Institution: Sheffield Hallam University		
Unit of Assessment: UOA05 - Biological Sciences		
Title of case study: Criminal profiling through molecular fingerprinting		
Period when the underpinning research was undertaken: 2010 - 2018		
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:**
Simona Francese	Professor of Forensic and Bioanalytical Mass Spectrometry (PI)	2008 to present
Rosalind Wolstenholme	Senior Lecturer	2007 to present
Robert Bradshaw	Senior Lecturer	2016 to present
Malcolm R. Clench	Professor of Mass Spectrometry	1990 to present
Period when the claimed impact occurred: 2014 - 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

For over 100 years fingerprints have only been exploited to provide biometric information through the ridge pattern. The pioneering development of Matrix Assisted Laser Desorption Mass Spectrometry Imaging and Profiling (MALDI MSI and MALDI MSP) methods allows recovery of additional intelligence about a suspect through detection and identification of molecules in their fingermarks, simultaneously providing molecular images of the ridge pattern.

This translational research by Sheffield Hallam University has resulted in:

(i) adoption of molecular fingerprinting techniques by the Home Office, UK Law Enforcement Agencies and international bodies;

(ii) application of molecular fingerprinting techniques in the investigation of serious crimes in the UK and Europe;

(iii) increased worldwide awareness and knowledge of the science behind fingerprinting.

2. Underpinning research

Fingerprints have been the most powerful means of biometric identification for over a century. Even with the advent of DNA, two-thirds of suspect identifications are still the result of fingerprinting techniques. The process has remained largely unchanged in scope, where suspect identification relies on the comparison between the ridge pattern of a crime scene mark and a fingerprint record. Consequently, there are a number of scenarios in which current fingerprinting may fail, such as smudged, partial, empty and/or overlapped marks, or no fingerprint record.

In 2008, the Fingerprint Research Group at Sheffield Hallam University (SHU) led by Francese, initiated the development of translational molecular fingerprinting, based on the use of Matrix Assisted Laser Desorption Ionisation Mass Spectrometry Profiling / Imaging (MALDI MSP/I) methods. Molecular fingerprinting greatly enhances the forensic value of the fingermark evidence by detecting and visualising the molecules that can be found within, including endogenous (naturally occurring), semi-endogenous (introduced into the body e.g. drugs, medications, food excreted through sweat) and exogenous (contaminants). The detection and visualisation of these molecules on the ridges of a mark enables the provision of ridge pattern details and of a novel way to conduct criminal profiling to be employed specifically for (i) informing crime scene management (ii) narrowing down the pool of suspects and (iii) speeding up investigations.

The research enables reconstruction of the ridge pattern through visualisation of the molecules detected whilst keeping the fingerprint intact (2009-2017, **R1** - **R4**). In this development, a UV absorbing matrix is sprayed (Imaging) or spotted (Profiling) on the fingermark to obtain biometric information and/or molecular intelligence, respectively. A laser is fired at a wavelength of ~337nm, causing desorption and ionisation of the molecules, which are detected and visualised on the fingerprint. The technology can provide fingerprint ridge detail additional to that obtained by conventional fingerprinting techniques. Multiple molecular images can be obtained from the thousands of molecules simultaneously detected; images can be stitched or superimposed to improve ridge pattern continuity/coverage. Overlapping fingermarks can be separated by individually recalling images of molecules that are distributed solely in one of the two (or more) overlapping marks. Both capabilities increase the chances of suspect identification.

In parallel, Francese's group pursued the recovery of personal and lifestyle information around the fingermark's owner (**R5**, **R3**) and/or on their actions prior to or during committing the crime (**R2**, **R4**). These findings provide:

(i) a method to determine the sex of the suspect from their fingermark peptidic/protein composition (2012, **R5**);

(ii) intelligence on the use of condoms enabling associative/probative evidence in the context of rape and sexual assault crimes (2011-2016, **R2**);

(iii) a method enabling the detection and mapping of drugs (2015, **R3**) confirming this capability operationally (2015-2017, **R6**);

(iv) a method for the detection of blood in marks and stains with higher specificity than the current forensic methods, providing insights into the dynamics of the bloodshed (2014-2017, **R4**).

