Institution: University of Warwick

Unit of Assessment: B12 – Engineering

Title of case study: Advanced forensic imaging technology improves quality of evidence in homicide investigations, securing criminal convictions and cost savings for UK policing

Period when the underpinning research was undertaken: 2011-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Mark Williams	Professor (WMG)	Aug 2003 – Present
Jason Warnett	Assistant Professor (WMG)	Sept 2013 – Present
Gregory J. Gibbons	Reader (WMG)	Aug 1997 – Present
Val Baier	Research Fellow	Dec 2018 – Sept 2020
Julia Brettschneider	Associate Professor (Stats)	Sept 2007 – Present
Thomas E. Nichols	Professor (Stats)	Aug 2009 – May 2017
Wilfrid S. Kendall	Professor (Stats)	1988 – Present
Jagadeesha Kumar	Research Fellow (WMG)	Oct 2009 – Apr 2011
Alex Attridge	Project Manager (WMG)	2003 – Present
Danni Norman	Project Engineer (WMG)	2014 – 2019; 2020 onwards

Period when the claimed impact occurred: 2014-2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Novel image processing methods and 3D visualisation techniques developed at Warwick have given police investigators a powerful new tool for uncovering and evidencing crime. This forensics innovation has been prolifically used to produce evidence for 171 investigations across 18 police forces in the UK, leading to multiple convictions in some of the most serious of cases. There are numerous key advantages for these techniques, including: aiding the understanding of juries, offering a non-destructive means of post-mortem examination, and providing savings in time and money for the police forces involved – with an estimated GBP500,000 saving in total for the 171 investigations. Through integration into the CPD training of 140 practitioners, in addition to underpinning new standard operating procedures, this research has changed criminal investigations into suspicious deaths nationally, enriching our justice system and engendering a safer society.

2. Underpinning research (indicative maximum 500 words)

Computerised Tomography (CT) is an X-ray technique where many scans are digitally combined to provide an accurate image of a solid cross-section. The most well-known application of CT is in medical CAT scans (Computerized Axial Tomography), where axial rotation around a person produces a 3D image of their skeleton. Micro-CT relies on the same underlying technology but is 43,000 times more detailed, down to micron scale. Beyond the medical field, resolution at this level provides a non-destructive technique to characterise materials by probing and measuring structure and properties. Research for this case study falls into two key areas: novel image processing technique development and 3D model reconstruction algorithms to produce manageable data sets for 3D visualisation in micro-CT; and the subsequent application of this technology in forensics. As science used in a court room must be robust by necessity, method validation has been a core focus of the research at Warwick.

In order to obtain high quality volume data from CT, a range of parameters need to be understood and optimized for different materials, shapes and sizes of the test object. Beginning in 2009 researchers in the Warwick Manufacturing Group (WMG – Williams, Attridge, Kumar, Warnett,

Gibbons), in collaboration with the Department of Statistics (Brettschneider, Nichols, Kendall), examined the measurement errors of CT systems to assess the statistical reliability of methods. Projects were conducted to identify the source of errors, revealing insights that had the potential to improve visualisation, accuracy and speed **[3.1-3.3].** On the back of this research Kendall was appointed an Alan Turing Fellow to drive forward statistical techniques for engineering.

The University then developed optimisation methods designed to reduce scanning time and minimise image artefacts which obscure important detail at higher resolutions. In 2010, WMG launched *Premium Vehicle Customer Interface Technologies (PVCIT)*, a GBP5,000,000 Centre of Excellence part funded by Advantage West Midlands, European Regional Development Fund and the EPSRC to provide support to industry in the region. The launch of PVCIT led to a research collaboration with practitioners at the Surgical Training Centre, University Hospitals Coventry and Warwickshire (UHCW) NHS Trust and research partnerships with key stakeholders in pathology. Initially applied to engineering structures, research at Warwick created methods and unique algorithms for reconstruction, in parallel with human anatomy studies to produce models of anatomical features (anterior cruciate ligament, heart, hip and femur). The aim of the anatomical research was to validate novel surgical procedures; physically using cadavers (legs) and virtually through high resolution scanning and reconstruction **[3.4].**

In 2014 a suitcase removed from a canal in the West Midlands was taken to UHCW and scanned, revealing a dismembered body. Warwick researchers applied their novel 3D technologies including micro-CT and 3D printing to the forensic investigation which followed. Micro-CT was successfully employed to virtually align severed skeletal elements from different locations, analyse tool marks created during the dismemberment, and virtually dissect charred evidence. High resolution 3D prints of burnt human bone allowed for physical visualisation to assist with reconstruction of the circumstances around the death. This research was the first time Warwick's scanning methodologies were employed in this way **[3.5].**

