Could ante-mortem computed tomography be useful in forensic pathology of traumatic intracranial haemorrhage?

**Background:** Imaging techniques have proven valuable in forensic pathology practice, with computed tomography being preferred for forensic use. In the era of virtual autopsy and a low- to middle-income, resource-constrained country, a question arises as to whether ante-mortem computed tomography (ACT) could be cost-effective by reducing the number of invasive autopsies performed.

**Objective:** The objective of this study was to assess the usefulness of ACT in forensic pathology by examining discrepancy rates between ACT scans and autopsy findings in cases of deceased individuals with traumatic intracranial haemorrhages and assess factors associated with discrepancies.

**Methods:** Eighty-five cases of ACT and autopsy reports from 01 January 2014 to 31 December 2016 from the Polokwane Forensic Pathology Laboratory, South Africa, were analysed retrospectively. Using Cohen’s kappa statistics, measures of agreement and resultant discrepancy rates were determined. Also, the discrepancy patterns for each identified factor was also analysed.

**Results:** The discrepancy rate between ACT and autopsy detection of haemorrhage was 24.71% while diagnostic categorisation of haemorrhage was 55.3%. Classification discrepancy was most observed in subarachnoid haemorrhages and least observed in extradural haemorrhages. A markedly reduced level of consciousness, hospital stay beyond two weeks and three or fewer years of doctors’ experience contributed to classification discrepancies.

**Conclusion:** Ante-mortem computed tomography should be used only as an adjunct to autopsy findings. However, the low discrepancy rate seen for extradural haemorrhages implies that ACT may be useful in the forensic diagnosis of extradural haemorrhages.

**Keywords:** forensic imaging; ante-mortem computed tomography; traumatic intracranial hemorrhage; forensic autopsy.

**Introduction**

Imaging techniques have in recent years been found to be greatly useful in forensic pathology.\(^1\,^2\) These modalities not only serve to augment but lower the invasive autopsies performed.\(^3\) The latter is convenient for various reasons, including religious and economic reasons. Computed tomography (CT) has been used as the preferred imaging modality in forensic imaging.\(^4\) Though in the era of virtual autopsies, the usefulness of ante-mortem computed tomography (ACT) compared to the inexpensive invasive autopsy in a middle-income country, such as South Africa, must be justified. Thus, it is necessary to determine whether ACT will be an augmentation or a cost-effective alternative to autopsy.

Head injuries are common, usually carry a high mortality rate, and are therefore important in forensic pathology practice. While post-mortem CT has been found useful in determining the cause of death in cases of traumatic intracranial haematomas,\(^5\,^6\) there is limited empirical evidence for the use of ACT scan findings to this effect.

Discrepancies between clinical or ante-mortem CT scan and autopsy findings exist and are common.\(^7\) According to Bruno et al.,\(^7\) radiologic interpretations cannot be programmed because interpretation is subject to a variety of factors such as doctors’ (radiologists’ and pathologists’) expertise and complex psychophysiological and cognitive level of the patient (e.g. level of
consciousness). Thus, ACT interpretation errors are inevitable.

This study assessed the rate and pattern of discrepancies between ACT scan and conventional autopsy findings of intracranial haemorrhages in cases of traumatic head injury submitted for autopsy at a facility in a rural South Africa province.

Methods
Ethical considerations
Ethical clearance for the study was secured from Turfloop Research and Ethics Committee (TREC/268/2017: PG). Consent was not applicable as we were not working on human subjects but case reports, permission for which was obtained from the Limpopo Provincial Department of Health. The case files were coded with numbers and names of the deceased were not recorded.

Study design
This quantitative descriptive study retrospectively analysed 85 cases of deceased individuals across three years from 01 January 2014 to 31 December 2016. Cases sustained head injuries, underwent ACT imaging and had no surgical intervention after being referred to an academic hospital. Deceased cases were subjected to autopsy procedure as per legal requirement at the attached forensic pathology facility in Limpopo, a rural province of South Africa.

