FINGERMARKS AND OTHER IMPRESSIONS LEFT BY THE HUMAN BODY

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A REVIEW (AUGUST 2007 – JULY 2010)

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ABSTRACT

The purpose of this paper is to review the scientific literature from August 2007 to July 2010. The review is focused on more than 420 published papers. The review will not cover information coming from international meetings available only in abstract form.

Fingermarks constitute an important chapter with coverage of the identification process as well as detection techniques on various surfaces. We note that the research has been very dense both at exploring and understanding current detection methods as well as bringing groundbreaking techniques to increase the number of marks detected from various objects.

The recent report from the US National Research Council (NRC) is a milestone that has promoted a critical discussion on the state of forensic science and its associated research. We can expect a surge of interest in research in relation to cognitive aspect of mark and print comparison, establishment of relevant forensic error rates and statistical modelling of the selectivity of marks' attributes.

Other biometric means of forensic identification such as footmarks or earmarks are also covered in the report. Compared to previous years, we noted a decrease in the number of submission in these areas. No doubt that the NRC report has set the seed for further investigation of these fields as well.

We invite the reader to use two levels of reading for the report: a summary level and a more detailed level. In each subsequent section, if the number of papers published in a given area is large, the subsection will start with a quick summary (in italics) followed by a more detailed analysis of the research at hand.

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1 INTRODUCTION

This paper offers a review of the publication regarding marks left by the human body with an emphasis on fingermarks. It will cover the scientific literature from August 2007 to July 2010. Because of the amount of material covered, this report does not intend to be a thorough critical review (unless it was felt required) but merely a point of focus and organisation of the available material. The material reviewed primarily originates from peer-reviewed journals and published books although non-reviewed electronic sources may at some points be used. Proceedings of colloquies will be used only when available in the form of full paper conference proceedings. More than 420 references are covered here and, of course, we run the risk of having missed important material. In advance, we apologise to any author(s) or organisation(s) whose contribution(s) should have been mentioned. We also would like to thank individuals, peer groups and organisations that kept us informed of current developments and initiatives in the areas covered in this report.

It is now customary to start our review by referring to the review by Brettell *et al.* in *Analytical Chemistry* (1) that contains also in some sections material that is in relation to the present topic. It can be complemented by (2), dealing with fingerprint detection techniques.

A major scholarly publication in forensic science has been edited by Moenssens and Jamieson. This *Wiley Encyclopedia of Forensic Science* offers a range of papers in relation to fingerprints and human marks and the individualisation process: A discussion on individualisation is presented in (3). Aitken (4) presents different probabilistic tools used in forensic science (relative frequency, discriminating power, significance probabilities, likelihood ratio, and Bayesian networks). The author also discusses errors, e.g. the prosecutor's fallacy, as well as a history of the different statistical tools used. Koehler (5) discusses how evidence is presented and understood in court. The author explains that a 'match' only indicates that no distinguishing characteristics were found between evidentiary marking and potential source, but does not indicate the evidentiary strength of this absence of distinction. Different ways of presenting statistical evidence are discussed as well as different misunderstandings of these statistics that can arise from the jury as well as the expert. More generally, Moenssens (6) discusses all demonstrative evidence (of which fingerprint evidence is a part if charting is used), and the necessity that the probative effect outweigh the prejudicial impact for the evidence to be admissible. One chapter is on observer effects in forensic science (7). Identification of human remains, including the use of fingerprints and techniques for obtaining fingerprints from decomposed, mummified or burnt bodies is the subject of a further chapter (8). Concerning fingerprints more generally, the anatomy of hands and feet as well as morphogenesis (9), comparison and identification of friction ridge skin (10), an overview of AFIS (Automated Fingerprint Identification Systems) (11) detection (12, 13) and interpretational issues in the fingerprint domain (14) are included. Two chapters concern footprints: One is very general and includes shoe sole impressions (15), while the second concentrates on footprints of bare feet, feet in socks, and impressions inside of shoes (16). Ear marks and comparisons are treated in one chapter (17). Finally, a chapter on the photography of marks, impressions and documents is included (18) in this Encyclopedia.

The field of biometrics is closely related to the topics under review. It is an impossible exercise to incorporate in this review all the scientific work carried out in this area. However a major Encyclopaedia has been published at Springer Verlag (19). An overview of the forensic

applications (20) along with specific chapters on fingerprints (21-24), the Universal Latent Workstation (ULW) (25), cognitive processing in fingerprint recognition (26), earprints (27) and footprints (28) are covered in this Encyclopedia.

A biometric handbook (29) offers also a good overview of the challenges in biometrics with one dedicated chapter on the relationships between forensic science and biometry (30). Another handbook but on forensic science (31) brings an overview chapter on fingerprints with specific emphasis on the situation in the UK (32).

The forensic science landscape will certainly change after the publication of the US National Research Council of the National Academies (33). The report highlights some major causes of concern with regards to impression evidence (including friction ridge skin), to name a few: disparate training schemes, large subjectivity in the comparison protocol, recent cases of misattributions, evidence of cognitive bias and reporting practices that are tainted by a myth of infallibility. There is an urgent need to deal with some of the issues and ultimately increase transparency and accountability. The recent conference by the chairman of the committee, Judge H. T. Edwards, gives a very specific picture of the current situation with regards to the NRC report (34). An element of warning though: the report deals essentially with the state of affairs in the USA and does not necessarily reflect the situation in other countries. We can expect more contributions attempting to make explicit the complex set of psychological and cognitive processes involved in the identification process. The recent paper by Busey and Parada is a good example (35). Likewise, it is expected that the amount of statistical research devoted to these fields will still increase. The forthcoming paper by Neumann *et al.* (36) should provide the statistical foundation to the operational assessment tool developed by the *Forensic Science Service in the UK*.

The NRC report received a very important press coverage including the most prestigious scientific journals such as *Nature* (37, 38) or *Science* (39). Professional organisations have reacted to the NRC report. We will retain here for example the statement by SWGFAST (Scientific Working Group on Friction Ridge Analysis, Study and Technology) (40). The IAI (International Association for Identification) also published a reaction to the NRC report. Here, the different recommendations in the report are reviewed from the association's point of view (41). The IAI furthermore sent a memo to its members, stating its support to many of the recommendations included in the report, cautioning against asserting "100% infallibility (zero error rate)" also advising its members not to state "their conclusions in absolute terms when dealing with population issues" (42). During the 2010 IAI conference in Spokane, the membership, following the recommandation of the *Standardisation II committee*, approved to rescind Resolution 1979-7 and Resolution 1980-5 (that prohibited examiners from providing less than certain testimony) and adopt a resolution acknowledging the recent progresses in fingerprint statistics: "The use of mathematically based models to assess the associative value of the evidence may provide a scientifically sound basis for supporting the examiner's opinion." (43) That finally opens the possibility for fingerprint examiners to report strengths of evidence spanning over the whole spectrum of support in favour (or not) of an association that the observed features may bring.

The NRC report stressed the lack of a structured research programme that underpins the identification process. We can only concur with this analysis; the resources attributed to research in the forensic identification disciplines outside DNA are indeed limited (this scarcity is somewhat due paradoxically to operational successes and proficiency, e.g.

fingerprint evidence). Such research efforts (some are mentioned in this report) constitute the best response to future challenges.

A framework decision of the council of the European Union requiring its members to ensure forensic laboratory accreditation according to EN ISO/IEC 17025 applies to laboratory activities resulting in DNA-profiles or dactyloscopic data has been published (44). This highlights the requirement to standardise forensic laboratory work.

It is expected that the NRC report will also impact on how impression evidence, and fingerprint evidence in particular, is received in courts, especially in the US. A few fingerprint cases retain our attention here: In *Langill*, the court although retaining admissibility insisted on the need of contemporaneous case notes associated with the comparison process (45). In the case against Brian Rose, fingerprint evidence has been challenged, initially ruled inadmissible (46) and finally accepted by the court (47) even in the light of the NRC report. Both of these cases highlighted two important issues for the latent print community: documentation and error rate. The days of claims of 100% certainty in this area are counted. The case against *J. Hull* is a good example of this trend (48) (see the transcripts of the Frye-Mack hearing). In that case the judge accepted fingerprint evidence even though the experts did not ascertain that they could identify the defendant to the exclusion of all others. They merely put their evidence in the context of the limited relevant population. A commentary on this Frye-Mack hearing is presented by Bush (49).

Finally the disputed identifications associated with the case of *H.M Advocate v McKie* are under review by a judicial inquiry (named the Scottish Fingerprint Inquiry). The associated report is due in the fall of 2010. All the documents used by the Inquiry can be found online: http://www.thefingerprintinquiryscotland.org.uk/.

Another major contribution is the *Fingerprint Sourcebook* elaborated under funding by the National Institute of Justice (NIJ). It is published in stages at http://www.ojp.usdoj.gov/nij/pubs-sum/225320.htm. Currently five chapters have been put online. They deal with the history of fingerprints (50), the recording of prints (51), the fingerprint classification systems (52), the documentation of friction ridge impressions (53) and quality assurance (54).

A special issue of *Law, Probability & Risk* presents a good overview of various arguments currently present in the fingerprint domain (55-60). Its content will be covered in detail in this report. Fingerprint comparison and DNA analysis are aptly juxtaposed in a recent book by Lynch *et al.* (61).

A few general works on human identification have been published during the review period. A history of personal identification, focusing on anthropometry, fingerprinting and DNA from the angle of racism and the different concepts and uses of race in identification is presented (62). Another historical review, but centred on the increase in the use of biometrics, is proposed by Maguire (63). The forensic use of marks left by papillary surfaces as a means of human identification is often traced back to Henry Faulds. Recent historical research has shown that a French chemist, Paul-Jean Coulier, suggested its use as early as 1863 (64). He made use of iodine fuming to detect surface alterations on questioned documents. Concurrently he observed the detection of latent fingermarks. At that point he proposed them as a means to identify the forger of the document.

2   FINGERMARKS

2.1   Friction ridge skin individualization process

This section starts with publications on AFIS (Automated Fingerprint Identification Systems). Here, in particular, collaborations between countries (the Prüm treaty implementation), the reduction of the number of candidates to match finely through database indexing or filtering, and tests on different automated systems are presented, as well as studies on the interaction between the human fingerprint examiner and the automated system.

The second part concerns fingerprint characteristics; studies concerning level I, II and III details (including frequencies of various characteristics, sex differences, studies aiming at estimating probabilities of random correspondence, improvements in matching rates) are presented here, as well as works on morphogenesis, influences on fingerprints, and the biological use of ridges. As far as possible, studies are presented by decreasing generality. Finally, the section on the individualization process and the judicial system presents first general works on considerations concerning individualisation, then errors, studies on bias, and discussions on the validity of fingerprint comparison and debates as well as studies concerning ACE-V.

2.1.1   Automated fingerprint identification systems

> *A general paper on fingerprint matching (65) and one on palmprint matching (66) have been published.*
> *Precisions concerning the implementation of the Prüm treaty are available (67-70). Two articles pertaining to the US-VISIT programme are integrated into this review (71, 72). The connectivity of systems is treated in (73), (74) and (75). Two trials involving several system providers are published, where the second investigates the usefulness of integrating extended fingerprint features (76, 77). Database filtering, indexing and clustering has been treated in the following articles: (78), (79), (80), (81), (82) and (83). The interaction between humans and automated systems is finally discussed and researched (84-86), including the use of expert assessments for improving the system (87). Image compression is the subject of several articles (88-91) and (92) analyses a risk in image enhancement.*

The incorporation of the Prüm treaty is defined as follows: a decentralised system will be used, where each nation has its database, and the contact points of other nations will have access to reference data (67). A detailed description of how this data is to be exchanged (format, communication channels) is provided (68). Estimated daily maximum throughputs for the different countries (for different search modalities) are available (69). Good practice for such searches is proposed (70); e.g. to start with the most relevant searches, and to grade the importance between crime types.

An overview of past work on fingerprint quality in US-VISIT is presented (72). A performance improvement by using two fingers and two stages (rather than increasing the number of fingers used to ten) for US-VISIT has been proposed. This two-stage process is compared to a two-stage process including two fingers and the face (71). The two-stage process for fingerprints consists first in a minutiae-based matcher and second on a texture-based matcher. The detection probability is increased with respect to minutiae based matching

both by using minutia matching and face and minutiae and texture matching, but more so for the second option.

The challenge of the increasing use of data interchange has been thematised. Discussions of both data interchange between countries (73) and between states, cities and federal government (74) have been published. This second reference also includes a historical overview and discusses connectivity between systems, which is opposed to interoperability (74). The interoperability between systems from different vendors and related challenges are described and investigated (75); in particular, the reduction of information in standard-compliant minutiae templates (as opposed to the proprietary format) significantly increased error rates in the different systems used, in a test carried out on a total of 4041 index fingers.

A comparison between different systems has been carried out (76). The different technology providers who participated in the trial were Motorola, Inc., Sonda Technologies, Ltd., NEC Corporation, Peoplespot, Inc., SPEX Forensics, Inc., Cogent, Inc., L1 Identity Solutions and BioMG, Ltd. Each technology provider submitted a software development kit (SDK), and the submission of research algorithms was encouraged for the study. The test set consisted of 835 marks and their ten-print mates, showing sufficient information to result in an identification conclusion. Two background databases were also used, one containing 5000 records and one containing 10000 records (50000 and 100000 fingerprints). The rank 1 and rank 10 identification rates are reported, as well as other measures. Particularly interesting is the fact that both the original images at 1000 dpi and the same images downsampled to 500 dpi were used. Most software development kits showed an increase in performance when 1000 dpi images were used (as opposed to 500 dpi); this improvement was not huge, however. Also, while some hits were gained with the increase in resolution, some others were lost. A related short communication has also been published (93).

Database filtering, indexing and clustering has been treated in the following articles: (78) and (79) use singular points for database filtering; indexing is proposed by (80), (81) and (82), and finally database clustering is the subject of (83). The specialised literature is so abundant in this area that we cannot hope for exhaustiveness here, but it was felt important to provide some entries dealing with this subject, especially when the research work proposed has the potential for a change in practice in the short term.

Matching performance is examined when plain as well as rolled impressions are used, and different fusion techniques are investigated, at feature, score, and rank level (79). Boosted max fusion at score level performed best; here, a rank-1 identification rate of 83% was obtained, which compares favourably to the rank-1 identification rates of 57.8% for plain and 70.4% for rolled impressions.

The NIST engaged in collaboration a range of AFIS providers and parties in the definition of a new exchange format adding an extended set of fingerprint features: dots, incipient ridges, ridge edge protrusions and pores. All relevant documents are available on http://fingerprint.nist.gov/standard/cdeffs/. The new standard ANSI/NIST-ITL 1-2010 (now in draft version 0.4) will replace the ANSI/NIST-ITL 1-2007 and ANSI/NIST-ITL 2-2008 standards that address the interchange of fingerprint, facial, and SMT data).

The use of this extended feature set has been the subject of a preliminary report (77). The participating organizations of this trial are SAGEM, NEC, Cogent, Sonda and Warwick. The number of marks used was 1114, and here, the mates had not been found using an AFIS search. The different features of the marks used were: image only; annotated region of interest

(ROI); ROI, pattern class and quality map; minutiae with ridge counts; extended features; extended features with skeleton; and minutiae with ridge counts but without the image. Human markup was used for the marks, while automated feature extraction was used for the 100000 (ten-print) records used as a background database. When extended features are added, performance is improved only for a subset of participants.

Kwan and co-workers propose to incorporate expert feedback into AFIS (87). Relevance feedback is proposed as an add-on module to automated systems. The examiners decisions ('positive', when the impressions are judged similar, or 'negative' otherwise) are used to transform the input space. When the examiner is faced with a list of possible matches, the positive match declared will be used to decrease the distance (or increase the score) by a certain amount, while a negative declared will do the opposite. A new comparison will then be mapped onto a semantic space created on the basis of the transformed distance (or score) matrix; in this way, the short-listed results will be increasingly similar with respect to the examiners assessment.

The use of large, computerized databases may lead to the discovery of impressions that come from different fingers that show more similarity than what was expected before the use of AFIS searches. This is the subject of an article by Dror and Mnookin (84). In particular, the authors consider that the way fingerprint conclusions are arrived at (in particular the sufficiency requirements for an individualisation) should change with the use of AFIS. They also discuss the possible introduction of bias through the candidate list and the associated scores. The interaction between the examiner and the automated system is also the subject of an article by Wertheim (86). The different necessary steps for a successful search in an AFIS were followed on a set of 1368 images of marks. These steps were formatting (proper orientation and scaling of marks), encoding (annotating minutiae and singular points in the universal latent workstation (ULW)), and comparison (submitting encoded searches to various databases and examining the candidates proposed, identifying one of the candidates if warranted). Failures occurred at all levels; however in the comparison, only false negatives were observed. At least some of these false negatives were caught by a blind verifier; the rate of individual examiner false negative errors was 14%. Furthermore, almost half (7 out of 15) of the examiners missed one or more individualisations in this way, which shows that false negatives may happen more frequently than previously thought.

Davis and Hufnagel have investigated the personal perception of NAFIS, before and after its implementation. The study was carried out on a small sample of fingerprint experts and younger fingerprint technicians (not yet having expert status). The organisational, role, task and process level changes, as expected or perceived by the fingerprint examiners, are exposed (85).

Wireless transmission of fingerprints for operational purposes requires the images to be compressed; experiments have been carried out to determine the optimum form of compression, allowing realistic transmission times without compromising AFIS searches (or storing of the fingerprints in AFIS) (88). Image compression is also the subject of two further articles, where a proposed algorithm is compared to the compression algorithm used by the FBI (89, 90). Lossy compression standards, as well as evidence acquired and used in a digital format in general and image processing in this context, are criticised by Cherry and Imwinkelried (91). The probability of creating a false minutia (leading possibly to a false positive) is computed by estimating the probability of creating a square of pixels of the width of ridge, with grey values that are within 10 of the grey value of a ridge (for an 8-bit scale; for

a 16-bit scale a difference of 2560 is used) by using an innocent image processing method. This probability is vanishingly small (92).

2.1.2 Papillary skin features

Both genetic (94) and environmental (95) factors influencing the development of friction ridge skin have been investigated, and a review presented (96). How ridges are linked to mechanoreceptor response is treated in (97),(98), and (99). Links between general characteristics of fingerprints and gender identity disorders (100), schizophrenia (101) as well as intelligence (102) have been investigated.

Finger number and general pattern allow the distinction between two populations in the same country (103). Gender differences in general characteristics of fingerprints, mostly ridge densities, are reported for a large number of different populations (104-111); these data show that while such differences are rather easily interpretable for a single population, the values diverge between different populations and therefore, gender discrimination is less easily applicable when it is unknown which population the donor comes from. The selectivity of hand-shape is shown in a biometric context (112). Creases are the subject of two publications showing their usefulness: While (113) demonstrates selectivity, Zhou et al. (114) furthermore investigate the permanence of creases qualitatively. Two studies use AFIS in the context of fingerprint individualization (115, 116). Several generative models for fingerprint individuality have been proposed (117-124). The addition of ridge points to minutiae has been evaluated with respect to matching performance (125, 126), and minutiae frequencies have been presented (127). An operational trial on an evaluative model has been carried out (128). Finally, twin studies show that twins' fingerprints are closer than randomly chosen ones, but distinguishable (129, 130).

With respect to level III features, several studies concern their integration into the matching process (77, 131-137), one study assesses fingerprint examiners' opinions on such features, and one study concerns the reproducibility of pore areas (138). Distortion has been qualitatively evaluated (139) and quantitatively modelled (140), and a different type of artefacts appearing in marks is discussed (141).

Morphogenesis

In order to gain a better understanding of the genetic modes of dermatoglyph inheritance, the dermatoglyphic traits after population admixture have been studied. The populations studied are Liujia Han, Kam and offspring of intermarried Kam and Liujia Han couples (China). Such marriages were not culturally permitted until recently. In particular it is observed that some traits either increase with respect to either of the parent populations (finger ridge counts and the whorl pattern) or decrease with respect to these parent populations (the frequency of arch patterns). These observations allow to suggest genetic pathways of the transmittal of these dermatoglyphic traits (94). A review of studies concerning the ontogeny of friction ridges is presented, concluding that these studies explain how the embryonic stresses and tensions result in the uniqueness of friction ridges (96). A study carried out using a sample of Dutch adults, identified through records of urban births during 1943-1947, showed that environmental factors (war, famine) influence the difference in ridge count between the first and the fifth digit (95).

Biological studies

The influence of papillary ridges on Slowly Adapting type I (SA-I) mechanoreceptors in encoding edge discontinuities has been investigated; three necessary criteria of the lever-arm functionality are subjected to finite-element analysis. This results in discounting the lever-arm model, and a revised functionality is proposed (97). The function of ridges with respect to mechanoreceptors (spectral selection and amplification) is investigated using a biomimetic tactile sensor by Scheibert *et al.* (98). Here, the mechanoreceptors investigated are Pacinian corpuscles. In reaction to this article, Dahiya and Gori, while acknowledging the added insight gained by this study, highlight the fact that skin structure is more complex than the model used by Scheibert *et al.*, and that therefore their study cannot conclusively answer all questions relating to the effect of skin structure on receptor responses (99).

