Fingermark Detection: Should we take the red pill or the blue pill?

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Abstract: During the last two decades, the progression of research dedicated to fingermark detection has continuously gained speed, as shown by the increasing number of publications in the field. Along with the emergence of new technologies, one can witness a split in the main research interests. First, those who advocate the use of emerging technologies to offer new possibilities in terms of detection and/or gain information about the donor's lifestyle, for example. Second, those who prefer slowing down the pace to strengthen the foundation of the discipline, by gaining a better understanding of some detection mechanisms or interaction schemes between secretion and substrates. These last years have also witnessed the publication of a couple of articles proposing guidelines for people not accustomed with research in the field of fingermark detection. This approach constitutes a step further to promote quality research and strengthened conclusions, especially in regards with emerging technologies. In this context, this paper aims at introducing both trends through critical opinion. As for the title (in reference to a famous movie from the late nineties), this contribution is built to offer the readers a glance to a limitless world in which everything seems possible (blue pill) or to a world in which things are not as easy as expected, with numerous fundamental issues still to be addressed (red pill).

Keywords: fingerprint; metadetection; profiling; lifestyle; mechanism; guidelines

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INTRODUCTION

"You take the blue pill, the story ends. You wake up in your bed and believe whatever you want to believe. You take the red pill, you stay in Wonderland, and I show you how deep the rabbit hole goes."

Morpheus [The Matrix, Warner Bros. – 1999]

One may think what such a citation could have in common with the field of fingermark detection, or how comes a fictional character is cited instead of a forensic scientist having contributed to the field. The reason is quite simple: the field of fingermark detection is currently facing two opposed approaches in terms of research interest. On one side, those who assert that it is time for fingermark detection to "evolve" and step plainly into the 21st century by encompassing the latest technologies and by going beyond the ridge pattern – towards a limitless perspective regarding donor profiling and lifestyle prediction through big data. Blue pill. On the other side, those who decide to mark the pace in favour of casework applicability and take a closer look at the foundation of the discipline – facing a diligent perspective: techniques suddenly not behaving as expected, substrates not fitting into the conventional (empirical) classification, lack of understanding about secretion/substrate interactions, poorly understood detection mechanisms. Red pill. Browsing through a couple of representative papers, this contribution will provide the readers the challenges, advantages, limitations, and perspectives associated with these two approaches. Hopefully it will also promote the consideration about how both approaches could gain from each other and how guidelines could help optimizing the research efforts. Finally, it will be one's choice to decide which pill (s)he wants to take.

Note: an extensive covering of the field is out of the scope of this contribution. Readers interested in getting a thorough view about fingermark detection and its latest developments could refer to the latest Interpol reports (Bécue & Champod, 2016; Bécue *et al.*, 2010; Egli *et al.*, 2013) as well as to recent monographies – such as (Champod *et al.*, 2016).

FINGERMARK DETECTION

Fingermark detection constitutes a very productive field of forensic science in terms of research interest and publications. This is mostly linked to the role played by fingermarks in an investigative process (Figure 1). It can provide information about its source (an individual), about the activity linked to its deposition (from the position and orientation regarding the item), and can constitute a way to link an individual with an item (direct contact).

