnetic Resonance Imaging (MRI) is a non-ionizing radiation imaging technique that creates images using a robust magnetic field and radio waves. The proton spins when the magnetic field is applied and the rate at which the spin return to its original normal alignment is different. Hence on calculating this, MRI forms an image.[17,18] MRI performed well in strangulation cases.

As compared to CT, the use of MRI is still underutilized, although it is gaining importance in forensic radiology. Both CT and MRI are non-invasive approaches, so they replace the surgical autopsy in many cases. Angiography coupled with CT and MR has also performed well in postmortem examination.[19]

3-D Photogrammetry & 3-D Body Surface Scans

Photogrammetry refers to the method of measurement of objects using photographs. It provides visual images using 2-D photographs taken from different angles. It works on the principle of triangulation. Forensic photogrammetry has been an essential approach in postmortem examination for body documentation. It usually worked well in traffic accidents cases.[20,21]

Surface scanning is another way of recording and documenting the object that provides images in 3-D view using optical scanners. The 3-D surface scan is often used non-invasive 3-D imaging technique in Forensic Science.[22,23] There are advanced surface scanners developed yet enhancing the use of 3-D scan in various field.

Forensic photogrammetry and 3-D Surface scanning are capable of providing 3-D representation. They are essential tools in 3-D reconstruction and providing 3-D optical models with their advantages and limitation.[24] Various software approaches are present along with photogrammetry, to construct 3-D model very efficiently.[25]

Minimally Invasive Autopsy

Minimal Invasive Autopsy, also known as Minimally Invasive Autopsy, is a systematic approach that involves the imaging procedures such as MRI and CT scan, as well as minor biopsies and needles. This autopsy procedure has been used for several years for its potential to provide outcomes with limited resources. It aims to target a variety of organs inside the human body. The main advantage is the less need for infrastructure and low-income settings. As it includes imaging technique, it provides a record of the whole body and lessens the risk of infection to practitioners.[26,27]

Virtual Autopsy in postmortem analysis:

Non-Invasive approach

Virtual Autopsy includes 3-D photogrammetry, optical scanning, computed tomography, Magnetic Resonance Imaging, Postmortem angiography, and postmortem biopsies. These techniques have the potential to work independently or augment with other. Photogrammetry-based approaches are easy and effective for 3-D body documentation in autopsy examination and provided high-quality models28. Photogrammetry is a reproducible and low-cost technique which doesn't require any professional training.[29] The Video recording is a faster method as compared to photo sessions for 3-D documentation.[30] Another approach for documentation is 3-D surface scanning by optical scanning, which is easy, time saving and efficient for dental identification.[31] In traffic accidents cases, external examination by 3-D surface scanning and internal by MSCT, MRI provide a better understanding in body analysis.[32] Even in the cases of late decomposition, CT scan and MRI successfully reconstructed the bullet trajectory through the skull.[33] The use of these imaging techniques is popularizing day by day in forensic medicine.

PMCT was able to detect major injuries in the body but couldn't completely surpass the conventional autopsy in the cases of traumatic deaths. It can be performed for all trauma cases. The performance of PMCT and PMMRI is comparable for determining the cause of death. Both the techniques have their advantages.[34] The studies show contrasting result on comparing these techniques. PMMRI detected extra cardiac and brain pathology efficiently in the cases of sudden death. Hence, it is a beneficial and informative approach when conventional autopsy is not possible.[35] Most of the comparative studies between Virtopsy and traditional autopsy promoted postmortem imaging techniques in autopsy examination. Virtopsy provides information about the cause of death but still can't completely replace the need of traditional autopsy. These imaging techniques are capable of coordinating with traditional autopsy. Virtopsy has the potential to be performed as an alternative to conventional autopsy. [36,37]

Virtopsy in postmortem analysis of COVID-19 patients:

Minimally Invasive Approach

The SARS-COV-2 infection present challenges in postmortem examination due to its contagious nature.[39] The minimal invasive approach has practiced for COVID-19 deaths to overcome the difficulties. Minimally Invasive autopsy includes use of the imaging techniques along with small organ biopsies. It enables the collection of tissue specimens for histologic examination.[40] This