Links between fingerprints and other characteristics

Several studies aiming at establishing links between psychological and physical attributes (e.g., fingerprints) have been published (100-102). These links are at most statistical and must be interpreted prudently.

Studies on general characteristics

A study on two populations (two cities in the same country) using a classification and regression tree algorithm is presented (103); here, the goal is to use only finger number and general pattern for the prediction of a population that an individual belongs to. The classification is expected to be correct, when using all ten fingers, 90.8% of the time if all ten general patterns of the individual are left loops or whorls with only the right ridge count, and 98.4% if all general patterns of the individual are whorls with two ridge counts.

Frequencies of various dermatoglyphic measures for males and females of Kavalan (one of the Taiwan aboriginal populations) are reported by Chen *et al.* (104). These include general patterns, identical patterns on the corresponding fingers of the right and left hand, corresponding patterns on all fingers of one hand and on both hands, ridge counts, atd angle, tPD, palmar interdigital, thenar and hypothenar patterns, different combinations of palmar interdigital, thenar and hypothenar patterns on left and right corresponding hands, angles and simian line on palms.

Ridge density in a sample of Spanish Caucasians is also reported (105). Ridge densities of $16/25 \text{ mm}^2$ or less in the radial area considered are more likely to be of male origin when using equal priors, while ridge densities of $17/25\text{mm}^2$ or more are more likely to be of female origin; for the ulnar area these numbers are of $14/25\text{mm}^2$ or less for males and $17/25\text{mm}^2$ or more for females. Sex-differences in an Indian population are reported by Nayak *et al.* (106) ; here, a mean ridge count of $12/25\text{mm}^2$ or less is more likely to be of male origin while a greater ridge count is more likely to be of female origin. Ridge densities for a South-Indian population are reported by Gungadin (107), where $13/25\text{mm}^2$ or less are more likely if the impression is of male origin, while $14/25\text{mm}^2$ or more are more likely if the impression is of female origin. Nayak *et al.* also report on ridge densities for Chinese and Malaysian populations (108, 109) ; here, in the Chinese population, a ridge density of less than $12/25\text{mm}^2$ is more likely to be of male origin while ridge densities above $13/25\text{mm}^2$ are more likely to be of female origin. In Malaysian subjects, it is a ridge density of $11/25\text{mm}^2$ or less that is more likely to be of male origin, and a fingerprint with a ridge density of more than $13/25\text{mm}^2$ is more likely to be of female origin. The relationship between ridge density and

stature has however not been investigated. Furthermore, fingerprint classification and gender distribution was studied in a South Indian population (110), and no difference by sex between general patterns was highlighted in this study. The reason for the observed difference between sexes as to ridge density is the object of a letter to the editor (111). Data in relation to the general pattern present in the feet have also been published (142). Duta (112) shows the selectivity of the hand-shape as a biometric.

Creases

An automated extraction and comparison procedure for palmar flexion creases, carried out on a sample of 100 palms with 10 images of each one, achieves a genuine acceptance rate of 100%, for a false acceptance rate of 0.0045% (113), thereby illustrating the selectivity of this characteristic. Crease detection has been investigated by Zhou and co-workers (114), with particular application to the fingerprints of elderly people. The stability of creases is investigated, and matching based on creases and minutiae carried out. Also, the creases are used to remove spurious minutiae around the crease, within a distance of 5 pixels. The combined use of minutiae and creases diminishes error rates in matching with respect to matching based exclusively on minutiae, but only for the database of elderly people. On a general population database this improvement is only very small.

Level II detail

The best way of analysing data in the form of match scores from a fingerprint matcher has been the object of two articles (143, 144). ROC (receiver operating characteristic) curves are compared to likelihood ratios (LR). Here, a LR above one yields the classification result that two impressions belong to the same person and a LR below one that they belong to different persons. For obtaining LRs, the within-and between-finger variabilities are modelled using gamma- and normal distributions. The likelihood ratio method outperforms ROC curves, but the performance of the two methods is similar when large numbers of minutiae are available (143). However, an analysis of four different matching systems shows that there is no definitive underlying distribution function for match and non-match scores. Nonparametric analyses on the discrete distribution functions of the four sets of scores (issued from the four different systems) are presented, and take the form of ROC curves (144). Note that while Srihari and Srinivasan (143) privilege LRs over ROC curves for performance reasons, Wu and Wilson (144) use ROC curves in the nonparametric approach. This second approach is, according to these authors, the proper way of analysing such data, due to differences in the distributions obtained when different matchers are used on one hand and the fact that the data is discrete (or can be transformed to discrete data) on the other hand.

A study on the variability of minutiae in a Spanish population is presented by Gutierrez *and al.* (127). The authors studied in particular the total count of the minutiae, the count of each different type (where combined minutia types were used), both in the whole fingerprint and in the centre (defined as a circle with a radius of 18 ridges) and periphery separately. The frequencies of the different minutia types are given. Also, the number of minutiae on the fingerprint is compared between male and female subjects. Differences are observed for the whole fingerprint, when the general pattern is whorl or loop, and differences are significant for all general patterns in the peripheral region, males having more minutiae than females. In the central area, none of the differences observed between male and female subjects are significant.

Zhu and co-workers (123) use minutiae location and orientation in a generative model. This work and related ones has been reviewed also by Dass *et al.* (23). Here, a joint distribution is

proposed, where minutiae locations are modelled by a bivariate normal mixture, and orientations by a Von-Mises distribution. A different approach, also using the model of Zhu *et al.* (123) as a basis, integrates image quality by adding a model for errors in minutiae detection and localisation (124). An internal report gives an overview of models for fingerprint individuality (145), proposing a classification of models into grid, fixed probability, ridge-based, relative measurement, and generative models. Generative models for birthdays, height and fingerprints are described (117). The fingerprint generative model includes minutiae locations and directions, as well as ridge lengths and the location and direction of ridge points, where one ridge point is selected in medium ridges and two ridge points for long ridges (none for short ridges). The parameters of the model are then estimated on the basis of data (100 fingerprints and 8 impressions from each fingerprint, FVC2002 DB1), and the model is used to compute a probability of random correspondence given the number of minutiae and ridge points in the reference and query images, as well as the number or correspondences between the two. This model is further described by Su and Srihari (118) : a mixture of bivariate Gaussian distributions is used for minutiae location, von Mises distributions are used for minutiae orientation and the ridge lengths are considered to be distributed uniformly. Ridge points are described by the distance from the minutia, the direction between the minutia and the ridge point as well as the orientation of the ridge point. The distance of ridge points to minutiae is modelled using a one-dimensional Gaussian distribution. The model, with a computation of specific random correspondence probabilities, is the subject of (119).

Chen and Moon carry out an investigation of discriminative power using minutiae data (location, direction). Minutiae location is modelled using a uniform (spatial) distribution, and a Von Mises distribution is used for the differences between orientations of two compared minutiae. First, the model for locations is compared to observed values (obtained on different available fingerprint databases), and second the model for both locations and directions is compared to known nonmatch-comparisons. The 'score' is constituted of matching pairs of minutiae between the (nonmatching) impressions. Good correspondence between the model and observations are shown (121). However, in a following paper, the authors show that the location of minutiae is not distributed according to complete spatial randomness, invalidating this first model (122), and the authors propose to model the minutiae locations using a quantitative stochastic model. The results obtained are again compared to observed data as well as to the first model, and an improvement (better correspondence to empirical data) is observed.

The neighbourhood of minutiae is analysed by Hsu and Martin. The locations of minutiae are shown to be non-random (a preference of four inter-ridge distances is observed). The relative minutiae orientations and positions are distributed non-isotropically. Probabilities for various numbers of minutiae and numbers of nearest neighbours are given. For example, the probability for 12 minutiae is inferior to 10^{-30}. The authors also show that manually annotated minutiae yield results that differ from those obtained on automatically extracted minutiae (120).

Ridge points are described in (125), and their use for improving fingerprint matching is assessed using a modified version of the Bozorth and k-minutiae matchers. Minutiae types and orientations, as well as ridge types (defined using the ridge points described in (125)) are used in order to compute a PRC (probability of random correspondence) for fingerprints by Fang and co-workers (126).

Two studies using AFIS (Automated Fingerprint Identification System) in the context of fingerprint identification have been carried out. One makes use of AFIS scores to determine

the validity of fingerprint identification (115). Comparing mated inked prints, and using a logistic regression classifier, a threshold is used to declare a match. When this threshold is set to a probability of 0.5, the classification error is of 2.4 ± 0.1 %. When marks acquired by research assistants were used in a second experiment, this classification error was of 4.5 ± 0.4%. In the third experiment, where marks from a NIST database were used (NIST Special Database 27), a classification error of 5.4 ± 1.0% was obtained (115).

The second study aims at obtaining likelihood ratios from AFIS scores in the context of 1:1, mark-to-print comparisons. Here, a within- and between-finger variability are modelled, based on the characteristics of the mark and the suspects' fingerprint examined. All computations are conditioned by the number of minutiae that are in agreement between the mark and the print (116). Two donors were used for the establishment and testing of this model. The rates of misleading evidence in favour of the prosecution (LRs above one when the impressions compared come from different fingers) for donor 1 (donor 2) are of 0.3% (5.2%), 0.3 (3.2%), 0.3% (0.8%), 0.0% (0.2%), and 0.0% (0.3%) for 6, 7, 8, 9 and 10 minutiae respectively, while for these same numbers of minutiae, the rates of misleading evidence in favour of the defence are of 0.7% (2.1%), 0.3% (0.3%), 0.3% (0.6%), 1.2% (0.00%), and 0.1% (0.00%). The background database used to extract the between finger variability consists only of images from the same finger number and general pattern as that of the finger that left the mark.

An operational trial using a model to evaluate cases has been presented (128).

Twin studies

A trial has been carried out on a new set of 227 pairs of identical (188 pairs) and fraternal (39 pairs) twins' fingerprints. Prints were acquired using a Smiths-Heimann scanner and processed using Cogent software. First, the probability that level 1 on the same finger of a pair of identical twins matches was computed and is of 66.71% (46.41% for fraternal twins). The MINDTCT algorithm was used for the extraction of minutiae and the Bozorth matcher for the computation of match scores. Distributions of scores are compared for twin-to-twin, twin-to-nontwin and genuine matches (where two impressions from the same finger are compared). These distributions all differ significantly. Error rates are also compared between non-twins, fraternal and identical twins ; these are 3.33%, 4.88% and 5.09%, respectively (129). Another study of twins (298 twin-pairs, 42 of which are fraternal twins) also shows that twins' fingerprints are more likely to show the same general pattern for a given finger (56.92% for identical twins, 39.44% for fraternal twins and 31.76% for non-twins. Using the MINDTCT and Bozorth algorithms, the equal error rate for twins obtained is 6.17%, and 2.91% for non-twins. Testing of the distributions of match scores shows that the distribution for twins is different than that for comparisons between impressions from the same finger. The distribution for fraternal twins does not differ from that of identical twins, and the statistical test used does not formally show a difference between the distribution for twins and non-twins; it is concluded however that the similarity of fingerprints of twins is different from the similarity between arbitrary fingers (130).

Level III detail

A survey among practitioners has been carried out in order to clarify the definition and potential value of level III features. Disagreements in definition could largely be attributed to the wording or misunderstandings in the questions, but large differences were observed among examiners concerning the expected reproducibility of level III features, as well as their discriminative value (146).

A large trial on level III features has been carried out, using pores, ridge contours and edge features. Matching capabilities are improved slightly by integrating level III features in addition to level II features (136), using the Bozorth matcher. A short overview of this trial has also been published (137).

A doctoral thesis (131) investigates additional features for use in fingerprint comparison, including ridge skeletons, pores, dots and incipient ridges. The matching performance of algorithms is improved by the addition of these features. When matching is performed in mark to inked print tasks (at 500 dpi) the improvement is largest for the worst images, and for ridge skeletons. These effects are attributed to the resolution of the images, which is small for the extraction of pores, in particular. When the comparisons are carried out between livescans, the improvement is greatest for the smallest areas used. In a second part, a fingerprint individuality model is proposed, incorporating minutiae locations and directions, ridge period and curvature as well as pore spacing. This model is an extension of one of the models presented above (123). The current model is fitted to five major fingerprint classes (whorl, left and right loop, arch and tented arch). Minutiae are clustered according to position and orientation, then position is modelled using a bivariate Gaussian distribution for each cluster, and the orientation by a Von-Mises distribution. The ridge period is modelled using a Gaussian mixture, and ridge curvature is modelled using a Poisson mixture. Finally, pore spacings along the ridge are modelled using a Gaussian distribution. Estimation of the model parameters follows, and the model is validated against empirical data. In the last part of the thesis, a touchless 3D fingerprint acquisition device is presented. In particular, the interoperability between these 3D images with legacy rolled prints is achieved through an algorithm constructing rolled-equivalent images from the 3D representations acquired by the sensor, and another to enhance the acquired images. The work carried out during this thesis is also the object of several articles (132-134).

The usefulness of integrating level III features into the matching process is also shown by Vatsa *et al.* (147), Zhao *et al.* (148, 149) and Jain *et al.* (135). In this last reference, ridge edges as well as pores are used, in a hierarchical approach (level II is matched, and then level III features are used). Matching results are improved using this approach, also for images classified as being of low quality. But Indovina and Hicklin (cited above, under Automated Systems) only find an improvement for some of the systems tested, therefore highlighting that level III is not always useful in the matching stage (77).

Pore area reproducibility has been measured on marks developed using ninhydrin and cyanoacrylate. Ten marks developed using ninhydrin and 50 marks developed using cyanoacrylate were used. The results show that pore area is not reproducible (138), indeed, the % coefficient of variance is between 38.5% of the mean and 81.9%.

Distortion

The deformation of the skin under distortion conditions is observed experimentally by Maceo (139). First, the anatomy of the hand is described in a detailed fashion, describing the elements that are relevant to distortion. Then, the effects of vertical and horizontal sheering stresses and torque are examined, first on stills from videos and second on developed impressions. The two fingers used present different general patterns (loop and whorl) and differences are analysed qualitatively. This article is richly illustrated with commented images. A model for skin distortion in a biometric setting is proposed by Maltoni and Cappelli (140) (as well as its use for generating fingerprints and a discussion of the use of distortion to detect fake fingerprints). Butterflies (merging, overlapping or misalignment of two sections of ridge skin) are discussed by Pierce and Turnidge (141), who present examples of such merged

impressions, and discuss how to detect their presence and interpret artefacts due to this kind of distorsion.

2.1.3 The individualization process and the judicial system

General considerations of the individualisation process are presented in (150) and (151). Errors are mentioned in several contributions (152-155); the definition of erroneous exclusions is discussed in (156). The influence of different evidence types (including fingerprint evidence) on verdicts is studied in (157). A change in the interpretation of fingerprint individualisation conclusion is apparent in (158, 159) and discussed in (160); these conclusions are, according to these publications, considered opinions (rather than facts). Bias is the subject of several publications (161-171); here (162), (163) and (165) present study results, and those of (162) and (163) show in part similar effects, while the third study has been criticised (166, 167). The validity of fingerprint individualization (i.e., the correctness of results) as well as the definition of ACE-V and whether or not it is scientific are all questioned (56, 58-60, 172-178) (criticised in (179))(180). Kaye makes interesting points on uniqueness and individualization (181, 182). Two articles spell out the ACE-V process (183, 184), while one study tests the validity of conclusions resulting from the process (185), and one other tests the validity of conclusions on laypeople (186). Finally, Cooney (187) inventories latent print training. Koehler (188) shows shortcomings of current proficiency tests for computing error rates and proposes solutions. Koppl (189) analyses the relative cost of errors and systematic blind verification for felony cases going to trial, and advocates blind verification.

A decision theoretical approach is proposed for the identification sciences in general. The problem of how to come to a definitive decision (inclusion, exclusion, inconclusive) using probabilities and utilities is described and elegantly solved (150).

The increase in the number of fingerprints (in the sense of the number of people on earth increasing, and not solely of the increase in database sizes) and the possible problems arising from this increase is the object of an article by Cherry and Imwinkelried (151). The 'return' to the use of the Henry system is also advocated by these authors (151), in particular they consider necessary to use the general pattern information of neighbouring fingers for identifications of marks (if a mark is found in conjunction with neighbouring marks that are highly likely to come from neighbouring fingers).

A book with a part on fingerprints has been published (152). A perjury case, as well as a few errors are included. For the perjury, the case of New York State fingerprint examiners who identified marks that were lifted in the booking room as having come from burglary scenes between 1982 and 1992 is reported. The error in the Rick Jackson case is also reported, (two fingerprint examiners identified a print to Jackson, and two others, who were called upon by the defence, found an exclusion), as well as the Cowans and Mayfield cases. A large number of erroneous identifications is reported in Michele Triplett's fingerprint dictionary under *"erroneous identifications and faulty evidence (not confirmed)"* (153). Here problems with the LAPD fingerprint unit are mentioned, as well as the case of a fingerprint examiner from Seminole County, Florida (also mentioned in (152) and (189)). Only secondary sources are available for some of these problematic cases, for the LAPD this is the Los Angeles Times (154), and for the Houston crime laboratory the Houston Chronicle (155). Although some of

these errors remain unconfirmed, recent events tend to show that profound problems concerning more than one case (LAPD laboratory and the Seminole county examiner) persist and are difficult to handle; therefore, appropriate reactions to such events should be foreseen. The results of the CTS test of 2010 (190) support this conclusion.

A discussion of erroneous exclusions, taking into account the fact that there are lower thresholds applied to exclusions (a single discrepancy that cannot be explained) than to identifications is proposed; the author emphasizes that the way false negatives are viewed depends on the individual. Also, the author discusses the applicability of the logic of hypothesis testing, and type I and II errors, directly to fingerprint conclusions. He proposes to rather view ACE-V as ternary predicate logic (which states that an outcome of -1, 0 or +1 is possible) (156).

In order to address the question of how different evidence types will affect jury verdicts, a questionnaire was given to jurors (n=233) and students (n=383); the first question addressed the perceived accuracy of the evidence, where fingerprints were rated as being slightly less accurate than DNA by both populations. The remainder of studies is carried out with students only. The participants received a case scenario (either a rape or a homicide) including different evidence types that were either incriminating or exculpatory. Incriminating DNA, fingerprint or victim testimony resulted in 100% of guilty verdicts, while hair analysis and eyewitness testimony lead to 92% and 75% of guilty verdicts, respectively. For the murder scenario, incriminating DNA evidence is the only evidence type leading to 100% of guilty verdicts. Hair analysis yields 83% of guilty verdicts, while fingerprint evidence leads to 67% of guilty verdicts. Victim testimony and eyewitness testimony lead to 55% and 60% of guilty verdicts, respectively. The results when the evidence is exculpatory are particularly interesting: in the rape scenario, the percentages of guilty verdicts remain at 15% (DNA), 70% (hair), 67% (fingerprint), 27% (victim testimony) and 54% (eyewitness testimony), while these numbers are of 36% (DNA), 25% (hair), 46% (fingerprint), 64% (victim testimony) and 27% (eyewitness testimony) in the murder scenario. In this first study, only the location for DNA (and hair) was given; it was said that the DNA was from semen found on the victim for the rape case, under the victim's fingernails and on her clothing in the murder case, while hair evidence was found on the victim in the rape and the murder case. A second study addressed the fact that this might have had an influence; this study was carried out with a student sample. Now, for all evidence types, the location of the evidence was given. Also, only a probability of guilt was asked for; the results are the following mean assessments of guilt : 65.2 (DNA), 55.71 (blood type), 48.00 (fingerprint), 43.15 (hair fibre) and 36.74 (eyewitness testimony). From a verification question, which asked whether each evidence type matched, it appeared that a part of the sample where only blood type was given as incriminating evidence considered DNA to be matching. In the third study reported, different elements related only to DNA evidence were tested (whether pre-trial beliefs regarding DNA, the reliability of the laboratory, or the style of cross-examination influenced the verdict (157)).

Starting from dictionary definitions of the words 'subjective' and 'objective', Leo develops arguments in relation to different court cases where the use of the word 'subjective' was important, according to this analysis (191).

An important change occurs in the argument about fingerprint identification: it is being more and more considered an opinion, based on the specialists judgement, rather than fact (158-160).

Bias

Review papers in the subject of cognitive bias are now available (26, 192, 193). A short summary of the research contributions made during the reviewing period is given hereinafter.