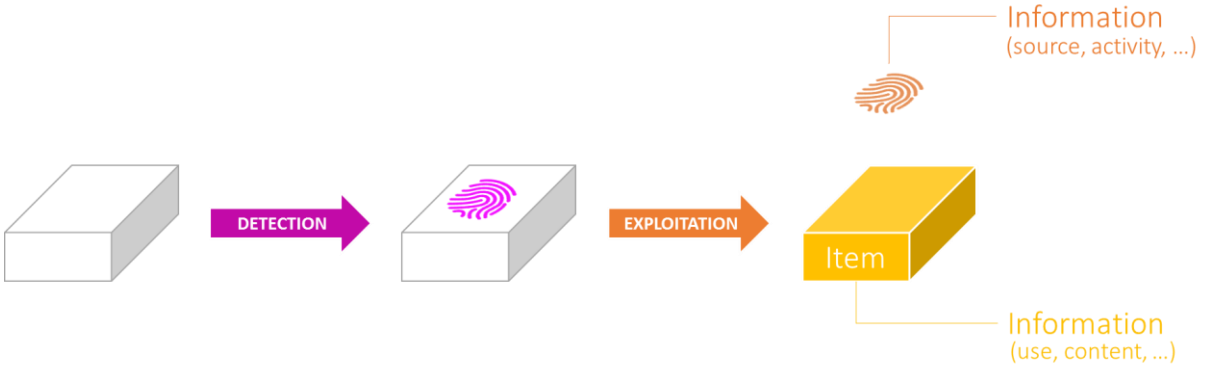

Figure 1. *Schematic representation of the integration of fingermarks in an investigative context.*

Figure 2 illustrates the evolution of the number of citations related with fingermark detection/composition since 1998. From July 2013 to July 2016, the topic associated with the highest number of publications was "powder dusting". Quite surprizing, in a way. The problematics of "contaminated marks" and "chemical imaging" followed. As such, those topics constitute two diametrically opposed approaches to detect fingermarks and reflect the torn interests between casework

application, societal context and technological developments. At first glance, fingermark detection appears as a field mature enough to provide forensic scientists and investigators with solutions to most of the encountered situations. However, behind all appearances, fundamental issues remain open: (i) daily substrates are still considered as challenging (e.g., banknotes, leather, …) or hardly fit in the current categorization system (e.g., "semi-porous"); (ii) the mechanisms behind common techniques remain poorly understood (e.g., cyanoacrylate – CA, physical developer – PD, multi/single-metal deposition – MMD/SMD, vacuum metal deposition – VMD); (iii) the actual efficiency of detection sequences remain hard to assess when considering non-supervised items (about this, it is sometimes claimed that "50% of fingermarks escape detection" (Jaber *et al.*, 2012), a figure difficult to prove but illustrating a known fact regarding the processing of realistic items); (iv) knowledge about the secretion residue, its behaviour, and its interactions with underlying substrates remains incomplete. Filling these gaps would assuredly benefit the field, for example through an overall increased efficiency of the detection process.