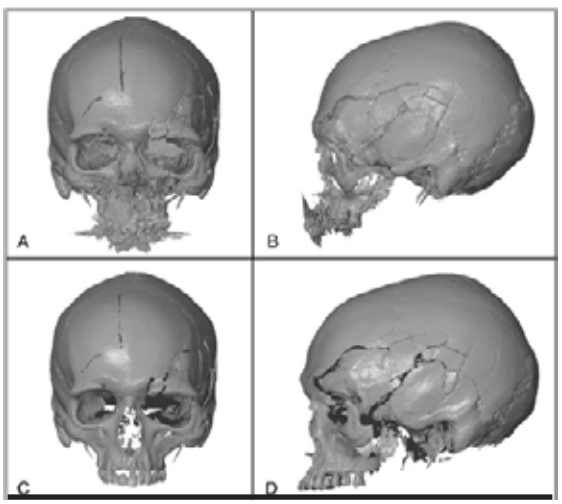

Figure 1 Comparative analysis of 3-D model of skull by CT scan A) Anterior view, B) Lateral view and 3-D surface scan C) Anterior view, D) Lateral view.

Source: *Scanning of a skull: first considerations regarding reproducibility issues . Forensic Sciences Research. 2017;2(2):93-99*

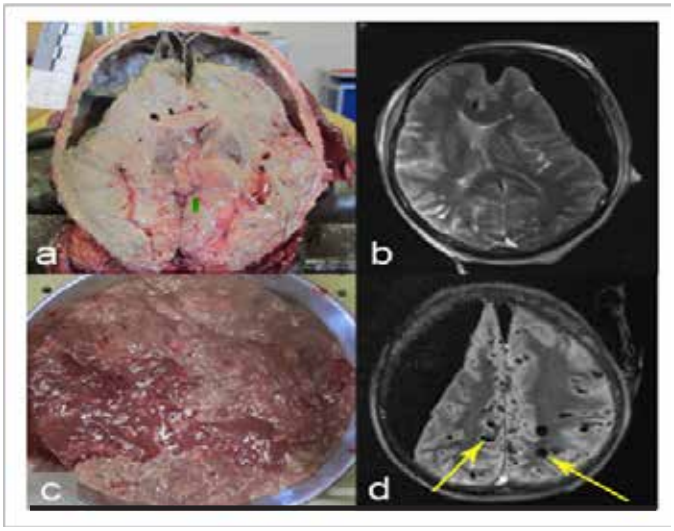

Figure 2 Shows Comparison representation between conventional autopsy in a) softened brain tissue, c) liquified brain at autopsy and PMMRI in b) softened brain tissue, d) liquified brain and yellow arrow indicating putrefied gas accumulation[38].

Source: *Tschui J, Jackowski C, Schwendener N, Schyma C, Zech WD. Post-mortem CT and MR brain imaging of putrefied corpses. International Journal of Legal Medicine. 2016;130(4):1061-1068*

method allows the collection of tissue samples, urine, bile, and blood samples for toxicologic and DNA investigations. In these circumstances, when the risk of transmission of the infection is high, minimally invasive autopsy reduce the risk of producing aerosols.[41] In terms of diagnostic performance, Minimal Invasive autopsy shows similar results as that of conventional autopsy in the diagnosing the cause of death.[42] Even when the consent of next-of-kin of dead is not present, it may work as an essential tool.[43] This approach is feasible for high infectious diseases for countries with middle and low income.[44] Ultrasound-guided minimally invasive autopsy performed well, providing 100% agreement conventional autopsy for the 2018 yellow fever epidemic in Sau Paulo.[45] MIA-US provided efficient in obtaining sufficient samples from multiple organs such as lungs, liver and spleen of COVID-19 patients.[46] MIA-US can help to determine the pathology of respiratory failure and systemic manifestation of COVID-19.[47] The main advantages offered by minimally invasive approach are its cost efficiency and low-invasiveness. It is a safer and quicker approach that provide accurate results during COVID-19. Hence, Minimal Invasive autopsy is an innovative approach in postmortem examination in the pandemic.[48]

Application of Virtopsy in Forensic Science

Age and Sex determination:

The CT scans have good reproducibility in estimating the age and gender of individuals. In a study on age estimation, CT scan well differentiated individual of age between 40-60 years from middle aged.[49] Through burnt and charred remains, Age can be easily estimated by CT scan using age estimation methods.[50] Sexually dimorphic bones are very often analyzed to determine individual's gender. A PMCT scan is also a simple and quick method to measure bone structures before an autopsy.[51]