Whitman and Koppl (161) discusses biasing effects of the justice system and the integration of forensic services with the police, as well as reaction possibilities. This article also discusses 'verification shopping', which consists in searching for someone who will verify the original conclusions. Dror and Rosenthal describe two previously published studies and carry out a meta-analysis, reuniting the effects of bias observed in those two studies; the effect size thus obtained is quite large and with a p-value of 0.015 would generally be considered to be significant (162). Bias in verification has been tested for both experts (n=43) and novices (n=86). Three groups were created for both the experts and the novices. The first group carried out comparisons without any information (control), the second group received the comparisons and had answers provided that were stated to have been given by a fingerprint examiner trained to competency (low bias group); in the third group, the answers provided were said to come from prominent and internationally recognized expert (high bias group). For experts, there was a significant increase in inconclusive opinions in the low and high bias groups with respect to the control group. This increase is larger for the three different source trials than for the three same source trials (only one of the same source trials produced inconclusive opinions). One trial lead to an increase in the relative frequency of experts' conclusion towards the bias prompt; in this trial the ground truth was different source, and the bias prompt was inconclusive. For novices, there were more inconclusive conclusions for the different source trials than for the same source trials, but there were not more inconclusive opinions in the bias groups with respect to the control group. There was, for novices, an increase in the relative percentage of responses in agreement with the bias prompt in the bias groups with respect to the control group (163).

Dror analyses the sources of biases that are represented by the four idols of Francis Bacon, in order to improve forensic science by identifying such vulnerabilities (164).

A study has been carried out with 70 fingerprint examiners, in a way resembling verification, and declared as an experiment. Examiners were in two groups, high and low emotional context (an allegation of murder and one of forgery). This study did not find any bias effects (165). The study has been criticised concerning both experimental flaws and problems with the interpretation of the data (166, 167). The authors react to both of these criticisms (168, 169).

Busey and Loftus discuss bias in eyewitness testimony and fingerprint comparison contexts, based on past research (170).

Charlton *et al.* explore the satisfaction in doing fingerprint comparisons through interviews with 13 experienced fingerprint examiners. In particular, they highlight the job satisfaction which is related to the sense of pride the examiners have with respect to their skills, and also satisfaction with crime solving. Finding a match is described as a buzz, a really good feeling, and examiners like to see cases through to conclusion; there is a need for closure (171).

Discussions on validity of fingerprint comparisons and ACE-V

A special issue of Law, Probability & Risk, which appeared in 2008, is anchored around the ACE-V process. After an introduction (55), the validity (interpreted as both validity and reliability here) of the ACE-V method is discussed. This discussion includes proposals to carry out testing for validity. Perhaps most importantly and contrary to the current evolution of evaluation procedures, they propose the use of a numerical standard for evaluation (without defining it), but also, alternatively, a 'training and experience' standard (56). The use of a

numerical standard is also defended in (194), as a safeguard, and to protect the infallibility of fingerprint evidence. The reaction by Champod (57) to the article by Haber and Haber (56) clarifies that ACE-V is just a protocol, which is general to the forensic comparison sciences ; it does not insure reliability. A discussion of the usefulness of statistical models, specifying the selectivity of fingerprint features, is presented, along with a call for transparency including the spelling out of the ACE-V protocol. Cole (58), also in reaction to the Haber's article (56), denies ACE-V the status of a methodology and discusses the irrelevance of the scientificity of the approach, highlighting the importance of validation (and reliability). Mnookin (59) estimates that indeed, research is necessary but that fingerprints could be used in court without the actually unfeasible testing Haber and Haber require *"so long as the fingerprint community has done as much as it reasonably can do to establish the validity of its approach and the accuracy of its practitioners' conclusions"*. She considers particularly problematic that such feasible research has not been carried out by the fingerprint community. Haber and Haber react to these articles, and the arguments presented therein (60). They are also the authors of a book which describes the forensic use of fingerprints, how fingerprint work is carried out, revises court-related issues, error rates and accuracy, bias, training issues and finally fingerprint testimony (172). A book review by Bono has just been published (195).

Cole emphasizes that it is the validity of the process that needs to be considered (173). Here, the author argues that expert testimony (not expert evidence) needs to be thought about, and that "evidentiary claims stand along a continuum of trustworthiness" rather than being clearly separable into reliable and unreliable evidence. In particular, rather than considering admissibility of evidence, according to the author, attention should be paid to over- or under-claiming during testimony. He then analyses fingerprint testimonies of 34 case transcripts (173), focussing on the "source attribution moments". These were then divided into Process Statements (the mark was identified/matched to the inked impression), Source Attribution Statements (the defendant made the print/defendant could be the only source) and Identity Statements (the fingerprint was one and the same with the mark). It is considered that Process Statements do not really attribute the mark to a source; it is only stated that the two impressions match, but how often this could happen in a population is not assessed. Source Attribution Statements are considered to represent over-claiming, while Identity Statements, which were less frequent in the 34 cases reviewed, go against the principle that no two impressions could be identical. In a later article, the same author argues that fingerprint individualization evidence satisfies neither the *Daubert* nor the *Frye* admissibility standard (196). Mnookin (174) argues that testing is needed to assess the scientific validity of a method, rather than explanations of the premises and the methods used. She considers that to know *how* a method works is less important than knowing *that* it works. An argument against the usefulness of uniqueness and the lack of necessity for individualisation conclusions in the legal system is presented in (175). A different approach to uniqueness, individualization and identification is used by Kaye (181), who discusses general and special uniqueness as well as 'local' and 'universal' individualizations. The same author argues that very small probabilities of fortuitous correspondence can reasonably be considered negligible (182). The author links this argument to the way that all science works today: Some inductions which, according to both laws of probability and Popper's writings, cannot be absolutely proven as true are, necessarily, considered as such. This directly responds to Saks and Koehler, who criticise the *"uniqueness fallacy"* which can occur when the frequency of occurrence is smaller than the number of objects that exist (e.g. $f*n<1$), and consists in concluding to uniqueness in such cases (176). These authors then discuss individualization/uniqueness, from an actual as well as a historical perspective. A probabilistic example is presented, where the number of pairwise comparisons that need to be carried out in order to find a relatively small number of

duplicates is computed. The very low probability of detecting a pair of identical objects in this context, even given a large number of comparisons, directly counters the argument that pairwise comparisons can be used to ascertain the uniqueness of an object. Finally, they support the use of probabilistic conclusions. A similar argumentation is proposed in a shorter article by Saks, which includes a global discussion of identification sciences, research to be carried out, and how to report findings while awaiting this research (177). In an earlier paper, Saks and Faigman ascertain the absence of science in the so-called individualization sciences (pattern evidence) (178); the presence of any scientific element is negated here. A criticism of this article has also been published, in an editorial (179). A primer to distinguish science from pseudo-science is proposed by Lilienfeld and Landfield (180). They propose ten indicators of pseudo-science and relate them to examples from police work. The first of these indicators is *lack of falsifiability and overuse of ad-hoc manoeuvres* (loopholes, escape hatches used when researchers find results that falsify a given claim); here, fingerprint analysis is used to illustrate this point.

An overview of the premises of fingerprint individualisation, the ACE-V process, standards for conclusions, what constitutes sufficiency, but also statistics and probability modelling, error rates, quality assurance, training, and SWGFAST guidelines is given by Peterson *et al.* (183). Reznicek and co-workers integrate ACE-V into a 7-step scientific method. These 7 steps are observation, stating of the question, generation of a hypothesis, conducting experiments, formulation of conclusions, replication and reporting, where the analysis and comparison steps of fingerprint comparison are considered to be the 'conducting experiments' stage, evaluation is the formulation of a conclusion and verification is the replication. Furthermore, the authors propose to consider the premises of fingerprint individualisation (persistence, unicity and classifiability) as a theory, hypotheses that have not been falsified through testing to date and therefore, being supported by evidence, have gained the status of theory (184). ACE-V, as applied by fingerprint examiners in a laboratory, has been tested in order to assess the accuracy, precision, reproducibility, repeatability and biasability of conclusions. Overall, three erroneous identifications (out of 720 comparisons) were observed but were attributed to transcription errors. Two of these were submitted in the course of the study to verification and were not verified, while the third erroneous identification was re-submitted to the same analyst, who did not repeat the error. Erroneous exclusions were more prevalent and less likely to be caught in verification. Also, divergences appeared between definitive exclusions (identification/exclusion) and inconclusive / no value conclusions. In particular, some comparisons resulted in 'identification' decisions from some examiners, and in 'inconclusive' decisions from others (185).

Accuracy in fingerprint comparison has been tested using laypeople (186) ; it is shown that some fingers are more easily discriminated than others.

Whether written training programs exist, whether they adhere to SWGFAST guidelines, whether the interpretation of these guidelines is consistent, and whether a difference exists between ASCLD/LAB accredited agencies and non-accredited agencies concerning the training standards has been investigated by the means of a survey (187). Out of 168 surveys sent out to members selected from the 2007 International Association for Identification directory, 75 were returned. 75% of the respondents claimed having a written training program, and 72% claimed adhering to SWGFAST guidelines. Five follow-up questions were used to determine whether these agencies actually did follow the guidelines, and, based on these follow-up questions, only 25% do. As to the consensus in the interpretation of the guidelines, it exists in 7 out of 11 categories tested; the four categories where no consensus

was apparent are degree requirements, the duration of the training program and of supervised case review, and the existence of a written pass or fail policy. There was a significant difference between accredited and non-accredited laboratories on a majority of the points examined, and the hypothesis that there is no difference between these two types of laboratories was therefore rejected.

The shortcomings of current proficiency tests for estimating error rates and a way to obtain error rates for fingerprints through proficiency tests is discussed in (188).

An argument for several verifications, including an economic perspective has also been presented (189).

2.2   Fingermark composition, detection and visualization

This chapter is structured as follows: the first section is dedicated to the composition and evolution of the fingermark residue under various environmental conditions. It is followed by the presentation of the recent developments in fingermark detection, the scientific contributions being classified according to the technique, the context, or the substrates.

The following contributions constitute recent reviews that can serve as good starting points for readers not accustomed to the range of methods available in the field: detection of latent fingermarks (197-199), forensic chemistry (200), and forensic science (1).

When summarizing the experimental studies published these last three years, we chose to focus on the *"fingermark sampling"* protocols, if described by the authors. This encompasses the nature of the secretions that were used (i.e., natural/non-enriched, eccrine-rich, or sebum-rich), the total number of donors and fingermarks, the time between the deposition of the fingermarks and the processing of the samples, and if depletion series were considered. A great versatility has been observed among the contributors, with protocols close or far-off realistic conditions (not necessarily casework-like). This emphasizes the fact that the sampling protocol is a key-element to be aptly chosen since it will influence the possibility to compare experimental results between researchers and to operationally implement a new technique. In this context, the recent publication by Terry Kent may constitute a step forward in the standardization of the sampling protocols (201). In this contribution, some sampling protocols and testing methods were discussed (e.g., effect of grooming, use of split fingermarks and of depletion series, timescale, substrates, donors, and performance evaluation). Another study, proposed by Croxton *et al.*, could provide a quantitative proof of the lipid over-representation in *"groomed"* fingermarks compared to natural ones (202). In a third study, an original concept has been presented to empirically quantify the differences in contrast between the ridges (of a fingermark) and the valleys (generally: the underlying substrate) (203). The so-called *"relative contrast index"* could help in assessing the actual efficiency of a tested technique, and simultaneously provide a documentable and objective way of measuring contrast enhancement that could be used to perform comparative studies. In this context, Vanderwee *et al.* performed a literature survey of ca. 45 published papers and reported the information that could be found in the manuscripts in terms of visual assessment, scoring protocols, side-by-side comparison, or development time (non-exhaustive list of reported parameters) (204). It would be interesting to see if the forensic science research community will follow these advices and propositions in the coming years.

2.2.1 Composition, aging, and persistence of fingermarks

Attempts to correlate the chemical composition of latent fingermarks with the age of the individuals who have left them were published (205, 206), both concluding that it is possible to estimate the age of an unknown individual by analyzing the infrared spectra of marks. In another study, the analysis of the amino acid composition of latent fingermarks was used as a witness of a genetic disease (207). Finally, the composition in amino acids and lipids between natural and sebum-rich fingermarks was compared using GC-MS (202).

The persistence of fingermarks under wet conditions has been investigated by various authors (208-210). If all emphasized the successful processing of wetted substrates to detect latent fingermarks, their conclusions differed about the techniques to be applied in such situation. Finally, photo- and thermal-degradation of eccrine secretion components has been studied (211).

Fourier transform infrared spectroscopy (FTIR) was used to determine if changes in fingermark composition could be correlated with the age of the person that has left the mark (205). For this study, latent fingermarks deposited on tin plates by 78 individuals aging from four to 68 years were considered. Analyses were performed 24 hours after deposition for children (0-19 years), and 48 hours after deposition for adults (20-70 years). The results showed that a combination of constituents could be found, whose composition linearly changes with age, with a significant shift around puberty. A linear model of age as a function of the FTIR spectrum has been proposed, with a root mean square error of calibration of less than four years. This linear model shows an inflection at the age of 25. If two linear models were constructed (i.e., for people <25 years, and for the older ones), the age estimation could become more accurate. It should be noted that the analyses were performed on one- or two-day-old marks, without taking into account the modifications of composition that could occur as the marks age (which is likely to be the case in the context of a crime scene investigation).

Another study aimed at comparing the chemical compositions of children's and adult's latent fingermarks over time, using FTIR (206). For this study, six fathers and their corresponding sons were asked to deposit eleven sebum-rich fingermarks on glass microscope slides. As a result, it has been concluded that a distinction can be made between both populations for up to four weeks after deposition when analyzing the sebum composition. Indeed, it has been observed that the lipid contents differ, with higher wax esters and glycerides for adults compared to higher cholesterol and corresponding esters for children. Moreover, if the lipid $/$ protein ratios decreased at a similar rate for both fathers and sons, the compositions evolved differently over time due to differences in the fatty acid nature and volatility. Finally, this study was in agreement with previous studies showing that children produce less sebum than adults. According to the authors, this study could allow establishing a sensitive metric providing an estimation of an individual's age, if the delay between deposition and analysis of the mark is known. Besides these conclusions, the authors also studied the effect of fingermark aging on the successful detection (powdering followed by lifting) of the marks. If the fathers' marks remained equally detectable during the experiment, the sons' marks became more difficult to visualize as they aged. This effect is in correlation to the fact that children's marks become more quickly inadequate for lifting compared to adults' ones.

The composition of amino acids in fingermarks has been linked with a genetic disease, i.e., the beta-thalassemia (b-thal) (207). In this study, the relative composition of free amino acids in the latent fingermarks of 24 b-thal patients and 24 healthy individuals (ages: five to ten year-old) were compared using high-performance liquid chromatography. When compared

with the composition of healthy subjects, the statistical and chromatographic profiles of b-thal patients were characterized by (1) a significant decrease of ornithine and lysine, (2) a significant increase of ammonia and proline, and (3) no tyrosine. In this study, no actual (casework-like) fingermarks were used since it was asked to the patients to press their finger on a glass beaker for at least two minutes. Nevertheless, it is interesting to see that the composition of the fingerprint secretions can actually be influenced by a genetic disease (in this case, beta-thalassemia) and that it can be emphasized through analytical measurements on latent residues.

In the context of standardization of the fingermark sampling protocols, the study proposed by Croxton *et al.* showed that lipids are logically over represented in *"groomed"* fingermarks (i.e., when the donors are asked to rub their fingers on their face or hair prior the deposition of fingermarks) compared to natural marks (202). Eighteen donors were asked to leave *"natural"* fingermarks and sebum-rich ones on a non-porous substrate. All the fingermarks were immediately analysed using gas chromatography coupled with a mass spectrometer (GC-MS). On average, fatty acid content could be over represented by a ratio of 4:1, squalene by a ratio of 16:1, and the total sebaceous mass by a ratio of 6:1, compared to natural marks. This over representation in lipids could seriously compromise the validity of some published results. It should be noted that the amino acid composition remained significantly similar between the two kinds of fingermarks. Moreover, the relative abundance of amino acids was consistent with previously published studies (212), with serine as the most abundant amino acid followed by glycine, alanine and aspartic acid. Finally, no correlation between the total amount of fatty acids and of amino acids was observed in both kinds of fingermarks. This result seems logical since these chemicals are secreted by different glands.

Soltyszewski *et al.* studied the effect of water on the recovery of fingermarks and DNA profiling (209). For this study, 456 sebum-rich fingermarks were left by eight donors, on glass (10 seconds of contact time, medium pressure). Additionally, four different kinds of water (i.e., river, sea, tap, and distilled), two temperature conditions (i.e., 5 and 20°C), and six immersion times (from one day to 42 days) were considered. The samples were then dried, processed by three fingermark detection techniques (i.e., aluminium and ferromagnetic powders, and cyanoacrylate), then swabbed for DNA profiling. Fingermarks were successfully retrieved for items being submerged in water for up to six weeks, with high success rates for one to seven days of immersion. Ferromagnetic powder and cyanoacrylate fuming showed to be more effective than aluminium powder. The quality of the fingermarks nevertheless decreased as the immersion times increased, and as the water temperature rose from 5°C to 20°C. Finally, no DNA profile could be obtained regardless of the tested conditions.

Kerr *et al.* investigated the effect of water immersion on the efficiency of the commonly used fingermark detection techniques (208). For this study, non-enriched fingermarks were left on glass before being immersed in different water baths (i.e., cold, 50°C, or soapy) for varying times (i.e., five seconds and one minute). It should be noted that the fingermark aging time (i.e., the time left between the deposition of the marks and their wetting) has not been specified by the authors. We assume that the freshly deposited marks were immediately rinsed after their deposition. Nine fingermark detection techniques were compared (i.e., aluminium and gold powders, small particle reagent – SPR, eosin blue, erythrosine B, physical developer - PD, gentian violet, sudan black, and cyanoacrylate fuming) according to their ability to reproduce ridge details. As a conclusion, the authors recommend to first air dry wetted glass samples vertically, before processing them with either aluminium or gold powder. If vertical

drying is impossible, they recommend using SPR while the samples are still wet. It should be noted that cyanoacrylate fuming gave poor results on the dried samples, which is in contradiction with the above-described study (209).

Wood & James investigated the persistence of latent fingermarks left on white paper and uPVC plastic immersed in different kinds of water (i.e., river, rain, and tap) or in an accelerant (i.e., unleaded petrol) (210). For this study, freshly-deposited sebum-rich fingermarks from one donor were used. The items were immersed in the different liquids for varying times (i.e., one hour, 24 hours and one week) before being dried and processed with commonly used fingermark detection techniques (i.e., magnetic powder, iodine fuming, ninhydrin, cyanoacrylate, SPR, PD, oil red O - ORO). On paper, the latent fingermarks were found to persist for over a week when immersed in water with successful application of magnetic powder, PD and ORO. After one week, identifiable marks were obtained only with ORO. Logically, ninhydrin gave poor results regardless of the immersion times due to the amino acids solubility in water. A more pronounced detrimental effect has been observed for the items immersed in the accelerant, with identifiable marks detected only for a 24-hour immersion time, using ninhydrin. On plastic, marks were easily detected after a water immersion for over a week, using all the compared techniques (with the notable exception of iodine fuming). The detrimental effect of the accelerant has been less than for the paper, with successful detection for all immersion times and techniques (except iodine fuming). Among the tested techniques, the authors recommend the use of ORO and SPR to detect fingermarks on porous and non-porous substrates, respectively.

To study the effect of sunlight exposure and temperature on eccrine secretions, aqueous standard solutions of aspartic acid, glutamic acid, glycine, histidine, ornithine, serine, threonine, urea, and lactic acid were prepared (211). The photo-degradation study was performed as follows: the standards were deposited on Teflon disks and steel coupons, then allowed to dry overnight in the dark before being exposed to a 200–500 Watt Xe∕HgXe arc lamp for varying times (up to ca. 3h40), corresponding to sunlight exposure times ranging from 0 to 56 days. The thermal-degradation study was performed by depositing the standards on galvanized steel, then allowing them to dry overnight in the dark before being exposed to temperatures ranging from 50 to 150°C using a heat gun. Mass spectrometry was used to analyse the samples afterwards. No notable photo-degradation of the amino acids and urea was observed for both substrates, even after 56 days of sunlight exposure. Lactic acid however quickly underwent degradation (already after two days), leading to the generation of pyruvic acid which subsequently also underwent degradation. A substantial thermal degradation of the amino acids and urea occurred for temperatures above 100°C. For lactic acid, the thermal degradation started between 50 and 100°C (along with pyruvic acid generation and subsequent degradation).

2.2.2 Amino acid reagents

The use of amino acid sensitive reagents still constitutes the method of choice to detect latent fingermarks on porous substrates. Even if such reagents have been known for a long time (199) and are widely used in casework, two major contributions have somewhat renewed the subject. First, the development of an amino acid standard obtained by printing a pattern using a modified inkjet printer (213), and a collaborative test carried out using this standard (214). Second, a thorough study detailing the intimate mechanisms of the reaction of amino acids with ninhydrin, 1,8-diazafluoren-9-one (DFO) and 1,2-indanedione/zinc (215).