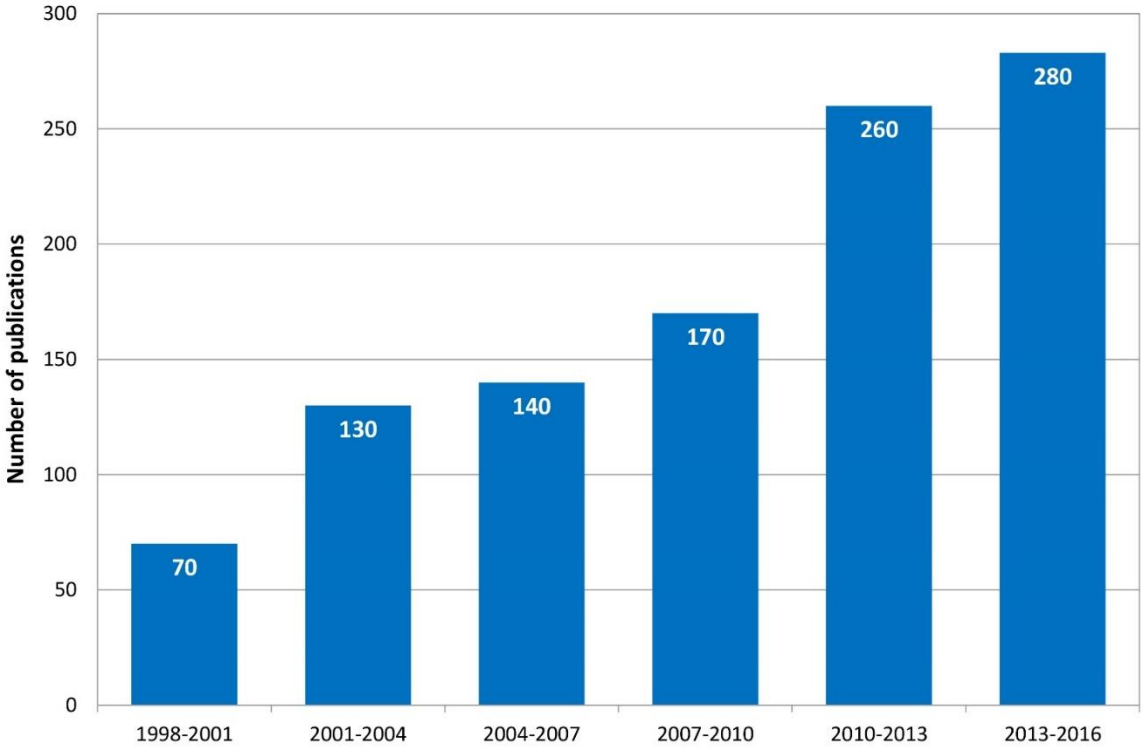

Figure 2. *Evolution of the number of articles in direct link with the detection of fingermarks or with the study of secretion residue reported in the last six Interpol triennial reviews (source: (Bécue, 2016)).*

FINGERMARK-SUBSTRATE INTERACTIONS

Addressing the issue of fingermark detection by ignoring the interaction with the underlying substrate would be like developing a new technique by monitoring reactions in a spectroscopic cell. Unconceivable for most forensic scientists, unless working with solubilized secretions (which appears unrealistic in the frame of fingermark detection). A fingermark is inevitably left on a substrate. From the contact of the fingertip on the substrate and as the mark ages, a series of interaction mechanisms occur between the secretion residue and the underlying surface (e.g., diffusion, affinity, repulsion). Getting a better knowledge about these interactions would provide valuable information about the persistence of marks over time, the (detrimental) impact of some application protocols, and could help developing a more efficient way of characterizing the substrates – to cite some examples. From the early optical observations, technological development such as scanning electron microscopy provided intimate information about fingermarks and ridge morphology (Scruton *et al.*, 1975; Thomas, 1978). Using a luminescent amino acid reagent and luminescence microscopy, Almog *et al.* showed how amino

acids actually penetrate into the paper matrix for 40-60 microns (Almog *et al.*, 2004). The amino acid penetration combined with a strong affinity for the cellulosic matrix explains why fingermarks left on paper are highly resistant over time (provided the item is not wetted). More recently, Moret *et al.* used different optical means to illustrate the difference in behaviour when secretion residue is left on different transparent and smooth substrates (i.e., glass, polyvinylchloride – PVC, polyethylene – PE, polypropylene – PP) (Moret *et al.*, 2015). Their study illustrated how fingermarks seem to penetrate/diffuse into coated plastics quite quickly after the deposition. Atomic force microscopy was used to study the minute change of topography along the ridges of fingermarks left on polished silicon and Formica (Dorakumbura *et al.*, 2016; Popov *et al.*, 2017). In both contributions, a dynamic process has been emphasized: the secretion residue first undergoes a transitory mobility from the ridge borders towards the substrate, before receding. Difference in physico-chemical properties can also affect the way a detection technique behave. For example, $VMD_{Au\text{-}Zn}$ appears to rely on the formation of metal clusters during the vaporization step, whose sizes regulate the deposition of the second metal (Jones *et al.*, 2001). Despite these observations, the intimate mechanism of VMD remains poorly understood and application protocols are still mostly based on empirical observations. Finally, the emergence of new substrates (e.g., new series of banknotes, "anti-fingerprint" treatments for digital devices) should trigger the conduction of research projects aiming at exploring the impacts of those substrates on the detection of fingermarks. For example, it has been observed that anti-fingerprint treatments result in fingermarks of better quality compared to unprocessed substrates (Forchelet, 2015) – in return, it is likely that these marks are more sensitive to friction or shearing movements (Stoehr *et al.*, 2016).