Forensic Odontology & Personal identification

The comparison of antemortem and postmortem records and development of individual's details are usually done for dental identification.[52] Some of these antemortem radiographic reconstructions are possible using cranial CT records. Documentation and examination are possible in charred and decomposed bodies without surgical removal by Dent scan.[53] MSCT is a quick approach for gathering data and allowing comparison of dental radiological information for identification in mass disaster cases.[54]

Forensic Ballistics and Firearm Injuries

Entrance and Exit wounds are analyzed to locate the projectile inside the body using radiological techniques.[55] CT scan is capable of providing information of wound and cavity inside the body in clinical and forensic cases.[56] A doctor uses an X-ray to locate projectile to save the living person. MRI is capable of better visualizing soft tissues than the MSCT. It can be used as an alternative tool in cases where the bullet trajectory is not easily detectable.[57]

Forensic Reconstruction

Reconstruction of crime scene is a vital task in criminal investigation. In case of fracture, the impact of force and direction of force is analyzed.[58] 3-D photogrammetry, 3-D body surface scans and CT scans are also capable of Forensic reconstruction of body parts.[59]

Burn Injuries

For the identification of hidden signs of wounds, gas collections, and foreign bodies in burnt patients, a PMCT preliminary to autopsy is an addition to the postmortem forensic examination.[50]

Cause of Death

Virtopsy has great importance in diagnosing the cause of death in forensic pathology as it enables examination of vital organs for example heart, lungs etc.[60]

Mechanical asphyxia

In the case of death caused by obstruction created by a foreign particle, CT allows the preliminary screening to autopsy. CT is comparable to the traditional autopsy in detection of bone fracture and soft tissues analysis. MRI was able to detect microfractures in cases of manual strangulation.[61] The vital responses reveal the sequence of injuries and death. The determination of whether an accident occurred before or after death is a crucial forensic problem. MRI and CT can analyze signs of strangulation and collect internal neck detail.[62]

Cardiovascular system

The primary cause of natural death is cardiac insufficiency. Cardiac insufficiency may be caused by chronic heart disease or sudden ischemic events.[63] PMRI successfully detected ischemic lesions and myocardial infarction. It has the potential to perform in the absence of an autopsy.[64]

Respiratory system

In determining infections of lungs and natural causes of death, PMCT is as efficient as traditional autopsy. It is more capable of detecting vertebral fractures, which will rule out hanging and indicate spinal injuries.[65] In cases of non-traumatic death, PMCT of lungs was able to determine the cause of death.[66]

Central Nervous system

CT and MRI are the beneficial diagnostic tools in neuropathology and forensic science.[67] Even when the brain is liquefied, PMRI of putrefied brain accessed the multiple regions of the brain.[38]

Future Implementation of Virtopsy

With some advances in techniques used in Virtopsy, it can contribute more in forensic science. Virtopsy produces massive amounts of digital DICOM data. Digital format reduces the expense of films and video handling, making it more portable.[68] Virto Scan is capable of documenting the body. It is a multi-camera-based approach which saves money and time.[69] A new version of the robotic system named 'Virtibot' has been introduced to perform the task such as body surface scanning and incorporation of needles for sample collection. It has the potential to be combined with imaging techniques.[70] Recent developments in MR imaging have the potential to shorten MR imaging test times, which may take up to 3 hours per corpse.[71] The postmortem imaging techniques necessitates a significant investment of time and money, as well as professionals with the skills to obtain and analyze PM images. Imaging equipment needs to be maintained, modified, and replaced regularly. The PM imaging may not be developed properly without sufficient financial resources.[72]