Besides these contributions, the use of promising ninhydrin analogues has been investigated (216-218), as well as the effect of pressure and sweat on the quality of ninhydrin-processed fingermarks (219). An alternative to the use of a temperature- and humidity-controlled development cupboard has also been proposed (220). Concerning DFO, Schwarz and Beisel proposed a new formulation, said to be more robust against the formation of two phases (221). The studies on 1,2-indanedione were mainly focused on the optimization of the formulations and of the development procedures (222-224). Finally, lawsone (225) and isatin (226) were proposed as new promising amino acid reagents, while pDMAC was proved to actually react with amino acids, and not with urea as it was thought for long (227).

Ninhydrin and analogues

A computational study, initiated by Petraco *et al.* (see Interpol report 2004-2007) on the reaction mechanisms between ninhydrin (and analogues) and amino acids, has been pursued (216). According to their conclusions, some analogues could constitute promising substitutes for ninhydrin and should be synthesized for experimental tests.

Following their research on a one-stage *"ninhydrin / metal salt"* premix formulation behaving like a dual reagent (i.e., leading to both coloured and luminescent fingermarks), Almog *et al.* showed that the use of commercially available ninhydrin analogues led to better results (217). By mixing 5-methoxyninhydrin (MN) or 5-methylthioninhydrin (MTN) with zinc or cadmium salts, coloured fingermarks could be obtained (MN: orange with zinc, and pink with cadmium; MTN: pink with zinc, and red with cadmium) and observed in luminescence at room temperature, without the use of liquid nitrogen. The *"MTN / ZnCl$_2$"* gave the best results, with fluorescence intensity comparable to the one of 1,8-diazafluoren-9-one (DFO), but with a much stronger visible colour. If classified according to the colour, the different reagents were ranked as follows: MTN/ZnCl$_2$ $\cong$ MN/ZnCl$_2$ > Ninhydrin/ZnCl$_2$ > DFO. If the classification is made according to the fluorescence intensity at room temperature: MTN/ZnCl$_2$ = DFO $\geq$ MN/ZnCl$_2$ >> Ninhydrin/ZnCl$_2$.

Jasuja *et al.* investigated the effect of various parameters that occur during the deposition of a fingermark on the efficiency of the subsequent ninhydrin process (219). For this study, thirty individuals (among which five were considered as good sweat donors, and five as bad sweat donors) aged from 20 to 25 years left latent eccrine marks on white paper following different conditions: conventional situation (no specific pressure, no induced sweat), with pressure (i.e., 50 g, 100 g, 150 g, and 200 g), and with induced sweat production before deposition using a polyethylene bag around the hand (i.e., for 30 to 180 seconds). Less than 24 hours later, all the fingermarks were processed using ninhydrin. Linear relations were established between the quality of the developed marks and the pressure intensity, under the studied conditions. As the induced sweating time increases, the quality of the marks increased as well for all types of donors (mixed, good and bad donors). An induced sweating time of 120 seconds produced the same quality of development of the fingermarks, irrespective of the donor quality. In case of good sweat donors, smudging of the fingermarks could occur when the pressure applied and induced sweating time exceeded 200 g and 180 seconds, respectively. On the contrary, in the case of the bad donors, greater pressure and induced sweating times definitely resulted in marks of better quality.

The successful modification of a commercial bubble jet printer so that the cartridges are filled with amino acid standard solutions has been proposed as an alternative to the deposition of fingermarks from fingertips (213). By doing so, one gets rid of the variability induced by actual fingermarks when comparing two techniques (even if split fingermarks are considered). The pattern to be printed contains a scanned fingerprint and halftone printed gray scale fields. This method is quite reproducible with a standard deviation of 7% calculated after having printed 126 patterns using 21 different cartridges (the method of calculation relies on the weight of the cartridges before and after the printing, so that the quantity of deposited amino acids can be evaluated). This method will not completely replace actual fingermarks (that should be considered before any casework application) but could be useful at the beginning of the comparison process between different detection techniques. A collaborative test has been carried out using this method to assess the efficiency of ninhydrin and DFO processes as used in different laboratories (214). Concerning ninhydrin, the results emphasized the role played by humidity during the development on the sensitivity of the method.

A thorough mechanistic study has been conducted on DFO, ninhydrin, and 1,2-indanedione (with and without zinc chloride) (215). It has been known for long that these reagents may produce varied results in different geographic areas, on different paper substrates, or under different environmental conditions, but no explanation of such different behaviours was actually reported. For this study, aqueous solutions of the nine major amino acids contained in a secretion residue (i.e., serine, glycine, ornithine, alanine, threonine, histidine, valine, leucine, and lysine) were deposited as spots on three kinds of porous substrates (i.e., ashless filter paper, 10% recycled copy paper, and cellulose-coated TLC plates), before being processed by the above-cited techniques. Absorption and luminescence spectra were finally recorded and analyzed. One of the most important observation made by the authors is the role played by water (moisture) in the successful reaction of 1,2-indanedione with amino acids. The role of zinc chloride has also been investigated as it seems to act as a catalyst, bypassing the need for high level of moisture for 1,2-indanedione to react.

Almog *et al.* are currently working on analogues for ninhydrin and 1,2-indanedione, bearing thiol groups (-SH) in their chemical structure (218). The aim is to artificially enrich latent residue with thiols so that they could constitute efficient anchoring sites for metal nanoparticles. This research is still in its preliminary stage, but it illustrates quite well the current trend consisting in using nanoparticles as new efficient reagents to detect fingermarks (as further developed in section 2.2.6).

Schwarz & Hermanowski proposed an alternative to the use of a development cupboard (with controlled levels of humidity and temperature) to develop ninhydrin-processed items (220). The use of a saturated aqueous salt solution in place of water vapors could help developing fingermarks even if the item is left in a classical bench cupboard, at room temperature. They observed that after two or three days, the development was optimal with no background staining. A prolonged exposition time could lead to some unwanted background staining, according to the nature of the salt (e.g., sodium chloride or potassium citrate).

1,8-diazafluoren-9-one (DFO)

Schwarz and Beisel noticed that different DFO solutions prepared according to the same formulation showed different propensities to form two phases, and secondly, that unstable solutions lead to inferior detection results (221). A more robust formulation containing only HFE-7100, acetic acid, ethyl acetate, methanol and DFO (as a prerequisite) was therefore

proposed. Petroleum ether, chloroform and dichloromethane were excluded, because of health and safety issues. The polarity of the solution is sufficiently important to avoid the formation of two phases, but is not sufficiently important to make inks run. The following development conditions were recommended: two immersions with a drying time in between, and then 40 minutes at 110°C.

1,2-Indanedione

The use of 1,2-indanedione as a competitive replacement of DFO (and ninhydrin) has been seriously considered after the publication of Stoilovic *et al.*, who proposed a one-stage premix formulation containing $ZnCl_2$ (Ind-Zn) (228). This formulation seems now to be widely accepted. Only few works were published since 2007, consisting mainly in minor optimizations of the formulation to enhance both colour and luminescence of the developed fingermarks. It has indeed been noticed by various people that 1,2-indanedione may perform inconsistently among laboratories worldwide.

In an attempt to enhance the results obtained with the formulation published by Stoilovic *et al.*(228), Russel *et al.* proposed to increase the amount of zinc chloride, to dip the documents twice in the solution, and to increase the heating time from 10 seconds to 30 seconds (222). Bicknell & Ramotowski performed a thorough study about the effect of laboratory humidity (% RH), moisture content of the paper, temperature, and zinc chloride concentration (223). They showed that there exists a correlation between the moisture content of the paper on which the prints are deposited and the % RH of the air, having for consequence that the development conditions have to be adapted accordingly. They also observed that increasing the quantity of $ZnCl_2$ improved the results up to a maximum limit above which the efficiency begins to decrease. Finally, they showed that Ind-Zn was superior in colour and fluorescence intensity compared to DFO, even for 11-year-old marks.

If several studies illustrated the superiority of Ind-Zn compared to DFO, it is not the case with the comparative study performed by Sears *et al.* in the United Kingdom (224). When comparing various formulations of Ind-Zn with the DFO formulation recommended by the Home Office (HOSDB), they concluded that DFO develops more fluorescent fingermarks of high quality than does the Ind-Zn solution. This was verified on a majority of the tested substrates, especially on two-day-old fingermarks. Nevertheless, the difference in luminescence tended to equalize (even to reverse) as the marks aged (14-day-old ones). It should be noted that, similarly to the observations made by the other authors, increasing the amount of $ZnCl_2$ in the working formulation has a positive effect on the quality of the detected fingermarks.

Other reagents

Lawsone (2-hydroxy-1,4-naphthoquinone) is a new amino acid reagent that has been proposed by Jelly *et al.* to detect fingermarks on porous substrates (225). The reaction of lawsone with latent secretions leads to purple-brown marks that are also luminescent. However, only preliminary results on filter paper were presented, and further research is required to assess the quality of this reagent compared with 1,2-indanedione or DFO.

Isatin (1H-indole-2,3-dione) is structurally similar to ninhydrin or 1,2-indanedione and has consequently been proposed as a new amino acid reagent able to detect latent fingermarks

(226). For this study, six donors were asked to leave fingermarks on white paper. The marks were aged during two days before being processed. The composition of the working solution, the development conditions, and the use of metal salts (i.e. zinc acetate, zinc chloride, and zinc nitrate) in the working solution or as post-treatments were studied. The authors concluded that a 0.05% (w/v) of isatin in 12.5% (v/v) acetone, 87.5% (v/v) dioxane and carbonate buffer gave the most intense luminescence, but with a less intensely coloured product. The development conditions were similar to those recommended for 1,2-indanedione, the samples being heated at 180°C for 10 s. The samples could subsequently be post-treated by dipping them in an ethanolic zinc chloride solution, and reheating them at 180°C for 10 s. When compared with DFO and 1,2-indanedione/zinc on half-cut fingermarks, isatin consistently showed lower luminescence intensity and greater unwanted background luminescence. When compared with ninhydrin, isatin consistently gave no coloured fingermarks. These results illustrate the fact that further research is still required before proposing isatin as an alternative to the classical amino acid reagents.

Para-dimethylaminocinnamaldehyde (pDMAC) has for long been considered as a reagent able to detect latent fingermarks by targeting urea contained in the secretions. A recent study performed by Lee *et al.* tends to prove that pDMAC is not reacting with urea but rather with amino acids (227). When compared with classical amino acid reagents to detect fingermarks on thermal papers, such as ninhydrin and DFO, pDMAC was shown to be far less effective in terms of colour and luminescence. Consequently, its use is not recommended.

2.2.3 Cyanoacrylate fuming

The possibility to rejuvenate old fingermarks to improve the cyanoacrylate fuming process has been investigated, and led to the conclusions that the items should be exposed to either acetic acid (229) or methylamine vapours (230). The role played by the environmental pH on the morphology and length of the polymer chains has also been investigated (231). An attempt to optimize the fuming time when processing fingermarks on skin failed in determining optimal conditions (232). Finally, a detrimental effect of cyanoacrylate fuming has been observed if the items (latex/nitrile gloves or duct tapes) have to be subsequently processed by powder suspensions (233).

Wargacki *et al.* proposed two studies about the understanding of the cyanoacrylate fuming mechanisms. Using mass accumulation and molecular weight analysis, they first showed that carboxylate moieties (coming from lactic acid or amino acids) seem to be the primary initiator of the polymerization process and constitute better initiators than primary amines (231). They also showed that the influence of the pH occurs at the latter stages of the polymerization process (not in the initiating step). Indeed, a basic environment will inhibit the polymerization chain termination, leading to the formation of long chains with high molecular weight at long exposure times, while an acidic environment will promote the termination process and the formation of short-chained polymers. They also showed that, contrary to what is believed, water does not constitute the primary initiator and does not create the long-chained polymers that are visible on a fumed fingermark. In another study, Wargacki *et al.* studied the aging process and the possibility to rejuvenate aged fingermarks (229). The decreased quality observed for aged fingermarks seems to be due to a loss of initiators as a consequence of the erosion and degradation processes induced by the loss of water. Exposing latent eccrine fingermarks to vapors of acetic acid (to provide polymerization initiators) or ammonia (to

bring the pH to basic values) for several minutes constitute two efficient enhancement processes able to rejuvenate old fingermarks and improve the growth of polymers on the ridges. Acetic acid is somewhat preferred compared to ammonia, given its higher efficiency and its lower toxicity.

Similarly to Wargacki *et al.*, McLaren *et al.* tried to rejuvenate old fingermarks to improve the quality of development once fumed with cyanoacrylate (230). They observed a minor positive effect due to the use of acetic acid and water vapours, whereas a more consistent effect was observed with ammonia. They nevertheless noticed that the donor plays a great role in the rejuvenating capabilities when using these chemicals. As an alternative, they recommend the exposition of old/dry fingermarks to vapours of a 10% w/v aqueous methylamine solution, for one hour. In this case, the role played by the donor seems not to be as pronounced as that of ammonia and acetic acid. It should be noted that, contrary to acetic acid and ammonia, some cases of excessive polymer formation across the ridges were observed with methylamine (leading to a degradation of the mark instead of an improvement). Additionally, health and safety issues were identified and should be investigated.

King studied the effect of the fuming time when trying to recover latent fingermarks on skin using cyanoacrylate (232). This question arose from contradictory observations published in the literature, in which optimal fuming times can vary from a few minutes to more than an hour. Using pig skin (previously washed, dried, and warmed at room temperature) on which fresh and sebaceous latent fingermarks from a unique donor were deposited, King set the fuming times between 10 minutes to 125 minutes. It should be noted that the fuming chamber was quite rudimentary, with no control of humidity or of the heating temperature. Once fumed, the fingermarks were powdered using a black magnetic powder and their quality rated. The author failed to find a significant relationship between the quality of the developed fingermarks and the fuming times.

The influence of cyanoacrylate fuming prior to a subsequent processing of tapes and gloves with powder suspension has been investigated (233). For this study, one donor was asked to deposit fingermarks on four kinds of tapes (i.e., red and gray duct tapes, masking tape, and Scotch tape), two donors wore two kinds of gloves (i.e., latex and nitrile) for a variable amount of time (not specified in the article) before removing them, and worn nitrile gloves were processed after having been removed from trash (unknown donors). One hour after fingermark deposition, the samples were either processed by the sequence *"cyanoacrylate fuming – black powder suspension (BPS)"*, either by BPS only. A detrimental effect caused by cyanoacrylate fuming was observed, since no ridge details could be obtained by BPS if the items were first processed with cyanoacrylate.

2.2.4 *Oil red O (ORO) & Physical developer (PD)*

When considering wetted porous items, PD and ORO constitute the two techniques of choice available to the forensic scientists. A comparison study between ORO and PD led to the conclusion that ORO performs better on fresh marks (up to four weeks) and PD on aged ones (more than one month) (234). Another study showed that ORO outperforms PD on sebum-rich marks, but that both techniques perform equally on natural marks (235). The following processing sequence was recommended: "ORO first, followed by PD". In another

study, a commercial PD formulation was shown to be as efficient as a "home-made" one (236).

Oil red O is quite a recent technique (first proposed in 2004) based on a lysochrome, staining the lipid fraction of latent secretion. This technique is usually proposed in competition (or in complement) with PD to detect fingermarks on porous substrates, especially if they have been wetted. Salama *et al.* performed an extensive comparison between both reagents, on various porous substrates (234). They concluded that both techniques are complementary, with the age of the latent fingermarks playing a key role. ORO is efficient on fresh fingermarks up to four weeks. For older marks, PD is preferred. Since it is generally difficult to assess the age of the marks to be detected, it is thus recommended to apply these techniques in sequence. On wet substrates, PD followed by ORO gave excellent results. Nevertheless, it is recommended to apply ORO first, followed by PD. This sequence is governed by the fact that PD could severely deteriorate a substrate on some occasions (e.g., blackening of the surface), annihilating subsequent attempts to process the item for fingermarks.

When comparing ORO with PD, Wood and James studied the role played by the substrates and the liquid into which they are immersed (235). For this study, one donor was asked to deposit two kinds of fingermarks (i.e., natural/ungroomed ones and sebum-rich ones) on four different papers (i.e., standard print, high-quality print, lined and card). The marks were then left for one hour before being immersed in four different liquids (i.e., tap, rain and river water, and un-leaded petrol) for times ranging from one hour to one week. After the immersion, the samples were dried and cut in half, each half being processed either by ORO or by PD. Both techniques were unable to detect any mark on the samples immersed in the petrol, for all the conditions tested (certainly due to solubilisation of the fingermark lipid components). When the samples were immersed in water, ORO outperformed PD for all immersion times and paper types, when loaded marks were to be detected. In this case, after one day of immersion, PD failed in detecting identifiable marks (contrarily to ORO). For natural marks, both techniques performed equally (in few cases, PD even developed better marks than ORO). This could be explained by the fact that PD targets more constituents than ORO (which only stains lipids). Finally, no difference was observed between the three kinds of water that were used. Additionally, the role played by the paper type is minor, at the exception of the card for which only natural marks of low quality were obtained.

The efficiency of a commercially available PD processing kit (brand: Sirchie Fingerprint Laboratories) and a *"home-made"* PD solution have been compared on different porous substrates (236). It has been concluded that both the commercial and the non-commercial solutions were competitive and acting equally in terms of fingermark quality (contrast and clarity), the commercial formulation being somewhat more sensitive when less secretions are to be detected. Nevertheless, a drawback of the commercial solution could arise if one wants to enhance the results using potassium iodide (KI) to darken the background (if it contains starch) while lightening the marks. Indeed, such post-treatment must be photographed while the substrate is submerged in the solution. Given that the tested commercial PD solution was opaque, the resulting contrast was considerably reduced.

2.2.5 Dry micron-sized powders and powder suspensions

Some contributions were dedicated to the traditional, dry and micron-sized powders. It is possible to cite the works performed on skin (237) and fruits or

vegetables (238), as well as the propositions of new powders based on phosphorescent compounds (239), on banana peel activated carbon (240), or on dye-doped silicate clay powder (241). Most of the publications were dedicated to powder suspensions (SPRs), used to detect marks on wetted non-porous substrates. Comparison studies were conducted between commercially-available SPRs (242-245), as well as between SPR and vacuum metal deposition (246). Original research led to the proposition of a luminescent SPR (247), and the relation between the smoothness of a surface and its processing using SPR has been investigated (248). Finally, it was observed that wiping an SPR-processed surface with a paper towel makes new marks appear (249).

Trapecar *et al.* illustrated the efficiency of some fingerprint powders (especially the Swedish Black powder) to successfully detect fingermarks on skin (237) and fruits or vegetables (238), compared to chemical techniques such as cyanoacrylate fuming and ruthenium tetroxide. For both studies, non-enriched fingermarks from several donors were left by prolonged contact with the items (several seconds), and were aged from 15 to 45 minutes for living bodies, from 15 to 180 minutes for dead bodies, and from hours to two days for fruits and vegetables, before being processed.

Liu *et al.* proposed a new phosphorescent powder based on a europium-doped strontium aluminate. This phosphorescent powder could be of a first interest in the case of fluorescent or multicoloured substrates that generally lead to an unwanted decrease of the resulting contrast when using traditional luminescent powders (239). For this study, fresh and aged fingermarks (up to two-month-old marks) from different donors were left on various substrates (i.e., non-porous, semi-porous and porous). The advantages are various: strong phosphor / afterglow effect that lasts longer than the fluorescence of the substrate, no specific device needed since the substrates are excited under UV light for two minutes before being observed in the dark, efficiency on non-porous and semi-porous surfaces (as well as some porous ones, such as wood or fabric) as well as on cyanoacrylate fumed fingermarks, and possibility to be lifted. According to the authors, there are no toxicity issues with this kind of powder. Nevertheless, since the samples have to be irradiated under long UV for two minutes, detrimental effects on DNA could occur.

Mopoung & Thongcharoen proposed a new powder to be dusted on latent fingermarks, based of banana peel activated carbon mixed with sodium acetate (20%), mineral oil (2%), and methylene blue (0.2%) (240). When compared with a commercially-available black carbon powder, the authors observed that the commercial powder adhered better on the ridges, but that background staining was less when using the banana peel-based powder. For this study, very fresh, sebum-rich fingermarks were left by one donor on glass.

Chen *et al.* incorporated cationic dyes (i.e., rhodamine 6G and methylene blue) into silicate clay powder that was subsequently rendered hydrophobic by chemical functionalization (241). The clay was eventually ground, to be dusted on fresh latent fingermarks left on glass slides. This preliminary study led to good results in terms of ridge details and little background staining. The authors assumed that better results could be obtained if the powder size distribution was optimized (for example, by grinding it more finely, to microscaled sizes or below), as well as the dye-loading step. Additionally, the attachment of biolabeling agents may help in targeting some specific components of the latent secretion.