DETECTION TECHNIQUE MECHANISMS

It is well known that several detection techniques have been imported from other scientific fields and modified to fit forensic purposes (e.g., ninhydrin – biology, PD – photography, MMD/SMD – cell staining, VMD – metallic deposition). Among the existing techniques, some detection mechanisms are quite well understood. This is the case for amino acid reagents or lipid/blood stains; even if there is still room for discussion regarding molecular intermediates (Spindler, 2010; Spindler *et al.*, 2009; Wilkinson, 2000). However, the limits to our current knowledge status are surprisingly quickly reached. One example: cyanoacrylate fuming, one of the most used techniques to detect fingermarks on non-porous substrates. Polymerization occurs through an anionic process. However, it is still hardly known which molecular species trigger the polymerization process regarding fingermarks, despite several studies aiming at identifying these initiators (Velthuis & de Puit, 2011; Wargacki *et al.*, 2007; Kupferschmid, 2007). Similarly, the role of the ambient humidity (i.e., 80%) and the impact of the morphology of polymers on the ridge quality are still unclear (Paine *et al.*, 2011). The lack of knowledge becomes more noticeable when dealing with advanced techniques, such as those driven by metal deposition or physico-chemical mechanisms (e.g., PD, MMD/SMD, VMD). In the case of MMD/SMD, attempts to elucidate the interaction mechanism between gold nanoparticles and secretion residue at acidic pH failed so far. The reason is quite simple: if it is relatively easy to characterize gold nanoparticles in solution (colloidal gold), it is extremely complicated to monitor the interactions of gold nanoparticles with fingermarks while the detection is occurring. Post-detection observations are also difficult as they could induce a disturbance in the observed specimen. Up to now, different hypotheses were proposed (encompassing electrostatic interaction, hydrophobic affinity and covalent bonding), but no joint mechanism. The same is observed for PD. Luckily, research efforts were recently invested in these problematics: identification of the molecular species involved in the detection of fingermarks by PD (De la Hunty *et al.*, 2015a, 2015b) or use of dye-doped functionalized silica nanoparticles to get a better understanding about how citrate-capped gold nanoparticles used in MMD/SMD could interact with the secretion residue (Moret *et al.*, 2014) – to cite two examples. Finally, it should be noted that the lack of fundamental knowledge does not prevent techniques to evolve (Bisotti *et al.*, 2016; Houlgrave *et al.*, 2011; Montgomery *et al.*, 2012; Moret & Bécue, 2015), but they make things more complicated in case of unexpected failure or imposed changes: replacement of a surfactant for ecological reasons (PD), sudden modification of the water quality (PD), or unreliable results on daily substrates (MMD/SMD).

METADETECTION

Quite recently, a new trend emerged in the field of fingermark detection: obtaining additional information about the donor and his/her lifestyle. This way of doing can be called "metadetection" for it aims at going beyond the conventional detection purposes (i.e., recording a ridge pattern) (Bécue, 2016). Donor profiling can be performed simultaneously to the detection process (as in chemical imaging) or can be implemented subsequently to the detection of the mark (in that case, this could require to swab the mark for analysis). The main argument behind metadetection is that a fingermark is much more than a ridge pattern and that donor profiling could provide valuable information to investigators (Figure 3).

Hypothetical scenario: a fingermark is detected on the handle of a knife collected in an alley, close to a dead body. Thanks to technological evolutions, a full lifestyle profiling can be obtained in less than a day: male, adult, carnivorous, uses aftershave (XXX by YYY), moisture cream (ZZZ by WWW), presents signs of diabetes, allergic to pollen and smoker. Databases are interrogated (including health insurances, supermarkets and national identity services) and the suspect is identified in a few minutes among the whole population [Note: no criminal record]. The lifestyle prediction is verified at 93% [apparently, the individual has recently stopped smoking and has started a nicotine-based treatment]. The protocol still recommends to compare his fingerprints and his DNA with the few elements of ridge pattern present on the mark and the "touch DNA" collected from it. Check, and Check!