DISCUSSION

This study shows how Virtopsy has widened the scope of postmortem examination in forensic science. A virtual autopsy can be used for postmortem examination in COVID-19 patients.[73] 'Virtopsy' is intended to implement radiological techniques in the field of Forensic Science.[74] It includes imaging techniques such as CT, MRI, scanning techniques such as 3-D photogrammetry, surface scans and postmortem biopsies. Postmortem radiology has developed incredibly since the decades. PMCT and PMMRI have used for examination of the vital organ after death. 3-D optical models and Forensic Reconstruction have been achieved by Photogrammetry and Surface scanners.[75] While there are substantial possible benefits of using postmortem MRI/CT imaging, it is doubtful that postmortem imaging would completely substitute conventional autopsy analysis shortly due to its inherent limitations. Besides that, for those cases where the next-of-kin refuse conventional autopsy, such "minimally invasive" autopsy examinations may provide at least some clinically valid details.[76] This approach has proved successful in postmortem examination in cases of highly infectious disease such as COVID-19.[77] The role of Virtopsy in forensic science includes detecting the sudden cause death due to failure of vital organs such as heart, lung, firearm injuries, burn injuries, traffic accident cases etc. It is also helpful in examining post mortem changes and in the cases of medical dispute. Even with so many advantages of Virtopsy, it is still not utilized to its complete extent.[78] Future researches are needed in this field to validate its use. However, depending on the situation, autopsy with histology or, in carefully chosen cases, non-invasive, minimally invasive or traditional autopsies are likely to be the most reliable method of determining the cause of death.[79]

CONCLUSION

Virtopsy is an essential diagnostic tool in forensic science. It can be used either independently or in combination with traditional autopsy, depending on the need of the hour. It has advantages in clinical and forensic fields. Minimal invasive autopsy is quick and safe. It can be an alternative to autopsy in the COVID-19 pandemic. Future research and funding can help in overcoming the limitations of the virtual autopsy. IJFMP

Acknowledgement:

The author is thankful for the encouragement, support and guidance. Thanks also to Deepa Verma, Director, Forensic Science Laboratory, Govt. of NCT of Delhi, Sector 14, Rohini, New Delhi, India.

Conflict of Interest:

The author declares there is no conflict of interest in this project.

Source of Funding:

The author declares that there is no funding for this project.