The development of the patented method for MALDI-compatible visualisation, removal, preparation and analysis of latent (invisible) fingermarks was the first example of translational research enabling MALDI implementation at crime scenes (2010-2013, **R7**). Since 2011, the potential applicability of MALDI MS to crime scene investigation has attracted funding from and collaborations with end users. The Home Office (now Defence Science and Technology Laboratory) funded four projects (2011-2018) at a total of GBP162,065. Three projects investigated compatibility of molecular fingerprinting with current forensic enhancement techniques for operational deployment (**R1**, **R4**); another project developed methods to provide additional personal information about a fingerprint donor. In 2014, the ERASMUS programme and the Netherlands Forensic Institute jointly funded the development of molecular fingerprinting methods for the detection and mapping of drugs and metabolites (**R3**). Translation of the technology was pursued, working with West Yorkshire Police (2016-2018), and the resulting publication (**R6**) was the first peer reviewed published demonstration of applicability of the developed protocols to police casework to inform and speed up investigations.

3. References to the research

R1. Bradshaw R, Bleay S, Wolstenholme R, Clench MR and **Francese S**, “Towards the Integration of MALDI MSI into the current fingermark examination workflow". ***Forensic Science International***, 232(1-3):111-24, 2013 https://doi.org/10.1016/j.forsciint.2013.07.013

R2. Bradshaw R., Wolstenholme R., Ferguson L.S., Sammon, C., Mader K., Claude E., Blackledge R., Clench, MR, **Francese S**., "Spectroscopic Imaging based approach for condom identification in condom contaminated fingermarks", ***Analyst***, 138(9):2546-57, 2013. https://doi.org/10.1039/c3an00195d

R3. Groeneveld G., de Puit M., Bleay S., Bradshaw R., **Francese S**., "Detection and mapping of illicit drugs and their metabolites in fingermarks by MALDI MS and compatibility with forensic techniques", ***Scientific Reports (Nature Publishing Group)***, 5:11716, 2015 https://doi.org/10.1038/srep11716

R4. Deininger L., Patel E., Clench M.R., Sears V., Sammon C., **Francese S**., "Proteomics goes forensic: detection and mapping of blood signatures in fingermarks", ***Proteomics***, 16(11-12):1707-17, 2016 https://doi.org/10.1002/pmic.201500544

R5. Ferguson L., Wulfert F., Wolstenholme R., Fonville J.M., Clench M.R., Carolan V.A., **Francese S**., "Direct detection of peptides and small proteins in fingermarks and determination of sex by MALDI mass spectrometry profiling", ***Analyst***, 137(20):4686-92, 2012 https://doi.org/10.1039/c2an36074h

R6. Bradshaw R., Denison N., **Francese S**., "Implementation of MALDI MS profiling and imaging methods for the analysis of real crime scene fingermarks", ***Analyst***, 142(9):1581-1590, 2017 https://doi.org/10.1039/C7AN00218A

R7. Ferguson L, Wolstenholme R, **Francese S.** GB2489215 (01/05/2013) Improvements to MALDI MSI (Dry-Wet Matrix Deposition). Granted Hong Kong patent (HK1169854A1) (15/03/2011) Granted US patent (US9261438B) (16/02/2016), Granted Europe patent (EP 2 684 021 B1) (08/07/2020). Available on request.

R1-**R6** were rigorously peer-reviewed prior to publication in leading journals in the field. **R7** lists the international patents related to this research.

4. Details of the impact

(i) Adoption of molecular fingerprinting techniques by the Home Office, UK law enforcement agencies and international bodies

Collaborative research with West Yorkshire Police and the Home Office has led to the inclusion of MALDI MSP/I in the Home Office Fingermark Visualisation Manual (FVM). The FVM sets out operational recommendations for formulations, protocols and methods to the major crime units of all 43 police forces in the UK. In 2014, MALDI MSP/I was included as a Category C technique, indicating *"A process at a developmental stage exhibiting potential […] for occasional operational use […] when Category A processes have been exhausted."* (**E1**) This is a five-point scale (A-E), where categories A-C require particularly rigorous and extensive validation. A Category C listing *"is an achievement in itself as the majority of new methods fail before this point."* (Editor, FVM, **E2**)