Is this scenario plausible? Worthy an Orwell's novel? It certainly raises many questions, as such prospect is already suggested by some. From a chemical point of view, it is true that fingermarks are more than the reproduction of a ridge pattern – in regards with the complex mixture of endogenous and exogenous compounds contained in the secretion residue. However, from a forensic point of view, the introduction of lifestyle information in an investigative context is debatable. It is true that some fingermarks may be slipped in such a way that they contain insufficient dactyloscopic information to reach a conclusion about the source. They are not useless either; and it is too simplistic to think that forensic scientists limit themselves to the ridge pattern (dactyloscopy), as illustrated in Figure 3. Indeed, fingermarks may contain DNA (i.e., "touch DNA"), whose analysis could lead to a source information or at least to the donor's gender. Several studies showed that most of the fingermark detection techniques do not prevent the recovery of DNA (Bhoelai *et al.*, 2011; Norlin *et al.*, 2013; Raymond *et al.*, 2004). It is consequently regrettable that DNA contained in fingermarks is not cited/discussed in most of the publications dealing with donor profiling. When cited, DNA is quickly dismissed because it may be degraded, in insufficient amount, contaminated, costly and time-consuming. It should however be noted that all these arguments apply to chemical profiling as well.

Readers interested in the topic of donor profiling can read the following review (Van Dam *et al.*, 2016). Among the reported techniques, chemical imaging using MALDI-MSI is worth being cited as it has been continuously explored and optimized by Bradshaw *et al.* to make it compatible with an investigative process (Bradshaw *et al.*, 2016, 2017). MALDI-MSI offer the advantage of ridge pattern visualization combined with molecular information. The combination of detection and donor profiling makes it interesting for future developments. More recently, proteomics combined with liquid chromatography has been applied on fingermarks left on users' mobile phones to try predicting their lifestyles (Bouslimani *et al.*, 2016).