REFERENCES

1. **Maiese A, Manetti AC, et al.** *Autopsy findings in COVID-19-related deaths: a literature review. Forensic Science, Medicine, and Pathology. Published online 2020:1.*
2. **Elsoukkary SS, Mostyka M, et al.** *Autopsy Findings in 32 Patients with COVID-19: A Single-Institution Experience. Pathobiology. 2021;88(1):56-68.*
3. **Eketunde AO, Mellacheruvu S priyanka, et al.** *Review of Postmortem Findings in Patients With COVID-19. Cureus. 2020;12(7).*
4. **No authors listed:** *India: WHO Coronavirus Disease (COVID-19) Dashboard With Vaccination Data | WHO Coronavirus (COVID-19) Dashboard With Vaccination Data.*
5. **Buja LM, Barth RF, Krueger GR, et al.** *The Importance of the Autopsy in Medicine: Perspectives of Pathology Colleagues. Academic pathology. 2019;6:2374289519834041.*
6. **van den Tweel JG, et al.** *The rise and fall of the autopsy. Virchows Archiv. 2013;462(4):371-380.*
7. **Sekhawat V, Green A, et al.** *COVID-19 autopsies: conclusions from international studies. Diagnostic Histopathology. 2021;27(3):103-107.*
8. **Perju-Dumbrav D, et al.** *Virtopsy - An alternative to the conventional autopsy. Romanian Journal of Legal Medicine. 2010;18(1):75-78.*
9. **No author listed.** *(PDF) Virtopsy-A Moral Boon In Forensics.*
10. **Bolliger SA, Thali MJ.** *Imaging and virtual autopsy: Looking back and forward. Philosophical Transactions of the Royal Society B: Biological Sciences. 2015;370(1674).*
11. **Wagensveld IM, Myriam Hunink MG, et al.** *Hospital implementation of minimally invasive autopsy: A prospective cohort study of clinical performance and costs. PLoS ONE. 2019;14(7).*
12. **Ebert LC, Ptacek W, et al.** *Virtobot - A multi-functional robotic system for 3D surface scanning and automatic post mortem biopsy. International Journal of Medical Robotics and Computer Assisted Surgery. 2010;6(1):18-27.*
13. **Pomara C, Fineschi V, et al.** *Virtopsy versus autopsia digitale: autopsia virtuosa. Radiologia Medica. 2009;114(8):1367-1382.*
14. **No authors listed.** *Indian Journals. https://www.indianjournals.com/ijor.aspx?target=ijor:jiafm&volume=39&issue=1&article=editorial. Accessed April 14, 2021.*
15. **X-ray Computed Tomography (CT).** *https://serc.carleton.edu/research_education/geochemsheets/techniques/CT.html. Accessed April 14, 2021.*
16. **No author listed.** *Berger A. Magnetic resonance imaging. BMJ. 2002;324(7328):35.*
17. **No author listed.** *Medical Imaging. https://www.cocir.org/our-industry/medical-imaging.html. Accessed April 14, 2021.*
18. **Ruder TD, Hatch GM, Ebert LC, et al.** *Whole Body Postmortem Magnetic Resonance Angiography. Journal of Forensic Sciences. 2012;57(3):778-782.*
19. **Brüschweiler W, Braun M, et al.** *Analysis of patterned injuries and injury-causing instruments with forensic 3D/CAD supported photogrammetry (FPHG): An instruction manual for the documentation process. Forensic Science International. 2003;132(2):130-138.*
20. **Schweitzer W, Häusler M, Bär W, et al.** *Evaluation of 3D surface scanners for skin documentation in forensic medicine: Comparison of benchmark surfaces. BMC Medical Imaging. 2007;7.*
21. **Fahrni S, Campana L, et al.** *CT-scan vs . 3D surface scanning of a skull: first considerations regarding reproducibility issues . Forensic Sciences Research. 2017;2(2):93-99.*
22. **Leipner A, Baumeister R, et al.** *Multi-camera system for 3D forensic documentation. Forensic Science International. 2016;261:123-128.*
23. **Castillo P, Ussene E, et al.** *Pathological methods applied to the investigation of causes of death in developing countries: Minimally invasive autopsy approach. PLoS ONE. 2015;10(6).*