Data collection
Data were obtained from post-mortem reports from the forensic pathology laboratory while CT scan reports, clinical data and human resource records were obtained from the Pietersburg hospital records section and radiology department. Autopsy findings served as a reference point because studies have demonstrated that it remains superior to ACT scan for the detection of brain injuries. The majority ($n = 80$) of the cases had only one ACT scan done and the rest a second; only the first scan reports were therefore used in the study. The following intracranial haemorrhages were assessed from these reports: epidural, subdural and subarachnoid haemorrhages.

Data analysis
Data were captured and analysed using Microsoft Excel (Microsoft Office Professional Plus 2013; Microsoft Corp., Redmond, Washington, United States) and International Business Machines Corporation Statistical Package for the Social Sciences version 23 (Armonk, New York, United States) running under Microsoft Windows (Microsoft Corp., Redmond, Washington, United States). Cross-tabulations were used to establish the percentage agreement between ACT scan and autopsy findings of extradural haemorrhage (EDH), subdural haemorrhage (SDH) and subarachnoid haemorrhage (SAH) single or combination occurrence.

If there is agreement between the ACT scan and autopsy findings the individual case scored 1, but if there is a disagreement between the ACT scan and autopsy findings, the case scored 0. Levels of agreement and resultant discrepancy rates were determined using Cohen’s kappa statistics. The pattern of discrepancies for identified factors such as the level of consciousness by Glasgow Coma Scale, the length of hospital stay, the experience of the clinician (radiologist and pathologist) and the site of haemorrhage was also evaluated. Results were considered statistically significant when $p$ was less than 0.05.

Results
Agreement in the detection and diagnosis of haemorrhages
In 75.29% (64/85) of cases, the ACT scan and autopsy agreed on the presence or absence of haemorrhage with a kappa coefficient of 0.3834 (Table 1). The remaining 24.71% represents the overall discrepancy rate between the ACT scan and autopsy detection of haemorrhage.

Note: Bold data – Agreement in diagnostic category for intracranial haemorrhage (singly or combination); Non-bold data – Discrepancies in diagnostic category for intracranial haemorrhage (singly or combinations); EDH, extradural haemorrhage; SDH, subdural haemorrhage; SAH, subarachnoid haemorrhage.

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In 38 of the 85 cases (44.7%; 25 with and 13 without haemorrhage), both methods agreed in the diagnostic intracranial haemorrhage category (i.e. single, binary or ternary combinations of haemorrhages), denoting a diagnostic category discrepancy of 55.3% (Table 2 and Table 3). ACT agreed in 7 of the 11 cases categorised as singular SAH by autopsy (bolded) but reclassified three cases as having binary haemorrhage (SAH and SDH) and one case as absent (no haemorrhage). For 25 cases classified as ‘Absent’ (having no haemorrhage) by autopsy, ACT agreed in 13 (bolded) cases but categorised the remaining 12 as having different haemorrhages.

**Pattern of discrepancies with regard to identified factors**

The analysis revealed that most discrepant intracranial haemorrhage diagnoses (5 out of 8 cases for EDH; 15 out of 22 cases for SDH; 19 out of 29 cases for SAH) were seen in patients with markedly low levels of consciousness, denoting severe traumatic head injury (Figure 1).

Half (4/8) of the discrepant cases for EDH were found to have been admitted on average for a day or less (Figure 2). On the other hand, most discrepancies for SAH were seen in cases that were admitted for two weeks or less (9/29) and four weeks or more (10/29) on average, while for SDH the majority (9/22) stayed in the hospital for more than a month.

In addition, more discrepant case diagnoses were seen with a radiologist or pathologist who had less than three years of working experience (Figure 3).

**Discussion**

The current study found a significant difference in haemorrhage detection between ACT and autopsy. Individual intracranial haemorrhage detection discrepancies ranged from 9.41% to 34.12%, with SAH carrying the highest rate. This is consistent with what has been reported by a number of previous studies that collectively reveal discrepancy rates ranging from 9% to 39%. There are varying findings concerning discrepancy rates for SAH with the majority of previous studies showing high discrepancy in keeping with the current study.