Working on current investigations over the last 6 years enabled Warwick and the West Midlands Police (WMP) to develop baseline datasets of normal anatomical variation and common types of injuries, which is being used to determine cause of death. The micro-CT images have been validated against histology, the current gold standard used in forensic analysis. This is a prerequisite for a new method to be used in the criminal justice process as demanded by regulatory bodies **[3.6].**

As a result Warwick have created a world first, a unique catalogue of anatomical variants and injuries resulting from strangulation, using high resolution micro-CT **[3.7].** This research has gathered data from homicide cases from the WMP to establish trends and patterns for different methods of strangulation – which is in essence similar to investigation of failure modes for engineering materials. In 2019 the Forensic Centre for Digital Scanning and 3D Printing was founded in collaboration with the WMP **[G3]**, to make Warwick's technology more accessible to police forces nationally and promote forensic science excellence in the UK.

3. References to the research (indicative maximum of six references) **Warwick = Bold**

All research papers were published in peer-reviewed journals

[3.1] Kumar, J., **Attridge, A.**, Wood, P. K. C. and **Williams, M. A.** (2011) *Analysis of the effect of cone-beam geometry and test object configuration on the measurement accuracy of a computed tomography scanner used for dimensional measurement*. Measurement Science and Technology, 22 (3). pp. 1-15. doi: 10.1088/0957-0233/22/3/035105

[3.2] Warnett, J. M., Titarenko, V., **Kiraci, E.**, **Attridge, A.**, Lionheart, W. R. B., Withers, P. J. and **Williams, M. A.** (2016) *Towards in-process x-ray CT for dimensional metrology*. Measurement Science and Technology, 27 (3). pp. 1-14. doi:10.1088/0957-0233/27/3/035401

[3.3] Kueh, A., Warnett, J. M., Gibbons, G. J., Brettschneider, J., Nichols, T. E., Williams, M. A. and **Kendall, W. S.** (2016) *Modelling the penumbra in computed tomography.* Journal of X-Ray Science and Technology, 24 (4). pp. 583-597. doi:10.3233/XST-160576

[3.4] Norman, D., **Metcalfe, A. J.**, Barlow, T., **Hutchinson, C. E.**, Thompson, P. J. M., Spalding, T. J. W. and **Williams, M. A.** (2017) *Cortical Bony Thickening of the Lateral Intercondylar Wall: The Functional Attachment of the Anterior Cruciate Ligament*. American Journal of Sports Medicine, 45 (2). pp. 394-402. doi: 10.1177/0363546516665804
[3.5] Baier, W., **Norman, D. G.**, **Warnett, J. M.**, Payne, M., Harrison, N. P., Hunt, N. C. A., Burnett, B. A. and **Williams, M. A.** (2017) *Novel application of three-dimensional technologies in a case of dismemberment. Forensic Science International*, 270. pp. 139-145. doi: 10.1016/j.forsciint.2016.11.040
[3.6] Baier, W., Mangham, C., **Warnett, J. M.,** Payne, M., Painter, M. and **Williams, M. A.** (2019) *Using histology to evaluate micro-CT findings of trauma in three post-mortem samples — First steps towards method validation*. Forensic Science International, 297. pp. 27-34. doi: 10.1016/j.forsciint.2019.01.027
[3.7] Baier, W., Burnett, B. A., Payne, M., **Warnett, J. M.** and **Williams, M. A.** (2020) *Using micro computed tomography to examine the larynx in cases of suspected strangulation- a comparison of case findings and control images.* International Journal of Legal Medicine, 134. pp. 1441-1450. doi:10.1007/s00414-019-02194-y

Grants

[G1] Kendall, W., Williams, M. A., Gibbons, G., Nichols, T., Brettschneider, J.A. *Inside-out: Statistical methods for Computed Tomography validation of complex structures in Additive Layer Manufacturing.* **Sponsor**: EPSRC [EP/K031066/1] **Duration:** Oct 2013 – Sep 2016 **Award**: GBP498,109
[G2] Williams, M. A., **Davis, C.**, **Warnett, J.**, **Loveridge, M.**, **Montana, G.**, **Dixon, S. M.** and **Shollock, B.**, *EPSRC Strategic Equipment - High Speed CT*. **Sponsor:** EPSRC [EP/S010076/1] **Duration:** Nov 2018 - Nov 2021 **Award:** GBP1,080,776
[G3] Williams, M.A. *Forensics Research & Homicide Hub* (series of 6 grants). **Sponsor:** West Midlands Police **Duration:** 2016 - 2023 **Award:** GBP274,500
[G4] Withers, P., **Williams, M.A., Warnett, J**. *National Research Facility for Lab X-ray CT*. **Sponsor:** EPSRC [EP/T02593X/1]. **Duration**: Nov 2020 – Oct 2025 **Award:** GBP10,097,652