In 2020 it was confirmed that the MALDI MSP/I process has been promoted to Category B as an *"Established process [...] likely to offer benefits [...] for occasional operational use [...] and when all Cat. A options have been exhausted"* (**E1**). *"Category B processes are generally more established and therefore more likely to be used on casework […] It is a lot harder for processes to be included as Category A or B due to the additional evidence required to establish its use and effectiveness. […] It is worth emphasising the importance of such advancements [...] where chemical information within fingermarks, for the first time, has the potential to add significant value to supporting major and more complex crime investigations".* (Editor, FVM, **E2**)

In addition to UK use, the European Network of Forensic Science Institutes (ENFSI) Fingerprint Working Group has adopted the FVM as the key reference document across all European forensic institutes, forming the basis of the ENFSI Fingerprints Best Practice Manual (**E2**). The FVM has sold >350 copies to agencies across the globe in 37 countries including EU, New Zealand, Australia, US, Scandinavia, South Africa, Israel and Hong Kong. (**E2**).

The Home Office scouts and communicates innovative scientific research and its potential operational applications to UK practitioners, the policing community and government agencies. In 2017, molecular fingerprinting was highlighted in a Home Office newsletter for use in serious crimes involving blood (**E3**). The Home Office Senior Technical Specialist and Service Lead has also recommended this technique for operational use to the Criminal Cases Review Commission (CCRC): *"We are already aware of one case being investigated by the CCRC where MALDI could provide resolution, and have suggested that CCRC explore this option"* (**E4**). CCRC subsequently requested method validation in order to grant access to relevant cases.

ii) Application of molecular fingerprinting techniques in the investigation of serious crimes

Molecular fingerprinting is considerably more resource-intensive than standard fingerprinting techniques. Consequently, it is specifically applied to 'serious crimes' (e.g. murder), rather than to 'volume crimes' (e.g. burglary). Of the 19 requests for MALDI MS analysis from police / forensic providers to date, the following three examples are illustrative of the implementation of molecular fingerprinting to assist in the investigation of serious crimes.

(a) Prevention of a potential miscarriage of justice

Following the publication on condom lubricant identification (**R3**), Dutch forensic provider FORENSICON requested the adaptation of MALDI MSP molecular fingerprinting in a 2016 investigation. The case involved the possible sexual abuse of minors by their father and required analysis to determine the presence of condom polymer lubricants in bedlinen stains. The use of MALDI MSP demonstrated that the detected polymer did not match any present in the condoms used by the father. The client (the mother) was reassured that no evidence was found suggesting sexual activities and did not press charges. The FORENSICON CEO highlighted how the intelligence provided avoided a potential miscarriage of justice: "*without this information the client might have made a declaration to the police with all the negative consequences for her marriage and her husband [...] it is an example of how research can provide a client with relevant insights needed to confirm or exclude their beliefs*" (**E8**).

(b) Provision of new biometric information

In 2017 the Danish National Police requested the application of molecular fingerprinting in a missing person case. The body of a young girl was found in a pond six months after her disappearance. A tape wrapped around her neck was recovered and conventional CSI enhancement techniques suggested the presence of a fingermark, with no ridge detail. Twenty-two months after the incident, molecular fingerprinting enabled the visualisation of a partial fingermark with ridge pattern detail. "*The MALDI MSI analysis showed that the fingermark details were severely enhanced [....] The clarity of the ridge details was improved […] which makes it more likely that the Danish Identification Unit will be able to identify the perpetrator of this homicide […] This kind of research gives the forensics a new way to examine traces which makes it more difficult to get away with any kind of crime*." (Case Commissioning Officer, Danish National Police, **E7**).

(c) Enhanced criminal profiling

In 2014 West Yorkshire Police were investigating a harassment case and requested the provision of any intelligence recoverable from a suspect's mark found at the crime scene. Twenty-six days after recovery, molecular fingerprinting was applied to the fingermark and determined the presence of a unique metabolite indicating simultaneous consumption of cocaine and alcohol. Alcohol potentiates the effects of cocaine and this information, not obtainable by standard investigations, was revealing of the state of mind of the individual. Just before the court hearing, the suspect confessed alcohol consumption, validating the molecular fingerprinting findings. The Director of the Regional Scientific Support Services, Yorkshire and the Humber, reflected that "*Prof. Francese and her team have demonstrated that contextual information can be obtained in fingermarks in an operational environment. [...] We see value of this capability and we have ensured that our Area Forensic Managers are fully briefed on this methodology in order for them to consider MALDI in their forensic strategies*" (**E9**).