The study also found that in general ACT had a diagnostic accuracy of 44.7%. As such, the high level of discrepancy for SAH was attributable to misclassification, which may mean misdiagnosis, and to a combination of haemorrhages that could have masked the SAH. Also, a high SAH discrepancy rate (79% of SAH cases) was noted with prolonged length of hospital stay, probably due to haemorrhage resorption with time. A progressive clearance of red blood cells in the cerebrospinal fluid results in approximately 50% of SAHs not being visualised after one week of occurrence, and this process can be shorter or longer. This implies that the majority of the SAH previously diagnosed under an ACT scan may after approximately three weeks not be seen in an...
Moreover, the study addressed only three types of brain haemorrhages (EDH, SDH and SAH); therefore, the findings cannot be generalised to forensic pathology practice, or any other type of intracranial haemorrhage. Further research with a larger sample size and broader scope is recommended.

Conclusion

The overall detection discrepancy rate of 24.74% and CT diagnostic accuracy of 44.7% implies that ACT scans may not be used as an alternative to reduce the number of autopsies performed at the mentioned facility but can only be used as an adjunct to autopsy. However, the low discrepancy rate in EDH, especially after a day of admission, implies that ACT may be useful for the diagnosis of this haemorrhage in the forensic setting. A markedly reduced level of consciousness, length of hospital stay depending on the type of haemorrhage and three or fewer years of doctors’ experience all contributed to discrepancies observed between ACT and autopsy findings. The study employed a limited sample and thus calls for more similar studies in both high and low- and middle-income countries.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors’ contributions

M.I.H. conducted the research and produced a mini-dissertation. M.J.S. supervised M.I.H. and prepared the publication manuscript.

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Data availability statement

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Disclaimer

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References

1. Jalalzadeh H, Giannakopoulos GF, Berger FH, Fronczek J, Van De Goot FRW, Reijnders UI. Post-mortem imaging compared with autopsy in trauma victims – A systematic review. Forensic Sci Int. 2015;257(December):29–48. https://doi.org/10.1016/j.forsciint.2015.07.026
2. Kasahara S, Makino Y, Hayakawa M, Yajima D, Ito H, Iwase H. Diagnosable and non-diagnosable causes of death by postmortem computed tomography: A review of 339 forensic cases. Leg Med. 2012;14(5):239–245. https://doi.org/10.1016/j.legalmed.2012.03.007

3. Yanig G, Guranda L, Or J, Zaitsev K, Konen E, Hiss J. Correlation between radiological and pathological findings for a sudden death incident in the emergency department. Isr Med Assoc J. 2011;13(11):707–708.

4. Bagliivo M, Winkelhoffer S, Hatchd OM, Ampanzi G, Thali MJ, Ruder TD. The rise of virtual autopsy computed tomography in forensic radiology – Analysis of the literature between the year 2000 and 2011. J Forensic Radiol Imaging. 2013;1(1):3–9. https://doi.org/10.1016/j.jforri.2012.10.003

5. Liisanantti JH, Ala-Kokko TI. The impact of antemortem computed tomographic scanning on postmortem examination rate and frequency of missed diagnosis – A retrospective analysis of postmortem examination data. J Crit Care. 2015;30(6):1420.e1–1420.e4. https://doi.org/10.1016/j.jcrc.2015.08.024

6. Brady AP. Error and discrepancy in radiology: Inevitable or avoidable? Insights Imaging. 2017;8(1):171–182. https://doi.org/10.1007/s13244-016-0534-1

7. Bruno MA, Walker EA, Abujudieh HH. Understanding and confronting our mistakes: The epidemiology of error in radiology and strategies for error reduction. Radiographics. 2015;35(6):1668–1676. https://doi.org/10.1148/rg.2015150023

8. Pandol A, Kumar A, Gamanagatti S, Mishra B. Virtual computed tomography in trauma: Normal postmortem changes and pathologic spectrum of findings. Curr Probl Diagn Radiol. 2015;44(5):391–406. https://doi.org/10.1067/j.cpradiol.2015.03.005

