# Chapter 4
# End User Commentary on Novel Technological Applications for Latent and Blood-Stained Fingermark Aging Studies

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As a matter of fact, since last century, forensic science borrowed technologies and methods from other scientific disciplines. In principle, this consolidated attitude has not to be regarded with a negative perspective. Being part of the broad science community should help forensic science to be more actively engaged with scientific methodologies and principles, as recommended by PCAST report: "Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods". Unfortunately, the trend over the decades in fingerprint science was to use these methods and principles, as formulated in the last century, in the daily routine, resulting in subjective assumptions without the necessary support of robust and reliable data.

By far, fingermarks and DNA analyses are the most widely forensic examinations leading to human identification, with a very high degree of admissibility as evidence in court.

The association between a fingermark found at the scene of crime and its potential donor mainly, or solely, originate from the morphological aspects of the trace, which have to find correspondence, within pre-determined tolerances, with a controlled print acquired from the donor. Currently, there are huge efforts among fingerprint community to standardize the steps of the methodology used to establish a correct association, and to populate with detailed sub-processes the so-called ACE-V method (Analysis, Comparison, Evaluation and Verification).

Moreover, as illustrated in the literature, fingerprints have the potential to reveal intelligence upon the donor habits, abuses, sex, DNA and gunshot residues. For the most, the acquisition of all these information comes through chemical analysis of the fingermark deposit and/or its contaminants. This type of intelligence could give to investigators and to criminal justice system a huge boost in the event reconstruction.

Nevertheless, the time of deposition of a fingermark remains an unsolved question for the vast majority of the cases. The time of deposition of the trace could not

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be practically considered as a valuable tool to avoid the erroneous attribution of a fingermark to a potential donor, reached on the bases of the friction ridge patterns and details.

In order to reduce erroneous inclusions, other avenues have to be followed. A re-consideration of the fingerprint evidence not anymore as a discrete variable, like a Boolean function, but as a *continuum*, which varies from exclusion to identification, will be the way forward for fingerprint science. Fingerprint comparison in the near future will be driven by probabilities and reference population data.

However, even under the hypothesis of negligible error rates in the comparison process between traces and reference prints, the time of mark deposition cannot be reliably estimated. Thus, fingerprint scientists could reasonably associate a person to a surface where the fingermark was recovered, but only in very rare cases, they are capable to prove to the trier of fact, when the fingermark residue was deposited.

Fingermark ageing arise as an issue when potential suspects had left their fingermarks at the scene and the trier of fact needs to discriminate between a legitimate accesses, from the one pertaining to the crime. In such case, fingerprint ageing becomes of paramount importance, but the answer to all these questions still needs to be found.

The main reason why this problem does not have a general solution yet, is due to the multiple factors governing the aging process, and their huge variations.

According to Girod, Ramotowski et al. five factors could be summarized, which have a relevant effect to the process: (1) donor sweat characteristics, i.e. intra-variability or inter-variability in the population, (2) deposition conditions, (3) type of substrate, i.e. material, roughness, porosity, electrical charge, coatings, (4) environmental conditions, i.e. variation of thermodynamic quantities, coupled with mechanical effects due to atmospheric agents, (5) visualization techniques used to reveal the fingermarks.

Because of the aforementioned reasons, at present, a robust and reliable technique does not exist allowing the determination, with an acceptable degree of approximation, the age of a fingerprint residue.

In literature, the publication of the very few aging studies started in the 1960s. From the early studies, probably the most complete is the one carried on by Holyst, published in 1987, lately largely used for the purpose.

In addition, some case reports were published, describing ad hoc experiments, carried on in very specific conditions, with limited consideration for the chemical and physical properties of the sweat, resulting in a very limited applicability in general cases. Some of them conducted to the conviction of the suspects, while some others were not considered to this respect.

Whenever the evidential value of a fingermark is disputed by a legitimate access to the scene, specific aging studies could be conducted by a very careful consideration of all parameters considered by Girod, Ramotowski et al. using the same visualization technique applied at the scene and/or in the laboratory. In order to evaluate correctly the most variable quantities, such as sweat composition and fingermark quality, depletion series and multiple donors should be used in the experiment. In any case, the results must be correctly evaluated, without discarding any possibility.

In a murder case occurred in Bologna, Italy, where the author carried out the investigation, a fingermark, among others, was developed with black powder on the frame of a door in the house of the deceased.

Later, a fingermark comparison was carried on, resulting in the association of the mark with the younger son of the victim. According to the very limited information usually available to the forensic department, the association was considered as a legitimate access, and therefore of no evidential value. Nevertheless, the prosecutor office contacted again the laboratory few months later: the outcome of the investigations proved that the younger son of the victim had no more relations with his family since almost ten years before the incident. Thus, the question "*How old was the fingermark found on the frame?*" was formulated by the prosecutor office; in this case, ageing assumed a high relevance in the case, even if only at a later stage.