(iii) Increased awareness and knowledge of molecular fingerprinting

Due to high profile and diversified dissemination, the research has raised awareness among end users and the wider public, stimulating interest in understanding the underpinning science. Between 2013-18, coverage of the technology appeared on a wide range of media outlets including BBC Breakfast and The Today Programme on Radio 4. A BBC online piece was the most read on the day across of all BBC online platforms (>1.6M reads) (**E5**). A TED talk by Prof Francese (2018) has accrued in excess of 2.5 million views and has been translated into 24 languages (**E6**). Other high profile dissemination routes include ('by invitation only') European Network of Forensic Science Institutes (ENFSI, 2017); the Australian and New Zealand Forensic Science Symposium (ANZFSS, 2018); and the 2018 UK Royal Society of Chemistry Christmas Lecture (>300 6th formers attendees).

The media coverage has prompted in excess of 100 online commentaries, personal letters and emails requesting more information about molecular fingerprinting. A member of the public commented online: "*I learned that there is a lot of information that can be found through fingerprints. It's amazing that we can find almost everything through fingerprints that I've thought were nothing*" (**E6**). From the Royal Society of Chemistry Christmas lectures, feedback included: "*incredibly eye opening*"; "*helped to spark my interest in chemistry, especially mass spectrometry*". Of the over 300 students surveyed, 72% declared to feel more positive about going to University in the future and 11% more students said that they "*would definitely pursue higher education as a result of learning about molecular fingerprinting*" (**E5**).

Dissemination has stimulated an interest in learning more amongst end user groups. Following ANZFSS, an Australian fingerprint expert wrote "*I am very interested to learn more about the process. Is it possible to get some of your publications/results? I would like share these with the fingerprint experts to create discussion on the opportunities this type of testing can add to our field*" (**E5**). Consequently, casework enquiries from government lawyers (UK, Denmark, Canada, South Australia, Emirates), law enforcement agencies (UK, Denmark, Canada, South Australia, Emirates), forensic providers (UK, The Netherlands, New Zealand) and criminal lawyers (UK, Austria, US) have been received to inform on-going (and cold) major crime investigations, appeals to Supreme Courts and testimony in Senate hearings (**E10**). Following the TED talk (**E6**), a Case Commissioning Officer from the Danish National Police wrote: "*I am going to inform all the units of the National Forensic Centre about the MALDI MSI analysis of fingerprints by showing the TED video by Prof. Francese*" (**E7**).

5. Sources to corroborate the impact

E1. Home Office- CAST publication H. Bandey, V. Bowman, S. Bleay, R. Downham and V. H. Sears, Fingermark Visualisation Manual, ed. H. Bandey, CAST, Home Office, Sandridge, UK, 2014. - pp 4.61-4.62 and 6.2.10

E2. Testimonial Defence Science and Technology Laboratory (Ministry of Defence) (UK) – Editor, FVM

E3. Home Office - CAST newsletter CAST Fingermark Visualisation Newsletter #2 March 2017, pp 3 and 10. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/604527/fingermark-visualisation-update-mar2017.pdf

E4. Testimonial Home Office (UK) - CAST Senior Technical Specialist and CAST Service Lead

E5. Evidence of public engagement impact and media coverage

E6. TED talk, Vancouver 2018, https://www.ted.com/talks/simona_francese_your_fingerprints_reveal_more_than_you_think?language=en

E7. Testimonial Danish National Police – Case Commissioning Officer

E8. Testimonial FORENSICON B.V. Testimonial (Netherlands) - CEO & Forensic Advisor

E9. Testimonial Yorkshire and Humber Regional Police testimonial (UK) - Director of Regional Scientific Support Services

E10. Enquiries from LEA, government agencies and forensic providers to use or implement MALDI/molecular fingerprinting in forensics. (Enquiries containing classified material can be made available for audit purposes).