24. **Weustink AC, Hunink MGM, et al.** *Minimally invasive autopsy: An alternative to conventional autopsy? Radiology. 2009;250(3):897-904.*
25. **Urbanová P, Hejna P, Jurda M.** *Testing photogrammetry-based techniques for three-dimensional surface documentation in forensic pathology. Forensic Science International. 2015;250:77-86.*
26. **Gitto L, Donato L, di Luca A, et al.** *The Application of Photogrammetry in the Autopsy Room: A Basic, Practical Workflow*. Journal of Forensic Sciences. 2020;65(6):2146-2154.*
27. **Flies MJ, Larsen PK, et al.** *Forensic 3D documentation of skin injuries using photogrammetry: photographs vs video and manual vs automatic measurements. International Journal of Legal Medicine. 2019;133(3):963-971.*
28. **Naether S, Buck U, et al.** *The examination and identification of bite marks in foods using 3D scanning and 3D comparison methods. International Journal of Legal Medicine. 2012;126(1):89-95.*
29. **Buck U, Naether S, Braun M, et al.** *Application of 3D documentation and geometric reconstruction methods in traffic accident analysis: With high resolution surface scanning, radiological MSCT/MRI scanning and real data based animation. Forensic Science International. 2007;170(1):20-28.*
30. **Peschel O, Szeimies U, et al.** *3-D reconstruction of skull gunshot injuries. Forensic Science International. 2013;233(1-3):45-50.*
31. **Jalalzadeh H, Giannakopoulos GF, et al.** *Post-mortem imaging compared with autopsy in trauma victims - A systematic review. Forensic Science International. 2015;257:29-48.*
32. **Puranik R, Gray B, Lackey H, et al.** *Comparison of conventional autopsy and magnetic resonance imaging in determining the cause of sudden death in the young. Journal of Cardiovascular Magnetic Resonance. 2014;16(1).*
33. **Shruthi M, Gupta N, Jana M, et al.** *Conventional vs virtual autopsy with postmortem MRI in phenotypic characterization of stillbirths and fetal malformations. Ultrasound in Obstetrics and Gynecology. 2018;51(2):236-245.*
34. **Roberts ISD, Benamore RE, et al.** *Post-mortem imaging as an alternative to autopsy in the diagnosis of adult deaths: A validation study. The Lancet. 2012;379(9811):136-142.*
35. **Tschui J, Jackowski C, et al.** *Post-mortem CT and MR brain imaging of putrefied corpses. International Journal of Legal Medicine. 2016;130(4):1061-1068.*
36. **Lacy JM, Brooks EG, Akers J, et al.** *COVID-19: Postmortem diagnostic and biosafety considerations. American Journal of Forensic Medicine and Pathology. 2020;41(3):143-151.*
37. **Weustink AC, Hunink MGM, et al.** *Minimally invasive autopsy: An alternative to conventional autopsy? Radiology. 2009;250(3):897-904.*
38. **Duarte-Neto AN, Monteiro RAA, et al.** *Pulmonary and systemic involvement in COVID-19 patients assessed with ultrasound-guided minimally invasive autopsy. Histopathology. 2020;77(2):186-197.*
39. **Blokker BM, Weustink AC, et al.** *Conventional autopsy versus minimally invasive autopsy with postmortem MRI, CT, and CT-guided biopsy: Comparison of diagnostic performance. Radiology. 2018;289(3):658-667.*
40. **Fan JKM, Tong DKH, Poon JTC, et al.** *Multimodality minimally invasive autopsy-A feasible and accurate approach to post-mortem examination. Forensic Science International. 2010;195(1-3):93-98.*
41. **Castillo P, Martínez MJ, et al.** *Validity of a Minimally Invasive Autopsy for Cause of Death Determination in Adults in Mozambique: An Observational Study.*