4. Details of the impact (indicative maximum 750 words)

Forensic science has always been a cornerstone of the criminal justice system. From highlighted evidence in the 2019 Science and Technology Select Committee report (Forensic science and the criminal justice system: a blueprint for change), the benefits of rapid forensic science are "*the potential to reduce costly police investigative time through early identification of offenders or the exoneration of innocent suspects; earlier arrests can lead to a lower financial impact of prolific offenders who are otherwise free to re-offend; and of course compelling, high quality forensic science can lead to earlier guilty pleas, quicker trials and a resultant reduction in expensive court time.*" At the same time, the report warned of what could come from an underdeveloped capacity for – and leadership in – UK forensic science: "*Crimes may go unsolved and the number of miscarriages of justice may increase*" **[5.1a]**.

Representing a first for such an inquiry, the University of Warwick and West Midlands Police (WMP) submitted joint evidence to the same 2019 Select Committee report **[5.1b]** based on an ongoing and productive collaboration which started in 2014 at the forefront of police forensics **[5.2]**. Submission of this evidence led to a roundtable meeting in July 2019, facilitated by the Home Office and chaired by the Forensic Science Regulator (Dr Gillian Tully), where the new Forensic Centre for Digital Scanning and 3D Printing (founded in 2019 between Warwick and the WMP) was heralded as best practice – in particular for "*demonstrating the value that can be leveraged from University research to provide evidence for forensic investigations*" **[5.2]**. With national reach, the Centre provides access to the forensic capabilities at Warwick to police forces across the UK and in overseas territories **[5.3]**. Stand-out examples of impact between Warwick and the WMP – on criminal cases, practitioner training, cost savings to police forces nationwide and on the development of forensic standard operating procedures (SOPs) – are detailed below:

Benefits of micro-Computerised Tomography (micro-CT) and 3D printing in forensics: As a complementary technique to existing post-mortem procedures, micro-CT grants a number of distinct advantages in criminal investigations. In addition, preparation of 3D printed models for use in the court room aids with prosecution of serious crimes. Just as production enhancements can result in efficiencies in manufacturing, so too can micro-CT and 3D printing constitute analogous process improvements in the criminal justice system:

- Forensic methodological advancements. In cases of strangulation, factures in the laryngeal skeleton were often too subtle to detect in conventional autopsy techniques. By scanning at a spatial resolution of 40µm, micro-CT allows for detailed examination of these delicate structures – with subsequent research **[3.7]** differentiating between accidental death and murder. This has been used directly to rule out foul play and well as in multiple convictions, with the former highlighted in the following section. On advancing national understanding the Assistant Director of Forensic Services at WMP expanded: "*This research is truly ground-breaking and has helped change our understanding of the impact of the use of force on the body during numerous modes of strangulation*" **[5.2]**.
- Non-invasive, non-destructive analysis. As with analogous Computerized Axial Tomography (CAT) scans, micro-CT similarly leaves forensic samples untouched. A Home Office registered Consultant Forensic Pathologist in the Forensic Pathology Services (FPS) outlined that this offers "*significant value to forensic analysis at the front end of an investigation*" before complementary, destructive analysis (e.g. histology) is deployed **[5.4]**. Where samples themselves are delicate – a burnt shoulder bone **[5.5]** – the non-destructive nature of micro-CT allows for structural interrogation while leaving this crucial forensic evidence intact **[5.3]**.
- Cost and time savings. Analysis has shown that in three separate criminal cases GBP10,000 was saved for each, with Mark Payne (Assistant Chief Constable of WMP) further qualifying that this saving extends to around a third of all investigations where micro-CT has been applied. By extrapolation, at least GBP500,000 had been saved up to mid-2020 – with Mark Payne adding, "*Technology and research at Warwick has therefore significantly improved our investigative processes and outcomes*" **[5.3]**. Any savings and efficiencies gained in policing correspond directly to a saving for the taxpayer.
- Presentation of sensitive evidence. Using 3D printed artefacts as well as interactive presentations of micro-CT scans in court reduces the distress of both the jury and family members who are present **[5.3]**, and otherwise assists in the jury's understanding of a very complicated pathological picture **[5.6]**. This expert witness evidence has been used in a number of convictions, with key examples detailed below.