The scene of crime was accessed again. A careful inspection of the surface of the frame was carried on, in order to analyze the nature of the surface and to start to design an ageing experiment. Eventually, during the examination, the Carabinieri verified that the mark was slightly indented in the transparent coating of the frame. Every further attempt to enhance the mark with the black powder and to lift it with acetate adhesive tapes was successful. The mark was left in the coating when the coating itself was still fresh, at the time of the last painting of the frame of the door.

The above-mentioned case has the purpose to demonstrate: (1) how ageing of fingermarks occurs in the daily work of fingerprint laboratories, (2) how difficult is to establish standard procedures to address the matter, (3) the need to be cautious to generalize the assumption that a good quality mark is necessary fresh.

Thus, we would recommend to subject matter experts to be reluctant in expressing any opinions in court, based solely on their experience, on the estimation of age of fingermarks. Some inferences could be made only in particular circumstances, whenever substantiated by verified hypotheses through a robust verification, which implies the strict application of a scientific methodology.

According to the literature available, also the quality of the mark could not be considered as the sole determinant for age estimation. In fact, cases of good quality marks have been reported after 30 years after their deposition.

More recently a series of studies has been published on fingermark aging which considers chemical composition of fingermarks. Ageing studies has been conducted since 1995 considering the degradation processes occurring in fingerprint chemical compounds, i.e. oxidation processes and decomposition reaction due to time.

More recently, Wyermann and Girod conducted a more comprehensive study started in 2013, which targeted lipids and their transformation due to time factors as a potential source of ageing measure of fingermark deposit. Among more than a hundred of others, ten lipids were selected with statistical techniques, as more stable in each donor (lower intra-variability) and the decomposition process has been analyzed by means of chemical techniques, as GC/MS, FTIR also combined with chemical imaging, resulting in a vast series of publications between 2013 and

2016. Nevertheless, blind trials conducted, showed reliable age estimation only in less than 2/3 of the examinations.

In parallel, the successful forensic application of the study of fingermark proteins by MALDI-MS have opened the field to the application of proteomics also for ageing researches. More recently, proteomic studies, recently published by Oonk et al. in 2018 seems to have identified a dating signature, by chemical analysis of fingermark residue obtained by LC-MS, which is composed by 5 proteins. This subset of proteins has been reported as time dependent and, with a certain rate, detectable after bodily fluids contamination.

In the near future, the analytical approach would certainly produce robust and reliable results. Even though this type of analyses requires high level of expertise, dedicated and costly equipment, are (partially) destructive of the sample, and they seem not to be applicable at the scene of crime, the science seems really promising, compared to other techniques. Moreover, it could be applied after visualization techniques.

However, at this point in time, from the perspective of the end user, it is unrealistic to invest efforts and resources to develop an in situ ageing technology. Developing crime lab technologies to be used remotely seems of greater importance in order to achieve a robust and reliable methodology, which allows the fingerprint expert to determine the age of the marks, especially in case the fingerprint evidence is challenged by the defendant at a later stage, i.e. claiming a legitimate access. This technology, operated in laboratory by adequately trained (forensic) scientists, should be used only in these particular circumstances.

Even though some authors theorized the opportunity to develop ageing technologies capable to be deployed at the scene of event (Wei et al. 2016), it would be more productive to concentrate the efforts in the development of a reliable technique for laboratory operations, whilst, as a latter improvement, to explore the feasibility of a mobile application.

Because of the above-mentioned reasons and in consideration of the status of the art of the research, it seems to be unrealistic to propose the inclusion of the ageing determination as a streamlining step to prioritize fingermark visualization at the scene of crime or to speed up database searches.

The main unsolved forensic problem is the age determination of the fingermarks, not the search of the unknown marks in the available databases. Currently AFIS search is very fast, robust and accurate at the point that if any ageing technique would be applicable to the vast majority of the cases, it should be applied after the comparison process.

Besides the examination of the variation in time of chemical properties and the degradation processes of the chemical constituents of the fingerprint residue, similar approach could be valuably applied to the study of the variation of physical properties of the fingermark, i.e. the thickness, the continuity of the ridges, or their response to the electromagnetic radiation. The two different techniques proposed by the authors of this chapter, the Optical Profilometry (OP), that visualize and describe variations in the topography of ridges, and the visible wavelength Hyperspectral Imaging (HSI), that measures spectral changes in blood-stained fingerprints, are two promising technique. The physical principles underpinning these two researches are robust and reliable. However the maturity of the two methods appears to have different technology readiness levels.

Optical Profilometers (OPs) are instruments capable to analyze very small surfaces in two (2D) or three dimensions (3D). OPs are currently used for the study of surface roughness of materials. The main advantage of 3D OP is due to the fact that is a contactless, three-dimensional technique, thus preserves the fingermark uncontaminated. The visualization of the trace is obtained by a detector (i.e. a CCD camera), that collect the signal coming from the inspected surface. By means of white light interferometry, it is possible to determine the height and widths of ridges and creases of the fingermark onto the surface.