REFERENCES

PLoS Medicine. 2016;13(11).

42. ***Duarte-Neto AN, Monteiro RA de A, Johnsson J, et al.*** *Ultrasound-guided minimally invasive autopsy as a tool for rapid post-mortem diagnosis in the 2018 Sao Paulo yellow fever epidemic: Correlation with conventional autopsy. PLoS Neglected Tropical Diseases. 2019;13(7).*
43. ***Brook OR, Piper KG, Mercado NB, et al.*** *Feasibility and safety of ultrasound-guided minimally invasive autopsy in COVID-19 patients. Abdominal Radiology. 2021;46(3):1263-1271.*
44. ***Monteiro RA de A, Duarte-Neto AN, et al.*** *Ultrasound-guided minimally invasive autopsies: A protocol for the study of pulmonary and systemic involvement of COVID-19. Clinics. 2020;75:1-2.*
45. ***Malizia A, Filograna L, et al.*** *Post-Mortem Investigation through Virtual Autopsy Techniques: Proposal of a New Diagnostic Approach to Reduce the Risks of Operators during Emergencies. International Journal of Safety and Security Engineering. 2020;10(4):535-541.*
46. ***Boyd KL, Villa C, Lynnerup N.*** *The Use of CT Scans in Estimating Age at Death by Examining the Extent of Ectocranial Suture Closure. Journal of Forensic Sciences. 2015;60(2):363-369.*
47. ***Thali MJ, Yen K, Plattner T, et al.*** *Charred Body: Virtual Autopsy with Multi-slice Computed Tomography and Magnetic Resonance Imaging. Journal of Forensic Sciences. 2002;47(6):15569J.*
48. ***Badam RK, Sownetha T, et al.*** *Virtopsy: Touch-free autopsy. Journal of forensic dental sciences. 2017;9(1):42.*
49. ***do Rosário AF, Souza PHC, et al.*** *Virtual autopsy in forensic sciences and its applications in the forensic odontology. Revista Odonto Ciencia. 2012;27(1):5-9.*
50. ***Thali MJ, Markwalder T, et al.*** *Dental CT imaging as a screening tool for dental profiling: Advantages and limitations. Journal of Forensic Sciences. 2006;51(1):113-119.*
51. ***Jackowski C, Aghayev E, et al.*** *Maximum intensity projection of cranial computed tomography data for dental identification. International Journal of Legal Medicine. 2006;120(3):165-167.*
52. ***Dirnhofer R, Jackowski C, et al.*** *Virtopsy: Minimally invasive, imaging-guided virtual autopsy. Radiographics. 2006;26(5):1305-1333.*
53. ***Jeffery AJ, Rutty GN, et al.*** *Computed tomography of projectile injuries. Clinical Radiology. 2008;63(10):1160-1166.*
54. ***Andenmatten MA, Thali MJ, et al.*** *Gunshot injuries detected by post-mortem multislice computed tomography (MSCT): A feasibility study. Legal Medicine. 2008;10(6):287-292.*
55. ***Raneri D.*** *Enhancing forensic investigation through the use of modern three-dimensional (3D) imaging technologies for crime scene reconstruction. Australian Journal of Forensic Sciences. 2018;50(6):697-707.*
56. ***Grabherr S, Baumann P, et al.*** *Post-mortem imaging in forensic investigations: current utility, limitations, and ongoing developments. Research and Reports in Forensic Medical Science. Published online March 2016:25.*
57. **Blokker BM, Wagensveld IM, et al.** *Non-invasive or minimally invasive autopsy compared to conventional autopsy of suspected natural deaths in adults: a systematic review. European Radiology. 2016;26(4):1159-1179.*
58. ***Fais P, Giraudo C, Viero A, et al.*** *Micro computed tomography features of laryngeal fractures in a case of fatal manual strangulation. Legal Medicine. 2016;18:85-89.*
59. ***Yen K, Thali MJ, Aghayev E, et al.*** *Strangulation signs: Initial correlation of MRI, MSCT, and forensic neck findings. Journal of Magnetic Resonance Imaging. 2005;22(4):501-510.*
60. **Jackowski C, Schweitzer W, et al.** *Virtopsy: Postmortem imaging of the human heart in situ using MSCT and MRI. Forensic Science International. 2005;149(1):11-23.*
61. **Jackowski C, Warntjes MJB, et al.** *Magnetic resonance imaging goes postmortem: Noninvasive detection and assessment of myocardial infarction by postmortem MRI. European Radiology. 2011;21(1):70-78.*
62. ***No author listed.*** *(PDF) Postmortem computed tomography for diagnosis of cause of death in male prisoners.*
63. ***Shiotani S, Kohno M, Ohashi N, et al.*** *Non-traumatic postmortem computed tomographic (PMCT) findings of the lung. Forensic Science International. 2004;139(1):39-48.*
64. ***Yen K, Lövblad KO, Scheurer E, et al.*** *Post-mortem forensic neuroimaging: Correlation of MSCT and MRI findings with autopsy results. Forensic Science International. 2007;173(1):21-35.*
65. ***Thali MJ, Jackowski C, et al.*** *VIRTOPSY - The Swiss virtual autopsy approach. Legal Medicine. 2007;9(2):100-104.*
66. ***Kottner S, Ebert LC, Ampanozi G, et al.*** *VirtoScan - a mobile, low-cost photogrammetry setup for fast post-mortem 3D full-body documentations in x-ray computed tomography and autopsy suites. Forensic Science, Medicine, and Pathology. 2017;13(1):34-43.*
67. ***Breitbeck R, Ptacek W, et al.*** *Virtobot - A Robot System for Optical 3D Scanning in Forensic Medicine. In: Hometrica Consulting; 2013:84-91.*
68. ***Aggarwal K, Chauhan A, et al.*** *Implementation of virtual autopsy in forensic medicine. Indian Journal of Forensic Medicine and Toxicology. 2019;13(2):68-72.*
69. ***Decker SJ, Braileanu M, et al.*** *Forensic Radiology: A Primer. Academic Radiology. 2019;26(6):820-830.*
70. ***Kanchan T, Saraf A, Krishan K, et al.*** *The advantages of virtopsy during the Covid-19 pandemic. The Medico-legal journal. 2020;88(1):55-56.*
71. ***Singal K.*** *History and Modalities of Forensic Radiology. Indian Journal of Forensic Medicine and Pathology. 2015;8(4):135-138.*
72. ***Grabherr S, Egger C, Vilarino R, et al.*** *Modern post-mortem imaging: an update on recent developments. Forensic Sciences Research. 2017;2(2):52-64.*
73. ***Sebire NJ.*** *Towards the minimally invasive autopsy? Ultrasound in Obstetrics & Gynecology. 2006;28(7):865-867.*
74. ***D'Onofrio V, Donders E, et al.*** *The clinical value of minimal invasive autopsy in COVID-19 patients. Pasin L, ed. PLOS ONE. 2020;15(11):e0242300.*
75. ***Yucong W, Haibiao Z, et al.*** *Application of virtopsy in forensic pathology. Journal of Forensic Science and Medicine. 2021;7(1):14.*