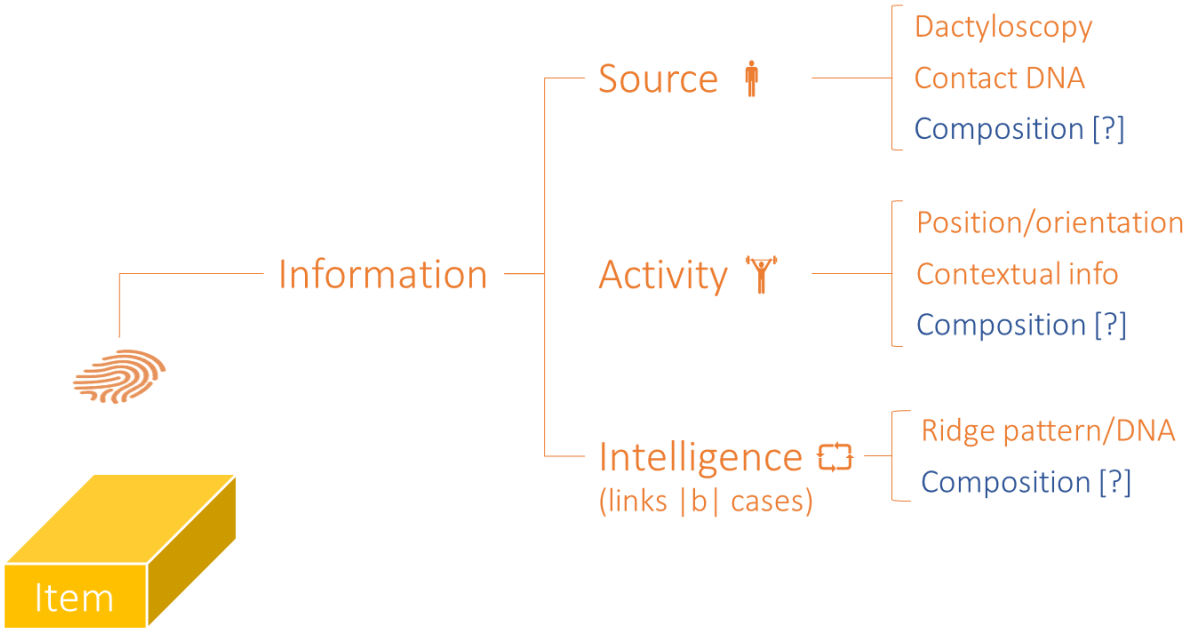

Figure 3. *Schematic representation of the range of information of investigative value that can be gathered from a fingermark. The rightest column refers to the elements that are used (or claimed to be useable) to obtain such information.*

CHEMICAL SIGNATURE AND LIFESTYLE PROFILING

The recent study of Bouslimani *et al.* illustrates perfectly the philosophy being the metadetection of fingermarks, and more particularly lifestyle profiling (Bouslimani *et al.*, 2016). Using high performance liquid chromatography and a metabolomics approach, they showed that fingermarks collected from mobile phones could provide information about the users' lifestyle. As an example, they identified molecules linked to cosmetics (e.g., sunscreen, soap, hair regrowth treatment), medications (e.g., skin anti-inflammatory, antidepressant, antifungal), diet (e.g., caffeine, aspartame, citrus and pepper derivatives) as well as to some activities (e.g., nicotine, anti-mosquito, pet pesticide). By crossing all these information, they could confirm some elements of the volunteers' lifestyle habits (e.g., regular camper, smoker). They also studied intravariability and intervariability in terms of chemical signature distance between specimens collected from phones and hands.

In their introductive text, the authors claim:

> *"Imagine a scenario where personal belongings such as pens, keys, phones, or handbags are found at an investigative site. It is often valuable to the investigative team that is trying to trace back the belongings to an individual to understand their personal habits, even when DNA evidence is also available […] The collective repertoire of molecules found on these objects provides a sketch of the lifestyle of an individual by highlighting the type of hygiene/beauty products the person uses, diet, medical status, and even the location where this person may have been […] Such information could help a criminal investigator narrowing down the owner of an object found at a crime scene, such as a suspect or missing person."*

The last sentence is certainly the one raising most of the questions regarding the usefulness of lifestyle profiling, or its application field. This brings forward the notion of "relevancy" regarding the information that can be obtained from a trace or an item (for an extensive covering of the topic: (Hazard, 2014)). What information is to be considered as relevant in an investigation? When does an information becomes irrelevant or counterproductive to the investigative efforts? The goal of any investigator is indeed to narrow down the number of suspects to a limited pool of individuals, more prone to the investigative

process. To reach that goal, an investigator generally relies on contextual information, traditional investigative efforts (e.g., witness interview, suspect audition), and information provided by traces of forensic interests (e.g., fingermarks, DNA, shoemarks, fibers). Currently existing databases (mostly fingerprints and DNA) prove to be extremely helpful as they can actually help investigators to narrow down the pool of suspects in an efficient manner. Such databases are indeed directly linked with an individual (biological identity) and may provide a name quickly if someone is already known from the justice. Unless expecting a global population surveillance combined with big data analysis, it appears quite unlikely that medication, diet, or daily products – as part of lifestyle habits – could help narrowing down efficiently the pool of suspects. In the same context, the item on which a fingermark is found also constitutes a source of information. In the example of lifestyle profiling obtained from fingermarks left on mobile phones, an investigators would certainly have gained valuable information about the identity of the phone's owner and his/her lifestyle by investigating the digital content of the device (digital identities, diary, phone numbers, pictures/videos, …). Technological possibilities should consequently not obliterate common sense solutions in regards with the investigative process.