9. Leth PM, Struckmann H, Lauritsen J. Interobserver agreement of the injury diagnoses obtained by postmortem computed tomography of traffic fatality victims and a comparison with autopsy results. Forensic Sci Int. 2013;225(1–3):15–19. https://doi.org/10.1016/j.forsciint.2012.03.028

10. Graziani G, Tal S, Adelman A, Kugel C, Bdolah-Abram T, Krispin A. Usefulness of unenhanced post-mortem computed tomography – Findings in postmortem non-contrast computed tomography of the head, neck and spine compared to traditional medical/legal autopsy. J Forensic Leg Med. 2018;58(April):105–111. https://doi.org/10.1016/j.jflm.2018.02.022

11. Panzer S, Covaïov L, Augat P, Peschel O. Traumatic brain injury: Comparison between autopsy and ante-mortem CT. J Forensic Leg Med. 2017;52 (November):62–69. https://doi.org/10.1016/j.jflm.2017.08.007

12. Sharma R, Murari A. A comparative evaluation of CT scan findings and post mortem examination findings in head injuries. Indian J Forensic Med Toxicol. 2006;4(2):2–4.

13. Jones HR Jr, Srinivasan J, Allam G, Baker R. Netter’s neurology [homepage on the Internet]. 2nd ed. Philadelphia, PA: Elsevier Saunders; 2012 [cited 2013 Mar 12]. Available from: https://www.elsevier.com/books/the-netter-collection-of-medical-illustrations-nervous-system-volume-7-part-1-brain/jones-jr/978-1-4160-8387-2

14. Kidwell CS, Wintzermark M. Imaging of intracranial hemorrhage. Lancet Neurol. 2008;7(3):256–267. https://doi.org/10.1016/s1474-4422(08)70041-3

15. Daroff RB, Jakovic J, Mazzotta TC, Pomeroy SC. Bradley’s neurology in clinical practice. 7th ed. Philadelphia, PA: Elsevier; 2016.

16. Bruni SG, Bartlett E, Yu E. Factors involved in discrepant preliminary radiology resident interpretations of neuroradiological imaging studies: A retrospective analysis. AJR Am J Roentgenol. 2012;198(6):1367–1374. https://doi.org/10.2214/AJR.11.7525

17. Meinlick V, Rapts C, McWilliams S, Picus D, Wahl R. On-call radiology resident discrepancies: Categorization by patient location and severity. J Am Coll Radiol. 2016;13(10):1233–1238. https://doi.org/10.1016/j.jacr.2016.04.020

18. Brady AP, O’Laide R, McCarthy P, McDermott R. Discrepancy and error in radiology: Concepts, causes and consequences. Ulster Med J. 2012;81(3):3–9.

19. Filograna L, Tartaglione T, Filograna E, Cittadini F, Oliva A, Pascali VL. Computed tomography (CT) virtual autopsy and classical autopsy discrepancies: Radiologist’s error or a demonstration of post-mortem multi-detector computed tomography (MDCT) limitation? Forensic Sci Int. 2010;195(1–3):13–17. https://doi.org/10.1016/j.forsciint.2009.11.001

20. Lee CS, Nagy PG, Weaver JS, Newman-Toker DE. Cognitive and system factors contributing to diagnostic errors in radiology. AJR Am J Roentgenol. 2013;201(3):611–617. https://doi.org/10.2214/AJR.12.10375

21. Krupinski EA, Berbaum KS, Caldwell RT, Schartz KM, Kim J. Long radiology workdays reduce detection and accommodation accuracy. J Am Coll Radiol. 2010;7(9):698–704. https://doi.org/10.1016/j.jacr.2010.03.004

22. Waste S, Scott J, Gale B, Fuchs T, Kolla S, Reede D. Interpretive error in radiology. AJR Am J Roentgenol. 2017;208(4):739–749. https://doi.org/10.2214/AJR.16.16963

23. Itabashi HH, Andrews JM, Tomiyasu U, Erlich SS, Sathyavagiswaran L. Forensic neuropathology – A practical review of the fundamentals. Burlington, VT: Academic Press; 2007.

24. Saukko P, Knight B. Knight’s forensic pathology. 4th ed. New York, NY: CRC Press; 2016.