Powder suspensions (or small particle reagents – SPRs) remain one of the well adapted solutions for non-porous substrates that have been wetted. In this domain, Jasuja *et al.* proposed an alternative to the classical black and white SPRs by combining zinc carbonate (white) with different kinds of luminescent dyes (i.e., rhodamine B, rhodamine 6G, acridine orange, anthracene, cyano blue, and basic yellow) (247). Excellent results were obtained when using rhodamine 6G, rhodamine B and cyano blue (other dyes led to non-luminescent marks) and after 30 to 60 seconds immersion in the working solution. It should however be noted that almost ideal conditions were tested with fresh marks (detected immediately after deposition, or after 24 to 96 hours immersion in water) on smooth non-porous surfaces (e.g., glass, aluminium, polyethylene). Rhodamine 6G and B being classified as suspected carcinogens, the cyano blue-based SPR is recommended.

Cohen & Cohen reported quite an original method to improve the number of latent marks that could be detected on smooth non-porous surfaces (e.g., metal, glass, plastic, aluminium) after application of a molybdenum sulphide-based SPR (MoS_2) (249). According to the authors, a thorough wiping of the surface using paper towel after the SPR treatment, initially done to remove dried SPR residues, led to the visualisation of several unobserved fingermarks. As a consequence of the wiping, the background turned yellowish-brown while the marks appeared as grey patterns. Three major observations were also made: (1) The stronger the wiping, the better the marks, (2) sebum-rich marks give better results than eccrine-rich ones, and (3) if the same paper towel is used on an un-treated surface, new fingermarks can readily be detected. The lifting of the marks was however impossible and all marks have to be photographed *in situ*. Further research is underway to elucidate the chemical and physical underlying mechanisms responsible for this phenomenon.

Two commercially available white powder suspensions (WPS) were tested (i.e., Wetwop and Wet Powder) in comparison with a *"home-made"* titanium dioxide-based formula (242, 243). Tests were performed with depleted series of one-day-old fingermarks left on some non-porous surfaces (e.g., various coloured plastic bags and black plastic-based car cowlings), before being immersed for six hours in water, dried (from two to eight days), and eventually processed. The results showed that all three WPS formulations led to similar results, with a slight preference for Wetwop for the least amount of background staining left after rinsing. On the same basis, the authors further compared the Wetwop SPR formulation with vacuum metal deposition (VMD) to detect fingermarks on wetted non-porous surfaces (246). The same kinds of substrates were used, and the fingermark deposition procedure was kept unchanged (except that drying times were of two to 28 days). Fingermarks were cut in halves and processed separately with the two techniques. Both techniques gave a large percentage of potentially identifiable marks across all substrates and ages (at the exception of the car cowling for which Wetwop outperformed VMD). Given that VMD requires extremely costly equipment and is a labor-intensive technique compared to powder suspensions, Wetwop is recommended to be applied when dealing with wetted non-porous surfaces. For those possessing a VMD machine, Wetwop could still be applied subsequently, in a sequence.

Since several researches observed variations in the effectiveness of commercially available powder suspensions (in terms of ridge quality and background staining), Jones *et al.* compared four WPS formulas (i.e., TiO_2 grade RG-15 - StanChem, Wet Powder white – Kjell Carlsson Innovation, Wetwop white – Armor Forensics, and Adhesive side Powder light - Sirchie) (244). The WPS formulas were applied on black insulating tape and the obtained results were analytically characterized using electron microscopy and X-ray photoelectron spectroscopy. The particle size distribution was quite similar for all brands (diameter range:

200-500 nm) and did not seem to play a role in the difference of effectiveness. On the other hand, the coating of the particles varies between the WPS formulations (in terms of morphology and chemical composition), and is more likely to explain the difference of performance observed between the different brands (245). In the same context, Jones *et al.* used atomic force microscopy and scanning electron microscopy to investigate the smoothness of surfaces classified as non-porous (i.e., formica, polyethylene, and unplasticised polyvinyl chloride) (248). They subsequently tried to correlate these analytical measures with the effectiveness of iron oxide powder suspension to detect fingermarks on those substrates (18-hour-old sebum-rich marks were used). They showed that both average roughness and topographical feature shape are important factors to consider for the processing of latent fingermarks.

A detrimental effect of cyanoacrylate fuming has been observed if the items (latex/nitrile gloves or duct tapes) have to be subsequently processed by black powder suspension (233), as described in the *"Cyanoacrylate fuming"* section.

2.2.6 Nanoparticles (nanopowders and nanocomposites)

The use of nanoparticles certainly constitutes one of the major contributions in forensic science research these last years, with a sharp increase in number of scientific publications related to their integration in security documents, paints, inks, and most importantly new reagents to detect latent fingermarks (197, 250, 251). Numerous publications were consequently dedicated to the development of new methods based on gold nanoparticles (252-255), silica nanoparticles (256-259) (260), quantum dots (261-267), aluminium oxide (268), zinc oxide (269), phosphorescent compounds (270), titanium dioxide (244), and nanoparticles functionalized with antibody/antigen complexes (271, 272). The use of metal nanoparticles (e.g., gold and quantum dots) to detect latent fingermarks has been reviewed by Choi et al. (273). Nevertheless, most of the proposed techniques are still under development and have not yet succeeded in replacing classical reagents. It is certainly only a question of time before some of these new efficient nanoparticle-based detection techniques are integrated in casework. An overview of different kinds of nanoparticles is also presented in (274).

Gold nanoparticles

Works on gold nanoparticles were mainly driven by a readiness to enhance multimetal deposition (MMD), a method based on the use of colloidal gold to detect fingermarks on a wide range of substrates (275). First, the single-metal deposition technique (SMD), based on a simplified MMD process, has been optimized and is strongly recommended as a replacement for MMD (252). A luminescent version of the MMD has also been proposed, into which the silver coating has been replaced by a zinc oxide deposition step (253). This luminescent alternative is however still under development and cannot readily be applied in casework. Gao *et al.* proposed a one step MMD-like process to detect fingermarks, using glucose-capped gold nanoparticles and operating in a wider range of pH (254). On the contrary to what the authors claim, the mechanism looks more like a *"gold-based SPR"*, especially when it is said that it is working with blueish colloidal solution (this colour being a consequence of nanoparticles aggregation). Other authors trapped glutamate-capped gold nanoparticles in a lipophilic and cationic polymer (i.e., chitosan) to detect fingermarks after several hours of

immersion (255). In this case, the way the fingermarks look like probably results from oil-enriched fingermarks. Extreme caution should be taken regarding the results.

Quantum dots

Quantum dots (QDs) are extremely luminescent nanoparticles, of one to 10 nm of diameter, which can be functionalized and solubilized in either aqueous solution or organic solvents. It is possible to identify three ways of integrating QDs in the detection of latent secretions: (1) as a dry powder, (2) as an aqueous solution, (3) embedded in a polymer that covalently binds to the secretion. Cadmium sulfide (CdS) encapsulated in a biopolymeric chitosan matrix has been used as a dusting powder for detecting fresh marks on aluminium foil (261). Luminescent fingermarks were obtained, but the use of dried cadmium-based nanoparticles as a dusting powder implies serious health and safety issues. Water soluble cadmium selenide (CdSe) QDs were synthesized and used to detect fresh marks on the adhesive surface of tape and promising results were obtained (262). Cadmium telluride (CdTe) QDs, synthesised in aqueous solution, were used to detect blood fingermarks on various nonporous surfaces such as aluminium foil, black polyethylene, glass or transparent polypropylene (265). A comparison with acid yellow 7, one of the best blood reagents for non-porous substrates, showed that the QDs were superior to acid yellow 7 on aluminium and equally effective for the other substrates. The immersion of a sample in an aqueous CdTe solution has also been proposed to detect fingermarks on non-porous substrates (263, 264). Several hours of immersion were however necessary, which constitutes too long a time. The embedment of QDs in a polyamidoamine dendrimer (PAMAM) has been successfully applied to enhance the contrast of fumed fingermarks on non-porous surfaces (266, 267). Nevertheless, an immersion time of several hours is required which is still much too long. As can be seen, the use of QDs to detect fingermarks currently remains a research topic and no casework uses of QDs have been reported yet. Some issues remain to be addressed before routine application, like the toxicity of cadmium and improved targeting of secretion residues by functionalization of the QD outer surface.

Silica nanoparticles

Silica nanoparticles constitute another kind of promising nanocomposites to detect fingermarks since a great freedom is offered in terms of outer functionalization and dye-doping. The use of luminescent silica nanoparticles for forensic purposes somewhat still remains at the pilot study stage. Theaker *et al.* recently reported entrapment of a variety of coloured and fluorescent dyes including basic red 28, basic yellow 40, fluorescein, methylene blue, oxazine perchlorate, rhodamine B, rhodamine 6G and thiazole orange within silica particles (256). The resulting doped nanoparticles were used in aqueous suspensions to detect fingermarks. The process is very similar to that described for small particle reagents. Micron-size particles also were used as dusting agents. Both fresh (20-minute-old) and aged fingermarks (40-day-old) showed good definition after development. Liu *et al.* entrapped an europium-based dye inside silica nanoparticles and further powdered the obtained nanocomposites to detect fresh and six-day-old latent fingermarks on various substrates (e.g., plastic bag, rubber glove, coloured paper, and green leaf) (257). Silica nanoparticles doped with carbon black have also been used as a fingerprint powder to detect fingermarks on glass and metal surfaces, before being lifted using a lifting tape (258-260). The originality of this work lies in the fact that the dusted marks were further imaged using surface assisted laser desorption / ionisation - time of flight - mass spectrometry (SALDI-TOF-MS). By doing this, it has been possible to differentiate fingermarks left by smokers (or drug users) from

fingermarks left by non-smokers, the silica nanoparticles performing as effective ionisation / desorption agents for the analysis of the drugs and metabolites contained in the secretion residue.

Other nanoparticles

Sodhi & Kaur chose to coat aluminium oxide nanoparticles with two different molecules: Lucifer Y (a fluorescent dye) and a natural hydrophobic substance (268). Their aim was to obtain a *"nanopowder"* to be dusted on substrates and characterized by an enhanced ability to detect fingermarks through lipophilic interactions. According to the authors, this nanopowder detects fingermarks on a wide range of surfaces (i.e., porous and non-porous, as well as white and multicoloured). It is particularly suitable for detecting fingermarks on glossy items, or on moist and sticky surfaces.

Choi et al considered the use of ZnO nano-sized particles to be dusted or applied as small particle reagents (SPR) (269). Processed fingermarks were characterized by a visible fluorescence when illuminated with a long-range UV light source. ZnO-based SPR gave good results for all the tested surfaces (i.e., glass, polyethylene, aluminium), while dry dusting led to some background staining on polyethylene surface. When compared with conventional commercial powders, ZnO particles were less luminescent but showed excellent ridge detail, with minimum background staining. The authors also tried to dope the powder using lithium ions, to enhance the visible luminescence, but this did not significantly improve the results.

Cheng *et al.* considered the use of two phosphorescent, surface-functionalized nanoparticles (i.e., doped LaF_3 and ZnS) to detect trace biomaterials, such as the ones contained in fingermarks (270). The functionalization was such that the nanoparticles were water-soluble and functionalized with carboxylic groups (i.e. –COOH) to target amine groups from the latent secretions. Positive results were obtained for fresh fingermarks left on four tested substrates (i.e., aluminium, plastic, glass, and quartz). The detection procedure consisted in putting the substrates in contact with the nanoparticle solution for two hours.

Finally, a new trend consists in functionalizing nanoparticles with biomolecules to take benefit of the highly selective antibody / antigen recognition process within the fingermark detection mechanism (271, 272). This strategy is further detailed in the next point.

As described in the previous section, Jones *et al.* compared four brands of nano-sized titanium dioxide to be used as powder suspensions on black insulating tapes (244).

2.2.7 Antibody / Antigen recognition

The use of antibodies constitutes a new and efficient approach to specifically target the secretion residue. We can distinguish methods using a direct antibody / antigen labelling procedure to target naturally secreted proteins (276, 277), from those using biofunctionalized nanoparticles to target drug metabolites present in the secretion (271, 272, 278).

Hazarika *et al.* functionalized magnetic nanoparticles with a variety of antibodies to detect a range of drugs (i.e., THC from marijuana and methadone) or drug metabolites (of methadone and cocaine) in fingermarks left on glass slides (271, 272, 278). The procedure requires the substrate to be in contact with the nanoparticles for 15 to 30 minutes. One advantage of their

method is that a magnet can be used to remove the excess of (magnetic) nanoparticles (the unbound ones). The remaining nanoparticles were fluorescently tagged before observation. Positive results were obtained for the four drugs and metabolites tested, with visible third-level details such as pores.

Reinholz chose to target albumin, a protein constituting ca. 60% of the serum-protein volume and secreted by the eccrine sweat glands (277). More precisely, given that an *"anti-human whole serum"* was used, the whole serum constituents were actually targeted, and not specifically the albumin. Fingermarks were left on five porous substrates (i.e., white and manila envelopes, recycled paper, post-it, and nitrocellulose), and aged from 15 to 130 days under artificial and natural light. Once processed, purple fingermark ridges could be observed on a more or less clearer background (depending on the substrate), with visible third-level details. It should be noted that the detected marks progressively fade with time. Finally, the integration of this technique in the existing detection sequences was assessed. A DFO-processed fingermark (fresh mark on white paper) gave more details once subsequently processed with the albumin recognition technique. However, when applied after ninhydrin, the visible mark vanished and no detail could be further observed. Finally, this procedure gave equivalent results when applied after physical developer. The described procedure seems promising. Nevertheless, it is extremely time-consuming and labour-intensive, with several blocking/staining and rinsing baths.

Drapel *et al.* identified and targeted three proteins present in the secretion residue and implicated in the skin regeneration process (i.e., keratin, cathepsin, and dermcidin) (276). Using a chromophoric enhancement process, positive results were obtained on fingermarks left on PVDF (a substrate commonly used in biology to fix proteins), but also on paper. Further research is currently performed, especially to decrease the time required by the procedure (several hours) and to introduce luminescent markers.

2.2.8 Detection of fingermarks on thermal paper

> *Some techniques specifically developed for thermal papers were described or renewed: incorporation of polyvinylpyrrolidones in a ninhydrin solution to avoid the darkening of the substrate (279), dry-application of 1,2-indanedione (280), use of heat and steam (281, 282), iodine fuming (283), or vacuum metal deposition (282). The use of pDMAC to detect marks on thermal papers was also assessed (227), with the conclusion that classical amino acid reagents are better choices.*

In the previous report (284), we mentioned the *"solution G3"* as a powerful post-treatment for ninhydrin- and DFO-processed thermal papers whose reactive layer could have darkened due to the polar solvents contained in the reagent solutions (285). Recently, Schwarz & Klenke proposed a modified ninhydrin formulation containing polyvinylpyrrolidones (PVP) (279). The introduction of PVP in the working solution prevents the darkening of the thermal layer, and allows a one-step detection of fingermarks which readily appear in clear contrast with the background. PVP being nontoxic and reasonably priced, it could constitute a promising alternative to the existing two-steps discolouration procedure. One drawback of the currently proposed formulation is the ratio of polar solvent (compared to non-polar ones) that could cause ink running in particular cases. Further research is still undergoing, especially about the possibility to include PVP in DFO or 1,2-indanedione working solutions.

The application of an amino acid reagent by *"dry contact"* with the thermal paper has been known for years. This technique simply consists in placing the substrate to be processed between two impregnated treatment papers, with no heat treatment (to avoid the substrate darkening). Recently, the use of 1,2-indanedione/$ZnCl_2$ (Ind/Zn) has been proven compatible with this application protocol (280). Natural, non-enriched, fingermarks were left by one to four donors on unprinted and printed thermal papers (from supermarkets), and were processed between one and seven days after deposition. The use of an acetic acid-free Ind/Zn solution, with HFE-7100 as the solvent carrier, gave the best results when the samples were left for 48 hours in contact with the treatment papers. It should be noted that HFE-7100 can be replaced by petroleum ether, but the quality of the developed fingermarks could decrease.

The use of heat to detect fingermarks on thermal paper is one of the oldest methods. This technique is still used, as described by Scott who used a portable hair dryer combined with the application of steam during the heating process (281).

Following their study about pDMAC, Lee *et al.* assessed the possibility of using this reagent to detect fingermarks on thermal papers (227). After having processed realistic depleted series of fingermarks on three kinds of thermal papers, they concluded that the best procedure to detect fingermarks on thermal paper consists in pre-dipping the sample into ethanol (warning: any text present on the substrate will be definitely lost) before using a classical amino acid reagent, such as DFO.

Iodine is known to temporarily stain fresh latent fingermarks on a wide range of substrates. Recently, Jasuja & Singh announced that the use of iodine on thermal papers could lead to a permanent dyeing of the marks (brown / green colour), with marks up to one-year-old successfully detected (283). Their hypothesis was that iodine molecules trapped in the latent sebaceous secretions could promote the oxidation of the leuco-dyes molecules contained in the thermal paper layers. According to the authors, sebaceous marks react more intensely than eccrine ones.

Vacuum metal deposition (VMD) or steam – by placing the sample in an incubator for ca. five minutes – were used to detect sebum-rich latent fingermarks, up to three-week-old, on thermal paper (282). Both techniques offer the advantage of not causing a darkening of the thermal paper, as it can be observed with classical chemical methods containing polar solvents.

2.2.9 Detection of fingermarks on metal and cartridge cases

In the context of fingermark detection on metal (and therefore, cartridges), John W. Bond is certainly the major contributor of these last three years, with several publications describing the metal corrosion effect caused by latent secretions (286-293). Besides these works, a statistical study showed that the rate of recovery of fingermarks on firearms and cartridges (using cyanoacrylate and dye) was actually lower than expected (294), and another study aimed at determining the best sequence to be applied on brass and nickel cartridge casings (295), without success.

The metal corrosion effect

The metal corrosion effect is based on the discolouration of metal surface through the action of an oxydizing element, more particularly the ionic salts contained in latent secretions. When a metal surface bearing latent fingermarks is heated up to 400-600°C, the marks become visible as a consequence of the metal corrosion induced by sodium chloride, in particular (287). The corrosion can also take place in air at room temperature, several days after fingermarks were deposited (287). Ambient humidity and oxygen are required for the corrosion to occur (292), as well as heat to obtain good ridge resolution. The success of the technique described by Bond *et al.* relies more on the composition of the metal (especially in terms of thermodynamic consideration, such as the redox potential) and on the quantity of salts in the secretion, rather than on the age of the fingermarks. Moreover, an effective (and therefore destructive) removal of the fingermark deposits from the surface is required before the corroded region could be processed. To this purpose, it was determined that immersing the sample in warm soapy water while rubbing with a tissue constituted the best technique so far to remove all traces on brass without affecting the properties of the metal surface (293). Once corroded, the marks are durable and resist any further cleaning attempt. This technique seems particularly suitable for samples found in arson scene or contaminated by paint (e.g., spray painting above fingermarks) (287).

Preliminary tests were performed on brass, copper, steel and aluminium disks using non-enriched fingermarks, aged from less than five minutes to seven days, left by 40 donors (287). For copper, temperatures should not exceed 400°C to avoid oxide flaking. On steel, fingermarks were of blue/dark appearance, certainly due to a chemical reaction with the metal (passivation or blueing). On aluminium, no fingermark could be detected, certainly due to the easiness of surface auto-passivation preventing the corrosion to take place. In a second time, ten metal surfaces (i.e., aluminium, copper, gold, lead, magnesium, nickel, silver, tin, titanium, and zinc) and ten metal alloys were processed and compared (286). No heat was used, but the fingermarks (left by 40 donors) were aged at room temperature for ten days before being washed using water and a detergent. Spontaneous corrosion led to the observation of well-resolved fingermarks on some substrates (e.g., Ni, Sn, Pb, Cu, Ag and Au). The presence of chloride ions in eccrine sweat led to the formation of metal halide complexes, which enhanced the degree of noble metal corrosion (e.g., gold or silver). Finally, metal alloys containing more than 40% copper gave satisfactory results, with a good contrast level between the corroded and non-corroded parts, and the presence of third-level details (286).

An enhancement procedure, based on electrostatic attraction, was also described (287-289, 291). This technique relies on: (1) the possibility to apply an electric potential (i.e., 2.5 kV) to metal objects, and (2) the preferential adherence of conductive carbon powder (10 μm, adsorbed on spherical beads) to the corroded parts of a metal surface (the corrosion occurring naturally with time due to the presence of fingermarks on the surface, as described above). This technique nevertheless requires washing the samples before they are processed, using water and acetone, to remove the remaining fingermark residue (and only leave the corroded part). The detection of fingermarks was successful for brass and copper disks, but failed for steel and aluminium. It should be noted that the authors compared this technique with small particle reagent (SPR), but after having cleaned all the samples. SPR logically failed in detecting fingermarks due to this destructive treatment. The comparison would have been more meaningful by applying SPR without having thoroughly cleaned the samples first.

When applied on fired brass cartridge cases, the metal-corrosion technique gave some positive results, but almost none, certainly due to the physical abrasion and increased temperature that occurred during the shot (287). The author also published a casework performed on four 14-year-old discharged brass shell casing found at a crime scene (290). During the investigation, cyanoacrylate fuming combined with dye staining have been applied without success. In this casework, the author decided to heat the casings up to 700°C to remove the cyanoacrylate deposit and to induce the corrosive reaction between the brass surface and any fingermark that could be present on it. The application of the electrostatic enhancement (2.5 kV), described above, led to the observation of some ridges.