Micro-CT and 3D printing in criminal investigations: Between 2014 and 2020 micro-CT was used in 171 criminal cases in 18 police forces, in addition to facilitating multiple convictions and with Warwick forensic services remaining available during COVID-19 lockdown **[5.3]**. Overall, this prolific usage is a testament to the broad applicability of micro-CT in forensics and indicates extensive national uptake. Below are but a few notable investigations where Warwick technology made a vital contribution:

- In a case of complex dismemberment, Warwick researchers delivered one of the first examples of micro-CT technology as a forensic radiological method in a UK courtroom. Asked to examine a charred piece of evidence thought to contain human bone, researchers discovered it was a perfect jigsaw fit to another piece of bone found elsewhere, and were able to show the tool marks on both pieces in micro scale (20 microns). This provided a crucial link between the site where the body had been disposed of and the home of the murder suspect – leading in part to a murder conviction **[5.5].** In recognition, Prof Williams was awarded a ***Chief Constable's Award*** for his work on Operation Sanderling: "*You worked closely with the investigation team with ground breaking 3D printing and scanning technology. Not only did this result in the crucial identification of a missing shoulder bone, but your subsequent assistance with the pathology and trial processes assisted the jury with their understanding of the case and eventual positive outcome*" **[5.7]**.
- Following the detection of several injuries to an 18-month-old infant, micro-CT scanning was conducted at WMG. The right femur (thigh bone) showed a grossly displaced fracture with a

large amount of callus forming around it, indicating that healing processes had begun without proper medical attention and the ribcage displayed 20 individual fractures in different stages of healing. The [text removed for publication] of the Crown Prosecution Service indicated that this "*evidence was instrumental in establishing the circumstances and causation of injury and death*." Further, [text removed for publication] elaborated that this "*was distinctly advantageous both from an evidential review and prosecution presentation perspective*", as with no witnesses to the crime establishing the sequence of events leading to the death by alternative means is critical **[5.6]**. The trial resulted in a manslaughter conviction.

- Beyond securing convictions, research at Warwick has also been crucial in ruling out foul play in suspicious circumstances. In the post-mortem examination of an elderly male, skull fractures were revealed to be only a few centimetres apart, which is not consistent with a fall and so murder was impossible to initially rule out. In working with a forensic scientist, modelling by the University revealed that in this instance the deceased had fallen backwards and injured himself on a door latch **[5.3]**. Similarly, in a separate instance that drew on techniques linked to the published research **[3.7]**, 3D scans of neck structures revealed a death to have been caused by accidental asphyxiation rather than strangulation as was initially suspected. On the subject of ruling out foul play, Assistant Chief Constable Mark Payne says: "*The ability to provide the families of the deceased with clarity earlier in the investigation has been invaluable and is one of the key benefits of the project*" **[5.3]**.

Wider uptake – CPD training and standard operating procedures (SOPs): Through the foundation of the Forensic Centre for Digital Scanning and 3D Printing in 2019 between Warwick and the WMP **[G3]**, an ongoing and lasting practitioner impact has been felt by UK police forces and forensic science experts. The Centre was founded expressly to make Warwick technology available throughout the UK, enabling the innovation to be exploited and disseminated nationally **[5.2]**. The Centre goes hand-in-hand with training delivered by the University, with over 140 specialist practitioners receiving CPD on image processing methods and 3D visualisation techniques to uncover evidence in homicide investigations **[5.3]**.

In addition, standard operating procedures (SOPs) for micro-CT have been developed by Warwick and WMP. These SOPs cover all aspects of forensic analysis of samples by micro-CT, including transportation, storage and calibration of the machines **[5.2]**. As a result, since 2016 referrals of suspicious child deaths and strangulation to Warwick for post-mortem examination have become national practice through use of these SOPs **[5.4]**. This establishes innovations from Warwick as an important part of the overall investigative arsenal available in UK policing.

In terms of broader engagement nationally a talk presented by Prof Williams and Assistant Chief Constable Mark Payne at the British Science Festival (BSF) was attended by 150 students from multiple schools, helping to further spark interest in UK forensic science. At the 2019 BSF talk Payne observed that through science "*it's increasingly difficult to get away with murder*" which, ultimately, is "*good news for everyone*" **[5.5]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1a] Forensic science and the criminal justice system: a blueprint for change (Science and Technology Select Committee, 2019); **[b]** WMP/Warwick inquiry evidence
[5.2] Statement from Assistant Director of Forensic Services, WMP
[5.3] Statement from Assistant Chief Constable, WMP
[5.4] Statement from Consultant Forensic Pathologist, Forensic Pathology Services
[5.5] The Telegraph article published 13/09/19 https://tinyurl.com/y26e6wsd
[5.6] Statement from [text removed for publication], Crown Prosecution Service
[5.7] Prof Mark Williams' Chief Constable Award letter