In favour of lifestyle profiling: the technological ability to gain information about secretion residue in terms of a chemical signature certainly constitutes an asset regarding the fundamental study of fingermarks. Indeed, it could help getting a better understanding about donor variability, about its impact on the efficiency of detection techniques, and may eventually provide an evidential tool comparable to DNA. The goal would consequently not consist in predicting someone's lifestyle but rather to get a comprehensive vision of secretion residue as a whole, which would go beyond the conventional "sebum-rich", "ecrrine", or "natural" distinction. Further researches on this topic are consequently expected in a near future. Additionally, donor profiling could be useful from a healthcare, medico-legal or security perspectives (devices).

GUIDELINES

Working with fingermarks is certainly not the simplest way of doing research as each fingermark is a specimen. It is consequently impossible to obtain a reproducible set of "identical" fingermarks. Despite its apparent simplicity (asking someone to leave one or several fingermarks), the design of a research plan linked to fingermarks requires many questions to be answered: What kind of secretion (natural, sebum-rich, eccrine, artificial) ? How many donors ? Fresh or aged marks ? Unique deposition or depletion series ? Which comparison protocol (half marks, pseudo-operational test, …) ? All these questions must be carefully thought and answered at the early stages of a study as they could strengthened or weakened the conclusions. Willing to increase the quality of research in the field, the forensic community provided hints and guidelines (IFRG, 2014; Kent, 2010; Sears *et al.*, 2012). The underlying aim is to refer to them and discuss any deviation from the proposed recommendations.

In the same context, the use of artificial secretion is still debatable as it is extremely difficult to simulate the complexity of the natural emulsion present on fingertips as well as the variability between donors. However, latest developments showed that complex emulsion could be synthesized and seem to behave similarly to natural ones (Sisco *et al.*, 2015). It is consequently awaited that additional research in this field may provide a way to obtain reproducible fingermarks. This could become valuable in the early stages of development of a detection technique or for proficiency testing purposes.

RED PILL? BLUE PILL? – OR BOTH?

The aim of this contribution was not to point out a negative vision of the field. On the contrary. Dozens of efficient detection techniques are currently available to detect fingermarks on a wide range of substrates. Moreover, detection sequences are continuously optimized to increase the success ratio regarding latent marks to be detected on an item. The field has continuously evolved since the mid-50s, even if the main developments occurred in the 1980s-1990s. It is true that some fundamental knowledge is still missing: interaction of the secretion residue with the underlying substrate, intrinsic detection

mechanisms, … But it is reassuring to see that groups of scientists are currently spending time and efforts to enlighten these shadow areas. The field definitely benefits from a strengthening of its foundations: increased rates of success with "difficult" substrates, optimized characterization of substrates, ability to react when facing a sudden modification in a technique efficiency, … It also reflects the fact that fingermark detection is still "young" in a sense and requires the community to spend time on its basements. Once detected, a fingermark can represent a valuable source of information, but it must be recalled that almost nothing can be done if the mark remains latent.

On the other side of the looking-glass: donor profiling. The main argument behind profiling is the fact that some fingermarks may be of insufficient quality for dactyloscopic purposes. In that context, two visions are opposed: the chemical one and the forensic one. Beyond the proof-of-concept, it is now awaited that donor profiling finds its place in the forensic context. Should it be closely related to the investigative field, then researchers should prove how lifestyle information could actually help an investigator narrowing down the number of suspects. Should it rather constitute a new technological way to strengthen the fundamental knowledge regarding secretion residue, then research should focus on a new way to characterize them. Finally, should it rather be used for healthcare or security purposes, then fingermarks certainly constitute a non-invasive way of providing valuable information.

To conclude: fingermarks are assuredly a very exciting field for researchers. From the foundations to strengthen to the emerging technologies, the field as yet to gain from scientific efforts.

So? … Which pill will you take?

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