Other techniques

Edmiston & Johnson investigated the best sequence to be applied for detecting latent fingermarks on brass and nickel cartridge casings (295). The study has been performed on fired cartridges that were first cleaned, before fresh fingermarks were left by four donors and immediately processed (ten casings per tested sequence). It was concluded that the best-so-far sequence to be applied on brass cartridges was *"Cyanoacrylate - Powder - Acidified Hydrogen Peroxide - Rhodamine 6G"*, and for nickel cartridges *"Cyanoacrylate - Rhodamine 6G - Acidified Hydrogen Peroxide - Powder"*. During a *"realistic test"*, cartridges manipulated by bare hands were shot, and processed according to the two sequences described above. As a result, no identifiable marks were detected on the brass casings, and two potentially identifiable marks were detected on the nickel casings. The authors concluded that the sequence proposed for brass casings may not be optimal, given the experimental differences between the first (fresh fingermarks deposited on clean fired casings) and second part (older fingermarks deposited before the shot) of the study. Further studies are thus required.

A statistical study showed that the rate of useable fingermarks detected on firearms, cartridges, or magazines processed by cyanoacrylate fuming followed by dye staining was quite low (294). The data provided by the Minneapolis Police Department Crime Laboratory covered a period of one year (from September 2006 to September 2007), representing a total of 3,436 items. Twelve percent of all firearms and twelve percent of all magazines led to useable fingermarks (35 and 19 marks, respectively). No fingermarks were useable on unfired cartridges, and only one mark was useable on a discharged cartridge casing (however, the mark is believed to have been left after the shot).

2.2.10 Detection of fingermarks on tapes/adhesives

> *The use of Un-du followed by the application of Wetwop was determined as being the best-so-far sequence to separate stuck adhesives and to subsequently detect latent marks (296). As an alternative to Un-du, submersing stuck adhesives in liquid nitrogen for 30 seconds could help in separating them (297). It was also observed that freezing adhesives before powdering them (while still cold) could help in detecting latent fingermarks (298). Finally, a comparative study was performed between four commercially available white powder suspensions (244).*

Molina tested the effectiveness of Un-du to separate stuck adhesives, and its effect on the subsequent detection techniques (i.e., gentian violet, Sticky-side Powder, and Wetwop) (296). Fingermarks were left on eight brands of adhesives and one self-adhesive stamp, which were further stuck on white paper and ironed for 2-3 minutes to induce immediate adhesion. Un-du

was subsequently applied before the samples were processed. The results showed that excessive amount of Un-du could cause detrimental effects on the adhesive backings. All attempts provided latent development, but the best results were obtained by combining Un-du with Wetwop, if the latter was rinsed immediately after its application to avoid severe and irreversible background staining (this procedure could be repeated if required).

The use of cold to help in detecting fingermarks on adhesives has been studied by Cramer & Glass (298). The study consisted in freezing (5.5°C) four types of adhesives (i.e., duct, clear packing, scotch and electrical tapes) bearing fingermarks for one to 120 minutes before being dusted immediately with black or magnetic powder. Successful detection was obtained in each case. Nevertheless, it seems that the operator was not experienced with fingermark powdering (according to the authors), leading to difficulty in evaluating the results at the beginning of the experiment, and no comparisons were made between frozen and non-frozen samples to really assess the role played by the freezing of the samples.

Bergeron conducted a study about the use of liquid nitrogen to separate adhesive tapes that have stuck together (297). Considering 20 different brands of tape, the author succeeded in separating stuck adhesives after having submersed the tapes for 30 seconds in liquid nitrogen, followed by the detection of latent fingermarks using Sticky-Side Powder once the adhesives were brought back to room temperature. It should be noted that some difficulties could be encountered with some adhesives (e.g., no separation or breaking of the adhesive into pieces). The author also studied the effect of environmental conditions (e.g., heat, rain, humidity) with samples aged up to 36 days. When the samples were protected from extreme conditions (e.g., kept in laboratory), successful results could be obtained, even after 36 days. Nevertheless, when subjected to outdoor environments, the likelihood of finding latent marks was poor after a few days. Another interesting observation was made: a mirror image of a mark could be detected on the opposite adhesive side (i.e., the one that was stuck on the fingermark). This should be kept in mind.

As described in a previous section, Jones *et al.* reported an analytical study in which they compared different white powder suspensions (i.e., TiO_2 grade RG-15 - StanChem, Wet Powder white – Kjell Carlsson Innovation, Wetwop white – Armor Forensics, and Adhesive side Powder light - Sirchie) used to detect fingermarks on black insulating tape, and tried to explain the differences of quality in terms of chemical coating (244).

2.2.11 Detection of fingermarks on items collected from arson scenes

Several authors assessed the possibility to detect fingermarks in arson scenes (299 pp. 12-31, 2009] #483). The conclusions were quite encouraging since many concluded with the fact that fingermarks are quite resistant to elevated temperatures and could be retrieved if the adequate procedure is followed (i.e., soot removal process and detection techniques). Physical developer and black powder suspension were identified as being the most suitable techniques to be applied on porous and non-porous substrates, respectively (299 pp. 12-31, 2009] #483). On paper, DFO was recommended for exposure temperatures below 100°C, and physical developer above 100 °C (300).
With respect to marks in blood, protein stains were shown to be still efficient up to 200 °C, on the contrary to heme reagents (such as LCV) (301 pp. 64-82, 2009] #577). Acid black 1 and acid violet 17 were recommended for porous and non-porous substrates, respectively. Tests performed with bloodstains in an

apartment-like structure showed that luminol, fluorescein, and Bluestar were still efficient in less burned areas (302), but failed to detect blood marks in the most burned area.

Some authors observed that fingermarks on paper could become naturally fluorescent once exposed to 160-180 °C (300, 303). Below or above these temperature ranges, this self-fluorescence could no longer be observed.

Silicone casting and Absorene (a commercial product) were both recommended as soot removal techniques (299 pp. 12-31, 2009] #483, 301 pp. 64-82, 2009] #577), as well as air-sprayed liquid latex (304, 305).

Bradshaw *et al.* conducted a study about the recovery of fingermarks from arson scenes, and more particularly: the range of temperatures and exposure times at which latent fingermarks could survive, the soot removal process, and the efficiency of the fingermark detection techniques (299 pp. 12-31, 2009] #483). Various substrates, representative of what can be found in household equipment, were used (e.g., paper, ceramic, metal, smooth melamine). On each substrate, several donors were asked to deposit depletion series of *"natural"* fingermarks (the marks were not artificially enriched with sebum by rubbing the fingers on the face, for example). Eighteen hours after deposition, the fingermarks were exposed at 100 to 300 °C in a laboratory oven (for one to seven hours), at 400 to 600 °C in a high-temperature furnace (same time interval), or directly put in a simulated fire that was extinguished with water (the temperature reached up to 900 °C). The authors demonstrated that fingermarks can still be detected after a prolonged exposure at 200°C using most of the current detection techniques (i.e., DFO, ninhydrin, physical developer - PD, dry powders and powder suspensions, cyanoacrylate, and vacuum metal deposition - VMD). Above this temperature, the detection of latent fingermarks is still possible, but the range of techniques that can be applied is limited to cyanoacrylate (if the substrate has not been wetted) and VMD. In most of the cases, the most suitable techniques to be applied on porous and non-porous surfaces were physical developer and black powder suspension, respectively. The authors do not recommend to re-humidify the fingermarks (e.g., by breathing on it) before applying powders, since it was found to have a detrimental effect on several marks. If soot has to be removed prior to the processing of the surface, the authors recommend lifting tapes, silicone casting and Absorene (a commercial product used for cleaning paper). Washing with 4% sodium hydroxide gave good results but should be used in combination with a mechanical technique, such as lifting tape. Washing under water, ultrasonic bath, or use of organic solvents (e.g., chloroform or xylene) are not recommended since they induce damage to latent fingermarks. It should finally be noted that the soot can make fingermarks already visible. A careful examination should therefore precede any further treatment (soot removal or application of a fingermark detection technique).

The possibility to recover fingermarks on paper exposed to elevated temperatures was also conducted (300). Five donors deposited non-enriched fingermarks on white paper. The marks were allowed to age from one hour to one month before being heated to temperatures ranging from 50 °C to 200 °C, for 10 to 320 minutes. 200 °C has been chosen as maximum temperature since paper auto-ignites at ca. 233 °C. DFO, ninhydrin and physical developer were further applied when attempting to detect latent fingermarks. The results showed that some fingermarks were readily visible after the heating process, especially at 150°C and 200°C. Moreover, the marks subjected to 150 °C were naturally fluorescent when excited at 473 to 548 nm and observed using a 549 nm filter (no fluorescence was however observed for the substrates exposed to 50, 100, and 200 °C). Successful results were obtained with the chemical methods for exposure conditions up to 200 °C for ca. five or six hours. DFO is the

recommended technique for exposure temperatures below 100°C, and physical developer above 100 °C. The substrate could also be processed with PD subsequently to DFO. If the substrates have been wetted during the extinguishing of the fire, PD is to be applied whatever the exposure temperature.

The natural fluorescence of fingermarks on paper exposed to elevated temperature has been further studied by the same team (303). Three kinds of fingermarks (i.e., eccrine, sebaceous, and *"natural"*/ungroomed) on white and filter papers were exposed to temperatures ranging from 110 °C to 190 °C, for 20 minutes. It was found that eccrine sweat was most subjected to fluorescence between 130 to 180 °C, with a maximum intensity obtained for the 160-180 °C range. It is hypothesized that thermal degradation of some amino acids could be at the origin of the observed luminescence. Sodium chloride and urea also fluoresced upon exposure to elevated temperature. Optimal observation conditions were determined as being: excitation source of 352 to 509 nm, combined with an observation filter of 510 nm.

Considering the effect of fire on fingermarks in blood, Moore *et al.* showed that some of the commonly used protein stains (i.e., acid black 1, acid yellow 7, and acid violet 17) continue to be efficient in detecting marks in blood for exposure of the fingermarks up to 200°C, while heme-specific reagents (such as LCV) stopped giving positive results between 100 and 150°C (301 pp. 64-82, 2009] #577). Various substrates were considered (e.g., paper, cotton fabric, ceramic tile, smooth melamine, metal) and defibrinated horse blood was used to create depletion series of blood fingermarks. Eighteen hours after deposition, the fingermarks were exposed to 100 to 300 °C in a laboratory oven, and to 400 to 600 °C in a high-temperature furnace, for one to eight hours. Commonly used detection techniques were tested, specific for blood or not (i.e., acid black 1, acid violet 17, acid yellow 7, DFO, Leucocrystal violet - LCV, PD, VMD, cyanoacrylate with dye, solvent black 3, and powder suspensions). The recommended techniques are acid black 1 and acid violet 17 for the processing of porous and non-porous surfaces, respectively. Interestingly, above 200°C, it is still possible to detect some marks but it becomes impossible to know if the mark was originally made of blood or not (due to a baking effect). Vacuum metal deposition has been shown to detect fingermarks up to 900°C on the ceramic tiles. Cotton fabric proved to be a very difficult surface, with none of the techniques giving ridge details. On this substrate, only acid yellow 7 gave luminescent spots above 150°C, even if it is commonly not recommended to be used on porous surfaces. In terms of soot removal techniques, their conclusions were similar to the above-described study, with silicone casting and Absorene. Contrary to classical latent marks, the use of lifting tape is not recommended since blood deposits could be lifted off.

The effect of fire exposure on bloodstains (and the subsequent chemical enhancement and DNA profiling) has been studied by Tontarksi *et al.* (302). An apartment-like structure was built, various bloodstains and marks were placed on walls or furniture, before arson was ignited (i.e., sofa fire) with burning developed for ca. 45 minutes, to be eventually extinguished using water. Once the place cooled, changes in the previously applied bloodstain patterns were documented, chemical enhancement techniques were used (i.e., luminol, fluorescein, and Bluestar), and samples were collected for DNA analysis. During the fire, temperatures from 146 °C up to 923 °C were recorded in different areas of the apartment. In the most burned area, the chemical reagents gave negative results and no bloodstains could be observed using white light. Nevertheless, in less burned areas, bloodstain patterns were observed using a bright light and positive results were obtained with all the chemical enhancement techniques. Nevertheless, fluorescein is recommended to be applied first, since it requires less reagent to give a positive observable result (compared to luminol and

Bluestar). Hemastix tests were conducted to assess the presence of blood, and gave positive results on stains visible with a bright light. It was sometimes necessary to remove the soot to obtain a positive result (done by wiping with 70% isopropanol or distilled water). As to DNA profiling, the results were primarily positive, except for some samples exposed to high temperatures and/or close to the ignition source (for measured temperatures above 845 °C, no DNA profile was obtained). The authors also showed that none of the chemical enhancement reagents interfered with the ability to obtain a DNA profile. The authors recommended trying to obtain DNA profiles even for stains that yield negative results after chemical screening tests for blood. This is especially true for the samples close to the fuel source that yield DNA profiles suitable for comparison despite negative indicative tests.

Liquid latex was air-sprayed on an arson scene to remove the excess of soot resulting from the fire, before processing the surfaces to detect latent blood marks supposedly lying beneath (304). The procedure consisted in spraying a thin layer of latex, letting it dry for five to ten minutes, peeling it off once dry, and examining the surfaces for latent marks using an alternative light source. On painted doors or glossy surfaces, 90% of soot was removed by following this method, allowing the observation of the underlying fingermarks or bloodstains. On untreated woods and wallpapers, the rate of removal dropped to 80 and 70%, respectively. In some cases, the soot acted like a fingerprint powder and remained on the fingermark after the peeling of the latex. This method could be considered as an inexpensive alternative to sodium hydroxide washings, which could be destructive on some marks (such as blood marks, for example). Nevertheless, further experiments on the effect of such treatment on the subsequent chemical detection methods have to be carried out.

Spraying of liquid latex was also used by Clutter *et al.* who assessed its efficiency in removing soot on glass and drywall board (wallboard) and its effect on a subsequent ninhydrin treatment to detect fingermarks (305). Latent marks and blood spatters were deposited on both substrates before being almost immediately placed near a controlled burn (ca. 500 °C, high level of soot). The items were then removed so that no water was poured on them. After the items cooled, latex was sprayed, let dry and peeled off. Ninhydrin was then sprayed on the wallboard, while the glass was powdered using black and magna powders. If soot made some fingermarks already visible before any soot removal attempt, ninhydrin and powders failed in detecting new marks after the application of latex to remove soot. It should be noted that ninhydrin was not tested on wallboard to confirm that this technique is suitable to detect fingermarks on this kind of substrate.

2.2.12 Blood marks - Fingermarks in blood and detection of bloodstains

Few studies were dedicated to the detection of marks in blood, certainly reflecting the quality of the currently available detection techniques. The effect of fire exposure on blood marks has however been studied by various authors (301 pp. 64-82, 2009] #577, 302, 306). An original study aimed at optimizing the deposition procedure of fingermarks in blood (307). Finally, a new method to lift blood marks from difficult substrates (like garments) has been proposed (308).

The influence of the deposition procedure on the ridge quality of blood marks has been investigated (307). The conclusions of this study could be of a first interest when conducting a study on blood detection techniques. To perform this trial, the author took into account several parameters such as the deposition pressure, the quantity of blood on the finger, the drying time before the deposition, or the orientation of the surface. This study showed that

more marks of evidential value could be obtained when small amounts of blood were loaded on the finger (i.e., 10 to 20 μL), and allowed to dry before being left on a vertical surface (glossy white poster board was used in this study) with some increased pressure. It should be noted that air temperature, airflow, blood and skin temperatures also affected the drying times and the resulting ridge details. The author also observed that negative marks (white ridges and bloody inter-ridges) could be obtained when first removing the excess of blood on the finger, then allowing the blood on ridges to dry before pressing the finger on the surface (the blood trapped in the inter-ridge furrows remaining wet). It has also been shown that the mechanism of formation of negative marks is not related with the pressure that would force the blood off the friction ridges and into the furrows during deposition, as it is commonly thought.

The effect of fire exposure on blood marks (and the subsequent chemical enhancement and DNA profiling techniques) has been studied by various authors (301 pp. 64-82, 2009] #577, 302, 306). These works are detailed in the *"Detection of fingermarks on items collected from arson scenes"* section.

The strong chemical affinity of TiO_2 for blood has been known for several years (it has especially been used to detect blood marks on non-porous substrates (309)). Recently, lifting strips containing titanium dioxide (TiO_2) were successfully applied to lift blood fingermarks from several porous or non-porous substrates (308). In this study, lifting strips were made by fixing different chemical products (conventionally used in blood detection techniques) to a nylon membrane: titanium dioxide, Kodak Photo-Flo, 5-sulfosalicylic acid, Liqui-Nox, polymers, and water. Bloody impressions were left on six substrates (i.e., three non-porous - aluminium, black plastic, and metal, two semi-porous - black leather and wood, and one porous - cotton), and were aged from one hour to six months before being lifted and processed. The lifting strips successfully lifted blood impressions from all six substrates up to one month after their deposition, with visible identifiable ridge details (except for the stained wood for which ridge details were observed for up to one-week-old marks only). An advantage of these lifting strips is that the lifted mark can be further processed using the conventional blood detection techniques.

2.2.13 Fingermark detection and DNA or biological fluid analysis

The interactions between fingermark detection techniques and DNA recovery/profiling are always of a first interest when both evidence types are to be retrieved. On this subject, it has previously been shown that most of the fingermark detection techniques have no detrimental effect on the DNA profiling (310-312), at the exception of shortwave UV light, DAB, or physical developer (12). Nevertheless, the quantity of DNA seriously drops after the application of fingermark detection techniques. Finally, it seems that no correlation exists between the ability of an individual to be a good fingermark donor (i.e., donation status) and the quantity of DNA that can be recovered from his fingermarks (i.e., shedder status) (313).

Sewell *et al.* investigated the effect of ninhydrin and 1,8-diazafluoren-9-one (DFO) on the recovery of DNA profiles recovered from fingermarks on paper (311). For this study, fresh sebum-loaded fingermarks from two donors were deposited on filter and office papers, glossy magazines, white card and newspaper. Two commercially-available DNA profiling techniques were compared: QIAmp DNA mini kit and DNeasy plant mini kit (both from QIAGEN). A significant increase in DNA recovery has been observed by using the DNeasy

kit as compared to the QIAamp kit, for all treatments and all paper types. This study also showed that the largest amounts of DNA were recovered from the magazines, on the contrary to white and office papers that interfered with the recovery process. Almost no DNA was recovered from the office paper, and no profile could be obtained. Full profiles were however obtained for traces on filter paper, magazines and newspapers. These observations were similar to previous studies on this topic (310, 312). Finally, a decrease of 60% in DNA recovery was observed after the application of fingermark detection techniques, especially on the filter paper and magazines. Nonetheless, these treatments were not shown to interfere with the PCR amplification and DNA profiling steps.

Dominick *et al.* investigated the possible relationship between the fingermark donation ability of an individual and his DNA shedder status (313). For this study, eight donors were asked to deposit ten series of seven successively deposited fingermarks (i.e., without recharging the fingertips with secretions) on glass. For DNA, they were asked to hold a tube for several seconds. Fingermarks were processed using aluminium powder and ranked according to their quality. DNA was swabbed from the tubes before being extracted and amplified. No relationship was found between the fingermark donation status and the DNA shedder status. The level of ridge details on a fingermark is consequently not correlated with the subsequent DNA profiling tests.

2.2.14 CBRNE-related evidence (Chemical, Biological, Radiological, Nuclear, and Explosive)

Research on CBRNE-contaminated evidence has seriously increased during these last three years. Most of the researches were dedicated to the effect of the contaminant, and of the decontamination procedures, on the subsequent detection of latent fingermarks. In the case of chemical contamination, if items were contaminated with acid chemical vapours, the use of volatile organic bases could help in improving the cyanoacrylate fuming process (314). In the case of biological contamination, the use of formaldehyde vapours during the decontamination procedure could be detrimental for some amino-acid reagents (315). No adverse effects were however observed if irradiation is used to decontaminate the items (316). Finally, bacterial activity showed almost no detrimental effect on the latent and blood fingermarks left on porous and non-porous substrates (variations were however obtained for adhesives) (317). In the case of irradiation, fingermarks could still be detected on glass and aluminium after high doses of irradiation (even if glass could become optically degraded) (318). However, detrimental effects induced to the substrate itself (especially for plastic and paper items) could hamper the fingermark detection processing. Nevertheless, up to 100 kGy, it has been shown that the processing of latent fingermarks using common detection techniques is still possible. In another study, some chemical and physical decontamination procedures were shown to be highly detrimental on the subsequent recovery of latent fingermarks on documents (319). In such cases, it is either recommended not to decontaminate the documents (even after the recovery of fingermarks), or to proceed to the decontamination after the recovery of fingermarks. Explosive contaminations could be located and identified on latent fingermarks using analytical tools such as Raman chemical imaging (320), or Fourier transform infrared spectroscopy (321, 322). Fingermarks on post-blast devices could still be detected using either cyanoacrylate fuming (323), or reflected UV imaging (RUVIS) (324).