The proposed approach consists in the realization of a validated mathematical model, which could allow the estimation of the age of a finger deposit on the determination of the changes occurred due to time, and other parameters considered in the model, to the physical properties measured with the OP.

The research has—in principle—all the factors needed to succeed. However, the state of the art needs further studies and investments. In particular, models need to be tested on various types of surfaces (i.e. the most common found at the scene of event). In fact, the persistence of the fingermark, for a given donor, is highly dependent on the nature of the surface. Moreover, two major questions/issues need to be raised. Firstly OP measures not only the fingermark on the surface, but also the roughness of the surface itself. Thus, would the technique be only suitable for applications on smooth surfaces? The second issue is related to the time needed to obtain the topographical image of a surface. Considering an area of 100 $cm^2$, given the considered technology, and if used without the pre-application of CSI or crime lab enhancement techniques, the time needed to obtain the data is over 10 h. This time lapse does not allow the application of the technique at the scene of event.

Concerning fingermarks contaminated with blood, they assume a particularly high evidential value in the contest of a violent crime. Traditionally, fingermarks produced by blood contamination, or produced by subtraction of blood in a blood pool has been regarded as almost coeval to the crime. However, this assumption may lead to erroneous conclusions. With laboratory trials, it is possible to demonstrate how fingermarks produced with other contaminants, mainly greasy substances (i.e. olive oil and hand cream) lately wiped with blood, assume the appearance of fingermarks produced by blood contamination. To this respect, chemical imaging techniques could be very suitable methods to determine whether blood is exactly located only on fingermark ridges or in other parts of the trace, thus making a more robust evaluation of the so-called "activity level" of the trace.

In any case, ageing of blood traces could solve disputes, which might arise in investigative scenarios, where the determination of the age of blood could avoid any claim of previous deposition of fingermarks by the defendant. With this perspective, hyperspectral imaging (HSI) is a technique that can be successfully applied to forensic scenarios, including the detection, identification and age estimation of bloodstains. The simple principle is based on the recording of images at series of different wavelengths. The spatial information at the various wavelengths is summed up in a “third dimension” containing all the single spatial data at the different wavelengths.

HSI applications might use all the electromagnetic spectrum. Typically, the wavelengths range from the ultraviolet (UV) to the infrared (IR). Multiple configurations can be designed: a simple one, used for this purpose, consists of a tunable filter applied in front of the detector, selecting the broad band light directed on the surface in steps of five nm from 400 to 680 nm.

One of the major advantages of this technique consists of its capability to determine that the “reddish” substance at the scene of event, or on the item, is actually blood.

In fact, the bloodstain identification approach based on the Soret $\gamma$ band (415 nm) absorption in hemoglobin, demonstrated a high sensitivity and specificity for the detection and identification of bloodstains, compared to other methods.

The HSI method is contactless and non-destructive, highly specific for blood, and allows also the determination of the age of the traces in an interval of time of 14 days, with a great discrimination within the first 24 h.

The research explored the compositional changes that occur within a blood-stained fingerprint, which result in a color change from red to brown, due to the complete oxidation of hemoglobin (Hb) to oxy-hemoglobin ($HbO_2$) and, finally to hemichrome (HC).

After HSI analysis, the absorption spectra have been analyzed. A ratio of the peak of the $\beta$ band at 525 nm to the trough at 550 nm has been selected as determinant for the age. The change in this ratio has been assumed for the establishment of a false color scale, which is very easy to interpret. At present, this research could be implemented in some real scenarios, because of the high specificity to blood and its non-destructive characteristics. However, for the use on real cases, some hypotheses need to be made on temperature and humidity of the environment where the trace was located, in order to calibrate the model, assuming the use of the same type of substrate.

The challenging research field of fingermark dating needs a concerted effort between a combination of techniques, detecting variations of the chemical and physical properties of fingermarks in time. Other factors, which are of paramount importance in the ageing process, are: (1) the gradients of the thermodynamic quantities, (2) exposure to air fluxes and atmospheric agents, (3) the nature of the surface.

Visual analyses, such as OP and HSI, should be promising techniques. OP seems to be still at an early stage, while an attempt to apply HSI could be made whether the blood mark age determination is necessary in a particular investigation.

From the end user perspective, in order to have in the future some reliable and robust ageing methods, investments to fund research are desirable, even if the field of application will be limited to the laboratory and/or to some specific subcategories.

The future researches need to consider the chemical decomposition products of fingermarks, their kinetics and, eventually, chemical compound ratios in statistically relevant samples of population. The effect of environmental factors and substrates could be subsequently determined, generalizing models designed within confined boundaries.

The interpretation of the tested and calibrated data could be eased by user-friendly interfaces, which can allow the forensic scientist to present the evidence with the support of robust and reliable methodologies.

In conclusion, the possibility to determine the age of a fingermark is still limited at present. Any conclusion in court regarding the age estimation should be done underlining limitations to the assumptions made. Nevertheless, the research in this field should be encouraged and supported, given the paramount importance of this information to the correct evaluation of the fingermark evidence by the trier of fact.