Chemical contamination

The exposure of evidence to hydrochloric acid (HCl) vapours or chlorine (from a chemical weapon or from methamphetamine laboratories) could result in an acidification of the secretion residue, causing detrimental effects on some fingermark detection mechanisms (such as cyanoacrylate polymerization or ninhydrin). McDonald *et al.* assessed the efficiency of a basic pretreatment (using volatile bases) prior to the application of detection techniques (314). Fingermarks on glass slides and standard photocopy paper were considered. They observed that exposure to high level of acid vapors could indeed lead to an inhibition of the cyanoacrylate polymerization and to a modification of the ninhydrin reaction mechanism (leading to light pink-red marks instead of dark purple). Exposure of the evidence to triethylamine and ethanolamine vapors prior to cyanoacrylate fuming leads to much more effective fingermark detection. Nevertheless, an increase of the background staining has been observed, especially if the evidence has not been exposed to acid environment prior to the basic pretreatment. Physical enhancement techniques (e.g., powder dusting or small particle reagents) could successfully be applied on the acidified substrates without any pretreatment step, but there is a risk that increased background staining occurs.

Biological contamination

Hoile *et al.* proposed to modify a decontamination protocol based on the use of formaldehyde, which acts like a biocidal/sporicidal agent and which is generally used in the case of biological contaminations (e.g., anthrax spores) (315). When dealing with an item suspected to have been contaminated with biological agents, a common decontamination procedure consists in using formaldehyde vapour for six to 12 hours. This treatment results in the destruction of the spores, but also to a degradation of the amino acids present in the latent residue. Hoile *et al.* studied the effect of this decontamination procedure on some commonly used fingermark detection techniques (i.e., ninhydrin, DFO, 1,2-indanedione, physical developer, cyanoacrylate, and powders). For this study, fingermarks were left on glass and paper substrates, which were put in contact with formaldehyde vapors from 10 minutes to 12 hours. If cyanoacrylate fuming, powdering, and physical developer continued to be successfully applied after the decontamination procedure, this was not the case with ninhydrin, DFO, and 1,2-indanedione which failed to detect latent marks. Hoile *et al.* revised the decontamination procedure by reducing the concentration of formaldehyde and the exposure time (i.e., 40 minutes instead of six to 12 hours), which resulted in 66%, 33%, and 8% successful recovery rates for ninhydrin, DFO, and 1,2-indanedione, respectively.

The impact of bacterial agents on the efficiency of the classical fingermark detection techniques has been studied by Wilkinson *et al.* (317). For this study, various porous, non-porous and adhesive substrates were considered (e.g., plastic, glass, cardboard, metal, paper, tapes) on which latent and blood fingermarks were left. A high number of fingermarks (ca. 400) from eight donors were used, and were aged for one to seven days prior being exposed to the bacterial agents. The samples were contaminated with bacterial cultures for 24 to 48 hours, before being processed with classical fingermark detection reagents (i.e., DFO, ninhydrin, amido black, Hungarian red, leucomalachite green, powder suspension, cyanoacrylate fuming, and dry powders). The authors observed no effect of the bacterial exposure for porous exhibits (100% trace recovery), and a minor effect on nonporous substrates (97% trace recovery for cyanoacrylate). Blood reagents reacted quite well, with a rate of recovery between 86 and 97%. Only the adhesive items showed varied results. In addition to these observations, the bacterial exposure time (from 24 hours to 48 hours) and the

age of the fingermarks (from one to seven days) seemed to have no effect on the recovery rates.

Hoile *et al.* investigated the use of gamma irradiation (25 to 40 kGy using cobalt-60 as irradiation source) to decontaminate spore-contaminated evidence, and its effect on the subsequent fingermark detection techniques, as well as on the recovery of human DNA (316). Different substrates were considered (i.e., paper, cardboard, glass, and plastic) on which fingermarks from three donors were left. After having been exposed to irradiation doses from 200 Gy to 5 kGy, the items were processed using common detection techniques (i.e., ninhydrin, DFO, 1,2-indanedione, physical developer, cyanoacrylate and dry powders). Preliminary tests on microbial colonies showed that a gamma dose of more than 3 kGy should be used to decontaminate evidence. As observed by Colella *et al.* (318), glass underwent some discolouration (browning) above 1 kGy without interfering with the quality of the fingermark detection process. No adverse effect due to irradiation (in terms of ridge details) was observed for the processing of the porous and non-porous substrates, even for a 40 kGy irradiation dose. This observation is in agreement with the results obtained by Colella *et al.*. About DNA profiling, the quantity of DNA recovered could be affected by the irradiation process, but the possibility to recover human DNA from paper, post gamma irradiation, is not excluded even up to 50 kGy doses (more severe degradation occurs above this value).

Radiation

Colella *et al.* investigated the possibility to recover latent fingermarks from evidence that was exposed to ionizing radiation (318). Common surfaces were considered (i.e., aluminium, glass, office paper, and plastic), on which fresh and good fingermarks were left, before being irradiated to doses from 1 to 1000 kGy (which constitutes significantly higher exposure doses compared to the electron beam irradiation used to sanitize mail). A cobalt-60 ionization source was placed at one, 10 and 100 mm of the substrates, and exposure times ranged from 24 hours to seven days. Common detection techniques were considered (i.e., cyanoacrylate with dye, black powder, ninhydrin, DFO, 1,2-indanedione, and physical developer). It was concluded that radiolysis had a considerable effect on the quality of the developed fingermarks, at the exception of marks on glass and aluminium which showed no influence due to the ionization process. With respect to glass, the irradiation caused an optical degradation of the substrate which became deep brown as the ionizing dose increased. Nevertheless, this effect had no impact on the detection of fingermarks (the only detrimental effect would be in terms of reduced contrast). For the other substrates, the irradiation caused physiochemical and mechanical damage in the inner structure of the material (e.g., plastics) especially for doses above 100 kGy. This resulted in unwanted polymerization sites or background fluorescence, in a degradation of the substrate mechanical properties preventing them to be properly processed (e.g., paper), or in a chemical modification of the secretion residue making them less prone to react. Nevertheless, up to 100 kGy, it has been shown that the processing of latent fingermarks using common detection techniques is still possible.

Parkinson *et al.* investigated the efficiency of two decontamination procedures used in case of irradiated documents, and their impact on fingermark detection techniques and ink analysis (319). Three irradiation sources were used (i.e., cesium-137, americium-241, and strontium-90) to contaminate paper samples that were subsequently processed for fingermark detection (using DFO, ninhydrin, 1,2-indanedione, and physical developer). After the detection of fingermarks, the substrates were decontaminated by following a physical process (scraping of the surface with a scalpel followed by the use of a pencil eraser) or a chemical one

(immersion of the evidence from 0 to 30 minutes in a sonication bath containing water or cyclohexane, and DEZ-1 - a complexing agent used as a decontaminant). The use of DEZ-1 allowed a decontamination rate of 97% for both solvents (water or cyclohexane), but total decontamination could not be reached since a radiation level of 10 times the background level always remained (even at higher concentration of DEZ-1, and for longer sonication times). The optimized concentration of DEZ-1 has been evaluated at 2 % for an immersion time of five minutes. Increasing these parameters does not improve the decontamination rate but induces a degradation of the paper structure. The physical method was unsuccessful in decontaminating the cesium-137 and strontium-85 isotopes, with only 1.2% and 0.2% decontamination rates, respectively. However, it proved to be highly successful in removing the solid contaminating isotopes (yellowcakes), with 99% decontamination rates compared to <90% rates for the chemical method. In terms of fingermarks detection, all detection techniques failed to detect fingermarks if the decontamination procedure (being chemical of physical) was applied before the detection techniques. However, if the decontamination procedure follows the detection of fingermarks, all of the ridge details were maintained for DFO-treated and PD-treated samples (ninhydrin and 1,2-indanedione developed marks were however destroyed by the chemical decontamination treatment). Physical decontamination showed no impact on the obtained marks, whatever the technique. It was found that the chemical decontamination procedure impacts the quality of the inks for its analysis (colour and composition). Physical decontamination showed no impact. The authors concluded that the best option should be to avoid the decontamination of documents. Since it is not always possible to do so, the choice for a decontamination procedure has to be carefully taken, taking into account the observed drawbacks.

Explosives

The possibility to recover and analyze DNA on post-blast pipe bomb fragments has been studied by considering the following parameters: (1) the time between the deflagration and the DNA analysis (e.g., due to the backlog of some laboratories), (2) the initial application of cyanoacrylate to detect fingermarks, and (3) the location of the biological material on the device (323). The pipe bombs were detonated in rolls of wire fencing to avoid the physical abrasion that could be caused by a direct burying into sand. The analyses of the swabs showed that the quantity of DNA decreases greatly as time passes (i.e., almost one order of magnitude less when comparing three-month-old samples with one-week-old ones), and that analysis of post-blast fragments should be prioritized to avoid DNA loss. Cyanoacrylate-fuming of the samples post-blast to recover latent fingermarks does not seem to play a protective role on DNA since a decrease in the quantity of recovered DNA was still observed. Finally, the quantity of DNA recovered from the pipe nipples was almost twofold the quantity recovered from the end caps. The cause of the loss of DNA material with time has not been identified, and further studies should be conducted.

Emmons *et al.* used Raman chemical imaging to detect and identify explosives (as trace contaminants) in contaminated fingermarks (320). The technique is based on the localization of crystals in fingermarks, followed by their analysis to determine whether they are composed of explosive material, finishing by the imaging of the spatial distribution of such substance. Fingertips were contaminated by touching small samples of the explosives (e.g., C4 or ammonium nitrate) or by smearing a finger on an aluminium-coated microscope slide that was previously put in contact with explosive vapours (e.g., RDX or HMX). Fingermarks were obtained by pressing the contaminated fingertips on an aluminium-coated microscope slide. The imaging was performed by comparing the spectra obtained from the scanned fingermarks

with the reference spectra of the targeted explosives, using Pearson's cross-correlation. In this preliminary study, it was possible to locate and identify explosives from contaminated fingermarks. The consideration of realistic surfaces and the effect of fingermark detection techniques (such as cyanoacrylate) on the subsequent identification of explosives have to be investigated in further experiments.

Attenuated total reflection – Fourier transform infrared (ATR-FTIR) was used to locate and identify explosive particles in latent fingermarks (321). Fingertips were first contaminated with explosives (i.e., TNT, trinitrobenzene, or ammonium nitrate) by touching a glass slide on which explosive powder was spread. Excessive powder was brushed away, until no more powder was visible by the naked eye, and the fingers were pressed on stainless steel (this substrate is transparent in the infrared region) as well as on a more realistic substrate (i.e., metal lid from a jar). The procedure consisted in locating (explosive) particles (as small as 20 µm) and comparing their FTIR spectrum with an infrared spectral library. It should be noted that sweat residue could interfere with the resulting FTIR spectrum. Similarly to this work, the use of RDX-containing solution were used to contaminate fingertips before they were pressed on aluminium coated slides, and further analyzed using ordinary FTIR (322).

The use of a reflective ultraviolet imaging system (RUVIS) is reported to locate fingermarks on post-blast material (324). The author stated that people generally look for fingermarks on tape and batteries (used to set up the explosive device), but not necessarily on the device itself, assuming that the heat of explosion had a strong detrimental effect on fingermarks. In this experiment, explosive devices were designed using C4, nitromethane and gasoline, a bag and plastic bottles. Following the blast in open air, pieces of the explosive device were collected and observed using a RUVIS. A single fingermark – further identified to the designer of the explosive devices - was found on a non-porous surface (a remaining piece of a plastic bottle). The advantage of RUVIS is that the resulting contrast is not dependent on the colour of the substrate. Moreover, this technique can be used on-site if explosive devices have to be destroyed in place, without a subsequent laboratory examination capability (e.g., Irak).

2.2.15 Detection and lifting of fingermarks on skin

The detection of marks on skin has been investigated through different environmental parameters (325) and by comparing several fingermark detection techniques (237, 325). Swedish Black, Magnetic Jet Black powder, or RTX spraying are recommended for use in this context (237). The lifting of unprocessed marks from skin should be done by using Transparent Instant lifter (237), whereas powdered marks should be lifted by using silicone casting material (325) or white gelatin lifter (326).

Four fingerprint powders (i.e., Magnetic Jet Black, Magnetic Silver, Silver Special, and Swedish Black) and two chemical methods (i.e., cyanoacrylate fuming and ruthenium tetroxyde - RTX) were compared to assess their ability to detect fingermarks on skin (237). The marks were either processed directly on skin, or lifted prior to being processed. It should also be noted that very fresh marks were considered (i.e., 45 min on living subjects and up to 180 min on dead bodies). Best results were obtained with Swedish Black and Magnetic Jet Black powders, as well as with RTX spraying. The authors failed to develop quality marks with cyanoacrylate, certainly due to the condensation that was formed on the dead bodies.

Four fingerprint powders (i.e., granular black, Lightning grey, white powder, and Magnetic Jet Black) were tested to detect fresh and sebum-enriched fingermarks deposited on pig skin (325). The Magnetic Jet Black powder was determined as being the most suitable powder to use on fresh marks. The author also studied the effect of time and skin temperature on the rate of success of fingermark detection. However, given that only one mark per temperature value was considered and that the pig skin began to putrefy after 43 hours, serious discrepancies were observed between results. Consequently, the conclusions of this study (i.e., 43h and 48°C as maximal values beyond which no identifiable fingermarks were recovered) should be considered with caution.

Four different lifters (Transparent Instant Lifter, Mipofilm for microtrace, Fuji glossy paper and silver plate.) were used for the transfer of untreated fingermarks from the skin before being processed (237). Best results were obtained using the Transparent Instant lifter.

Five different lifting methods (i.e., white instant lifter, white gelatin, black gelatin, silicone casting material, and transparent adhesive tape) were compared to determine which one was the best to lift powdered fingermarks on skin of living bodies, using Swedish Black powder (326). Silicone casting material and white gelatin have given the best results, on the contrary to white instant lifter and transparent adhesive tape which gave the poorest results.

Baran compared three different lifting materials (i.e., Mastercraft Silicone, AccuTrans, and Zhermack High Definition) to collect powdered fingermarks (using Magnetic Jet Black) on pig skin (325). The clear Mastercraft silicone casting material constituted an efficient solution in that context.

2.2.16 Miscellaneous detection techniques

This section reports all the fingermark detection techniques that were proposed in the literature during these last three years and which do not fit in the previous sections. Some of those deal with emerging reagents or procedures, pending further research before considering a casework application. Briefly, we can cite: use of a powder-based fire extinguisher to detect fingermarks on non-porous surfaces (327, 328), application of heat on paper leading to naturally luminescent fingermarks (303, 329, 330), polymerization of volatile sulphur nitride on various substrates (331, 332), application of a hydrophobic and luminescent gel on non-porous items leading to luminescent fingermarks (333), tests of new luminescent chemical reagents (334, 335), determination of the best procedures to detect oil-contaminated fingermarks or fingermarks left on oily substrates (336), successful detection of fingermarks on snakes to fight against animal smuggling (337), determination of the best procedures to detect marks on untreated plywood surfaces (338) or on a petroleum jelly jar (339).

Dean reported the use of dry powder coming from a fire extinguisher to detect latent fingermarks on metal, plastic, glass and melamine substrates (327). Such powder is composed of ammonium sulphate, monoammonium phosphate, attapulgite clay, potassium aluminium silicate, silicon dioxide, methyl hydrogen polysiloxane, and colour pigment. The procedure consisted in spraying for a few seconds the substrates using a fire extinguisher with a rubber hose extension, then puffing away the excess of powders using an air stream and eventually photographing the visible fingermarks. The obtained marks are extremely labile and the use of any means to enhance the result (such as a brush) would degrade the marks. Lifting of the

marks also seems to be a difficult task: tape lift or gel lifter should be applied directly on the mark and lifted straight up (no attempt should be made to remove air bubbles). Apparently, fresh marks from six donors were used, but no comparisons with classical detection techniques were illustrated to assess the actual quality of dry-powdered fingermarks (obtained using a fire extinguisher). Nevertheless, the author indicates that his method could be used in the case of a complicated crime scene for which traditional methods would be too expensive or time-consuming (328).

The thermal development (i.e., detection of latent fingermarks on untreated substrates, using heat only) has been known since 1940s but has never been really applied for casework. It has recently been revisited by some authors (303, 329, 330). Brown *et al.* observed that a short heating (i.e., 10 seconds) of paper substrates at 300 °C led to UV-fluorescent (but invisible) fingermarks, which become visible (but no longer luminescent) after longer exposition (i.e., 20 seconds) (329). The marks were characterized by dark brown ridges on light brown background. Excessive heat led to a loss of the ridge details and contrast as the papers turned black and combusted. For this experiment, sebum- and eccrine-rich fingermarks from ten donors were left on various paper substrates, and aged for 48 hours before being processed. Optimal observation conditions were determined as being 505 nm for the excitation source, and 549 nm for the observation filter. The heat source also seemed to play a major role as the heat should be precisely monitored. Under these conditions, the use of an oven or a furnace set at 300 °C is recommended, rather that a hot air gun which gives uneven heat distribution and can only process a small area at a time. Direct contact heating (e.g., by using a heat press or a domestic metal iron) are not recommended since such apparatus failed in detecting fingermarks due to a quick background colouration. Nevertheless, in a further study, these authors re-investigated the direct contact heating and refined it by using a coated, non-metallic or ceramic surface (i.e., a commercial hair straightener) set at ca. 230°C (330). By following this procedure, they produced superior results compared that what was obtained using hot air, since they succeeded in obtaining both visible and luminescent marks (which was impossible to obtain using hot air). The effect of heat on the chemical techniques commonly used to detect fingermarks on paper was also investigated. Using depletion series (of assumedly fresh fingermarks), thermal development was compared with ninhydrin and both techniques were shown to be equally sensitive. In an attempt to place thermal development in a sequence, it was determined that it should be placed before DFO and ninhydrin, and strictly up to the fluorescent stage only (short heating time). Further work is still required to study the effect of heat on DNA. During their work on evidence recovered from arson scenes, Dominick *et al.* investigated the effect of heat on the natural fluorescence of fingermarks on paper (303). They observed that eccrine sweat was most subjected to fluorescence between 130 to 180 °C, with a maximum intensity obtained for the 160-180 °C range. Optimal observation conditions were determined as being 352-509 nm for the excitation source, and 510 nm for the observation filter. It should be noted that Brown *et al.* (329) concluded that heating at lower temperature (i.e., below 200 °C) for longer durations did not yield successful fingermark detection, which seems to be in contradiction with Dominick's observations. It certainly emphasizes the fact that thermal development is still not entirely understood and that further researches are required. For example, according to Brown *et al.*, the luminescence arises from the degradation of the substrate, while Dominick *et al.* speculated that it is the result of the chemical degradation of the secretion residue due to heat.

Volatile sulphur nitride (S_2N_2) is reported to form a dark blue polymer on fingermarks, allowing their visualization after two or three hours of exposure (331, 332). Once processed, the fingermarks remain visible for several days before the polymer hydrolyzes (if exposed to

air). The method is said to be successful on a great variety of substrates: porous (e.g., paper), non-porous (e.g., glass, plastic wrap, metal), cotton, fired cartridges, wetted substrates, washed with organic solvents, or heated up to 500 °C for several hours. Nevertheless, the production of S_2N_2 from S_4N_4 seems to be a time-consuming operation requiring adapted laboratory equipment. Safety considerations have also to be kept in mind, given that those chemicals are sensitive to friction. The use of an adapted sealed vessel is also necessary to process fingermarks, due to health and safety issues related with the use of sulphur nitride. Besides the detection of fingermarks, it should be noted that S_2N_2 is also able to detect traces of inkjet inks (e.g., traces transferred from a printed paper to an envelope, by contact).

Kwak *et al.* reported the use of a solid, highly fluorescent, and hydrophobic polymer gel able to detect marks by direct contact with a non-porous surface bearing latent marks (333). The detection process is based on the increase of the polymer fluorescence (more than ten times the initial level) when oily components (from the latent secretion) diffuse into the gel film, through close contact. Once transferred into the film, the mark can be imaged using UV light. The film can be subsequently rinsed by using acetone, which has for effect to *"erase"* the transferred mark and reinitialize the film for further detection.

Plater *et al.* proposed new fingermark detection reagents. First, N-alkyl- and N-aryl-substituted benzimidazole-2-carboxyaldehydes were tested (334). When these reagents are solubilised in dichloromethane, fingermarks on a silica plate were detected by immersion, followed by a two-minute-development at 60-100 °C. Upon excitation at 254 nm, ridge details could be observed. In another study, 3,7-dibromophenothiazin-5-ium perbromide was tested as an amino-acid reagent leading to a red-coloured product (335). When this compound is dissolved in a 2-butanol:pyridine (100:0.5 v/v) mixture, fingermarks on a silica plate were detected by immersion, followed by a five-to-ten-minute-development at 100 °C. Fingermark ridges appear pink or pale red, in visible light.

A Master Thesis aimed at determining the best ways to detect fingermarks contaminated with oil or deposited on greasy/waxy surfaces was published (336). Three types of oil were considered: edible soybean oil, engine oil, and diesel fuel. RUVIS was determined as being the most suitable optical method for detecting marks on glass. After optical detection, the samples were frozen using liquid nitrogen, and kept at -20 °C, before being cyanoacrylate-fumed (and observed using RUVIS again). The most suitable subsequent treatments (following cyanoacrylate fuming) depend on the kinds of substrates and oils: black powder dusting (followed by adhesive lifting) for glass, aluminium, and galvanized iron surfaces; Basic Yellow 40 staining for glass and aluminium surfaces (this can be followed by black powder dusting and lifting); magnetic powder followed by Tex-Lift (a special glue used to lift powdered fingermarks from rough surfaces - manufacturer: SPEX Forensics) for plastic oil container. It should be noted that Sudan Black, which has been successfully tested by the HOSDB (Home Office Scientific Development Branch) for such specific oil-contaminated fingermarks, has not been considered in this work.

In the context of illegal animal smuggling, the possibility to detect fingermarks on the skin of reptiles has been investigated (337), the aim being to link the animal with a smuggler. Using 48 reptiles of different kinds, fresh sebaceous fingermarks were deposited then powdered using a black or white commercial powder. On frozen dead reptiles, fresh sebum-rich fingermarks were deposited then cyanoacrylate-fumed, and subsequently dye-stained. The authors showed that it was possible to detect fingermarks on reptile skin, with some limitations (besides casework conditions, instead of fresh sebum-rich marks): it can be

difficult to detect marks on some reptiles with smaller scales or rough-textured skin. The author suggested the possibility to swab the reptile skin to collect DNA samples.

A thorough study has been conducted about the most suitable techniques to detect fingermarks on untreated plywood surfaces (338). For this study, three donors (good, average, and poor) were asked to deposit fingermarks on an untreated plywood surface. The fingermarks were aged (i.e., from one day to 28 days) before being processed by 13 commonly used detection techniques (e.g., powders, ninhydrin, 1,2-indanedione, cyanoacrylate). Ninhydrin and physical developer (PD) succeeded in detecting 28-day-old fingermarks. Iodine fuming followed by 7,8-benzoflavone succeeded in detecting one- and three-day-old marks. It was however less efficient than silver nitrate, able to detect one- to 14-day-old marks if UV exposure immediately follows the silver nitrate processing, to minimize unwanted background staining. Nevertheless, on a simulated casework example, it appeared that PD applied as a single method (i.e., not integrated in a sequence with ninhydrin or silver nitrate) gave the best results in terms of mark recovery rates for untreated plywood surfaces. If the result of a PD process is too weak, the use of bleach could help enhance the results by darkening the existing marks.

When facing a sexual assault case, it is possible that a petroleum jelly jar has to be processed. Given that such non-porous items (side and lid of the jar) can be contaminated with semi-solid petroleum jelly medium, a study investigated the possibility to optimize a detection sequence, as well as casting methods (339). For this study, one donor was asked to rub his fingertips on petroleum jelly before depositing fingermarks on jars (side, lid, and label). The fresh marks were processed according to eight different sequences, using five common detection techniques (i.e., cyanoacrylate fuming, sudan black, magnetic powder, ninhydrin, and physical developer). Different casting materials were also tested, as well as two storage conditions (i.e., room temperature and freezer). The best method consisted in processing the item at room temperature, according to the following sequence: first photographing visible prints using oblique light, then casting with Mikrosil before applying sudan black (this method will colour the underlying label, making the fingermark appear as white ridges on a darker background).

2.3   Forensic light sources, photography and digital/chemical imaging

2.3.1   Alternative light sources (ALS)

Nd-YAG laser (340) and, for the first time, LED arrays (341) were proposed as alternatives to the commonly used alternative light sources based on xenon arc or quartz halogen lamps. The use of an ultraviolet emitting light source combined with a specific digital recording was also described (324, 342). Finally, the forensic application of infrared imaging was discussed (343).

Lin *et al.* discussed the forensic application of infrared imaging (343). A digital camera able to record infrared light combined with a filter blocking all wavelengths below 930 nm has been used to capture bloodstains (dilution series), inks on fabric, tire marks, gunshot residue, and charred document on dark background. Even if this technique has not been applied to detect fingermarks, it could be interesting to note that bloodstains were shown to absorb the near-IR light, and could be detected up to 1/4 dilution when using white light, and up to 1/8 dilution when using an IR light source.

Following their studies on the use of a Nd-YAG laser in the ultraviolet region to detect sebum-rich fingermarks (284), Akiba *et al.* reported that a 280 nm excitation source is optimal to visualize fluorescent marks on white paper, with emission peaks at 330 and 440 nm (340). Under continuous excitation, the fluorescence at 330 nm decreases while the one at 440 nm increases. It should be noted that this technique seems to be successful on sebum-rich marks, but gives poor results on eccrine-rich ones.

Besides the conventional ALS based on xenon arc lamps or quartz-halogen lamps with filters, Takatsu *et al.* proposed an alternative based on LED arrays (341). LED arrays present two major advantages: (1) the lower cost compared to traditional ALS, and (2) the uniformity of the emitted light throughout the illuminated area. One of the biggest disadvantages is certainly the output power of an individual LED that is insufficient to detect weakly luminescent marks. To overcome this problem, arrays of several LED units were considered (i.e., 50 x 60 mm arrays composed of 90 LED). Nevertheless, the illumination intensities of LED arrays are still weaker by a proportion of 1:7 to 1:9 compared to a xenon arc lamp such as the Polilight. The authors tested two kinds of LED arrays (i.e., blue and green) on dye-stained cyanoacrylate-fumed fingermarks left on plastic, and on metal-complexed ninhydrin-processed fingermarks left on paper. Well-contrasted images were obtained, making of LED-based excitation systems an attractive alternative for those for which conventional ALS are too expensive.

The use of reflected ultraviolet (such as RUVIS) is recommended as an efficient optical method allowing the detection of marks before any chemical treatment or in specific occasions (e.g., bitemarks or post-blast evidence) (324). However, one of the difficulties inherent to this technique is the photographic recording of the detected marks since reflected ultraviolet is invisible to the eye. Sanfilippo *et al.* discussed this issue and gave an overview of the advantages related with the use of reflected UV, as well as some experimental recommendations for a successful digital recording (342). First, they recommended to replace old camera loaded with panchromatic films with a recent digital camera able to record in the ultraviolet region (without the need of a light intensifier) and equipped with a *"live-view"* system, such as the Fujifilm FinePix S-3 Pro UVIR or IS-Pro. The sensitivity of the current sensors is sometimes better in the infrared region than in the near-ultraviolet light. To circumvent this problem (that could cause an unwanted loss of contrast), the use of highly efficient filters able to block all non-UV radiations (i.e., visible and infrared radiations up to 1,100 nm) is recommended in replacement of the classical barrier filters (which might let pass some near-infrared light). The authors cite, for example, the Baader Venus filters. A less efficient alternative could consist in stacking two classical barrier filters, as a way to maximize the blocking of all non-UV radiations. Finally, the light source used to illuminate the evidence has a major role to play, since a pure near-ultraviolet light is preferred to an incandescent light (that emits near-infrared light as well).

2.3.2 Photography

> When facing multicoloured backgrounds, full benefit should be taken from digital imaging functions, such as high dynamic range (HDR) (344) or the Black & White adjustment function included in the Adobe Photoshop software (345). When dealing with fingermarks left on rear-view mirrors, it could be necessary to remove the back reflective layer before attempting to capture the marks (346). Finally, a discussion about the image quality is proposed (347).

The issues related to the digital recording of cyanoacrylate-processed fingermarks found on the interior of rear-view mirrors (i.e., inside vehicles) has been addressed (346). Indeed, due to the double reflection effect caused by such mirrors, ridge patterns may be split into two overlapping ones, creating fuzzy areas reducing the overall quality of the mark (even using coaxial lighting). To overcome this problem, the author proposed to remove the reflective layer at the back of the mirror by using a paint remover and cleaning abrasive metal oxide.

Day proposed a tutorial explaining the advantages of using high dynamic range (HDR) images to extend the luminance of some fingermark images (344). An HDR image is built through the fusion of different photographs of the same scene but taken with different exposure times. Such operations are now easily achieved in some commercially available imaging software, such as Adobe Photoshop. This technique could be of interest in the case of scenes with strong differences between dark and bright regions, or presenting difficult contrast conditions (e.g., powdered mark on a soda can or ninhydrin-processed fingermark on a pink paper). HDR processing allows producing ridge detail of greater quality and contrast compared to normally exposed images subsequently processed with standard digital modifications.

When speaking about fingermarks (or about reference fingerprints), the image quality is of a first importance if it is defined as the apparent visibility of the existing ridges and ridge details. This subject is discussed by Smith in an article whose aim is to encourage the readers to think about such issues (347).

A tutorial was dedicated to the use of a function named *"Black & White adjustment"* (B&W), included in the Adobe Photoshop CS3 software (and later), to enhance images of fingermarks left on multicoloured substrates (345). The B&W option provides the ability to work on a monochromatic representation of an image while still having the full access to the individual colour channels. Compared to the *"channel mixer"* function, which works on three colour channels (i.e., red, green, blue), the B&W option allows to work on six colour channels (i.e., red, green, blue, cyan, magenta, yellow), providing fine image tuning capabilities such as multicoloured background removal.

2.3.3 Chemical imaging using Fourier transform infrared (FTIR) and Raman

Vibrational spectroscopic techniques, such as Fourier transform infrared (FTIR) or Raman, represent a non-invasive way to investigate the chemical composition of latent fingermarks left on non-porous (348, 349) or on difficult substrates (350, 351), as well as to monitor the presence of exogenous substances, such as cosmetics (352), drugs (352-356) or explosives (320-322, 353, 357). But they could also be used to image superimposed fingermarks (357). Nevertheless, the sensitivity of these spectroscopy-based methods (to image fingermarks or to identify contaminants) strongly depends on the differentiation between the spectrum of the material from the spectral response of the substrate and of the secretion. Moreover, the issues related to the size of the imaged area, the difficulty to localize a mark on an entire item prior to any imaging attempt, and to the scanning time still constitute limiting aspects that are not always sufficiently emphasized in the contributions.

FTIR

The conjunction of attenuated total reflection microscopy with Fourier transform infrared spectroscopy (ATR-FTIR) provided the possibility to image gelatine-lifted (untreated) fingermarks to study the chemical composition of various components contained in adult fingermarks (348, 349). The advantage of ATR-FTIR, compared to conventional FTIR, mainly lies in the possibility to reduce the interference of the substrate (the gel lifter in this case) that could cover and hinder the spectral features of the latent secretions. In a first study, sebum-rich fingermarks were left on various substrates (e.g., door handle, mug handle, curved glass surface, computer screen) before being lifted using two commercial gel lifters (i.e., BVDA Gelatine Lifter and Dycem Gel Print Lifter) and analysed by ATR-FTIR. Imaging of sebaceous-rich regions of the lifted-fingermarks showed that the gels could spectrally dominate and hinder the latent secretion spectra, making difficult the investigation of the chemical composition of the fingermarks. By changing the angle of incidence, the interference from the gel could be decreased and ridges could be visualized. The authors recommended the BVDA Gelatine Lifter to be used on this kind of imaging. In a second range of experiments, the authors imaged fingermarks left on non-porous surfaces and heterogeneously contaminated with cosmetic and drugs, by following the same procedure (352). Fingermarks were obtained by either rubbing the donor's head which had previously been treated with cosmetics, or by first touching drug powder (i.e., gamma-hydroxybutyrate - GHB) before depositing, lifting, and imaging the marks. They finally tried to image cosmetic-contaminated marks on fabric (cotton and polyester) and imaging them directly (without lifting them). Even though it was not possible to reconstruct the pattern of the fingermarks, the cosmetic products left on the clothes were successfully identified. The equipment allowed imaging an area of a size of 2.5 x 3.6 mm² (348) or 4.3 × 5.9 mm² (352), with a total scanning time of ca. 100 seconds per image.

Other studies investigated the use of FTIR to image latent fingermarks contaminated with explosives (321, 322), as already described in the *"CBRNE-related evidence"* section.

Ordinary reflectance FTIR was chosen to image processed fingermarks left on *"difficult"* surfaces, that is, containing illustrations or text that render the visualization difficult (e.g., polymer banknotes, papers, masking tapes, or aluminium drink cans) (350). An image area up to 4.48 x 4.48 cm² could be scanned through mosaics, in a few hours. One of the key-points of the study consisted in a systematic optimization of the settings (e.g., spectral resolution or number of scans) so that the collection time and the file-size were reduced without compromising the spatial resolution and the quality of the final fingermark images. For this study, sebum-rich fingermarks were left on various substrates before being processed by cyanoacrylate fumes or amino-acid reagents (i.e., ninhydrin, DFO, or 1,2-indanedione), then imaged by FTIR. Cyanoacrylate-fumed fingermarks on non-porous substrates yielded good results, especially when imaging the frequency slice within the 1750–1800 cm^{-1} range. On the contrary, the attempts to image ninhydrin-processed fingermarks on paper failed in giving positive results due to the swamping effect of the cellulose constituents of the paper. Moreover, the amount of product formed in fingermarks developed by ninhydrin or DFO must be less than or equal to the original number of amino acid molecules, whereas cyanoacrylate development of fingermarks has the advantage of amplification (which is of a first interest during the imaging step). The authors did not use ATR-FTIR, which may have enhanced the results, because *"ATR imaging of an area as large as a fingermark was not technically feasible at the time of writing"* (citing the authors).

FTIR was used to locate and identify exogenous substances contained in latent fingermarks (e.g., caffeine, cocaine, paracetamol) through comparison with pure product libraries (353). For this study, sebum-rich fingertips were put in contact with the powder of interest (the excess of powder being brushed away from the finger), before being pressed on either a metal oxide-coated glass slide (Kevley Technologies) for reflection experiments, or on a silicon window for transmission experiments. Full fingermark images were obtained by scanning an overall area of 1.12 × 1.12 cm, which took ca. 1h20. Different library searching algorithms were tested and compared, when trying to identify the exogenous materials.

The use of FTIR has also been proposed to detect superimposed or contaminated marks on reflective substrates (e.g., door knob, knife blade, or handle) (357). For this study, aluminium-coated glass substrates were used to image all the samples, and three scenarios were considered: (1) latent marks left by unwashed hands, (2) superimposition of two marks left by two differently-washed hands, and (3) latent marks left by hands having touched RDX powder. The authors observed that sebum-rich features formed continuous patterns along the friction ridges, while protein-rich material was deposited as flakes along the ridges, producing a speckled pattern. The second scenario illustrated that morphological information obtained through imaging was similar to what could be obtained by chemical development followed by optical imaging, but that additional information could also be linked with the intrinsic chemical composition of the secretions. This allowed distinguishing two different marks that were optically similar in appearance. The third scenario consisted in the spatial localization of material without the need to sweep the entire area (to be further analyzed). No precise information was given on the time required to image a sample, or on the scanning size (even if sequential moving of the sample allows extending the scanned area to the required size).

Maynard *et al.* conducted a thorough study about the chemical imaging of latent fingermarks in the near-infrared region (NIR) (351). For this study, sebum-rich latent fingermarks were left on several substrates (eight porous: cardboard, cheques, newsprint, and five coloured office papers – four semi-porous: white and coloured glossy inkjet paper, soft drink labels, and Australian banknotes – three non-porous: clear polyethylene bags, orange recycled polyethylene garbage bags, and glass microscope slides). The marks were allowed to age for one day, one week, two weeks, and one month, before being processed by conventional detection techniques. The absorption and luminescence properties of the treated marks were then examined over the spectral range 650–1100 nm, using a Condor Macroscopic Chemical Imaging System. Under these wavelengths, some fingermark detection reagents were characterized by NIR absorption (e.g., ninhydrin, iodine/benzoflavone, physical developer, powdering) or emission (e.g., 1,8-diazafluoren-9-one, ninhydrin with/without metal salt post-treatment, 1,-2 indanedione, genipin, cyanoacrylate stained with NIR dyes, dye-coated metal nanoparticles), resulting in a good contrast between the marks and some difficult substrates (e.g., highly luminescent). It should be noted that most of the good results were obtained on the fresh mark sets, especially the NIR absorption imaging.

Raman

West & Went applied Raman spectroscopy to the detection and identification of exogenous materials present in fingermarks after those were powdered and lifted (354, 355). This study is thus not directly related with imaging of the ridge patterns, but more on the identification of exogenous materials in fingermarks. In a first study, the authors used commercially available analgesic powders, as well as GHB, to contaminate fingertips by contact, before leaving fingermarks on glass slides (total of 100 marks from one donor) (354). In another study,

fingertips were contaminated with seized drugs (i.e., ecstasy, cocaine, ketamine, and amphetamine) before being powdered, lifted, and imaged (total of 70 marks from one donor) (355). Those marks were further processed with aluminium or magnetic iron powder, then lifted using lifting tape or hinge lifter, and imaged by Raman spectroscopy. If the application of fingermark detection powders prior to the Raman analysis did not interfere with the detection and identification of the contaminants, it however increased the time taken to locate the exogenous material due to the physical presence of more material within the fingermark (four to five fold increase of time). Special care should be taken when choosing the lifting tapes since interfering Raman bands coming from the lift are to be avoided. Successful imaging of the sample through transparent evidence bags was performed, meaning that the items do not have to be removed from such bags to be examined. This consequently reduces contamination risks, and allows preserving the chain of evidence.

Emmons *et al.* used Raman chemical imaging to detect and identify explosives (as trace contaminants) in contaminated fingermarks (320), as described in the *"CBRNE-related evidence"* section.

Raman spectral mapping was used on tape-lifted fingertips to extract chemical information about sebum or contamination drug particles (356). For this study, one donor was asked to rub his fingers on his forehead, or to touch drug mixtures (containing ibuprofen, arginine and sodium bicarbonate for a first one, and sucrose and aspartame for a second one), before a Scotch tape was applied directly on his fingertips to lift a fingermark. These tapes were further imaged by Raman. Scanned areas were of 200 x 200 μm² for sebum-rich marks, and of 400 x 400 μm² for the drug-contaminated samples, which is too small to image a whole ridge pattern but sufficient to identify the contaminants. Advanced multivariate data analysis of the spectra was however necessary to overcome the overwhelming contribution of the tape on the spectra, and to be able to identify the trace components (sebum or drug).

2.3.4 Miscellaneous imaging techniques

Several other techniques were developed with a common aim: imaging the ridge patterns according to chemical or physico-chemical behaviour. However, these techniques are still seldom used compared to FTIR and Raman, mainly due to (1) the scanned area being too small to image a whole ridge pattern, (2) labor-intensive methods requiring too specific equipment. Therefore, most of the contributions constitute only preliminary studies that may be further investigated before considering casework application. These imaging techniques, briefly described below, are based on: scanning electrochemical microscope (358-361), electrochromic enhancement (362), tomography (363), surface roughness and refractive index (364), mass spectrometry (365), time-resolved luminescence (366), MALDI-ToF-MS (367), ToF-SIMS (368), scanning probe microscopy (369), MALDI-MS (370), and SALDI-ToF-MS (258-260).

Scanning Probe Microscopy (SPM) was used to analyse latent fingermarks left on glass slides (369). The scanned area was 40 x 40 μm², which is insufficient to image a whole fingermark. The authors proposed the use of the *"step-and-scan"* mode that permits to enlarge the scanned area by generating a mosaic composed of 40 images of 70 x 70 μm². Nevertheless, this is still insufficient to distinguish ridge patterns. Attempts to analyse superimposed fingermarks was also illustrated.

Zhang *et al.* showed that it was possible to chemically image multimetal deposition (MMD)-enhanced fingermarks using a scanning electrochemical microscope (SECM) (358-360). This method is based on the measurement of the redox activity on a localized area through to the solubilisation of silver. Since silver is preferentially reduced on the gold nanoparticles, themselves located on papillary ridges, it was possible to visualize the ridge details by scanning fingermarks processed by MMD. This method could help visualizing classical MMD results on dark or patterned substrates. Alternatively, SECM can also be used on silver-stained or benzoquinone-tagged fingermarks (361). However, SECM imaging needs to be optimized to enlarge the scanning area and to reduce the time required to perform a scan before it could be applied in casework.

Full-field swept-source optical coherence tomography was applied to image latent fingermarks left on semi-reflecting glass (363). This technique provides information about tomography as well as topography of the marks. According to the authors, the detection of very poor quality marks as well as old ones, buried beneath dust layers, is possible. Reconstructed ridge details are however not as clear as it should be, and the scanned area is smaller than the size of a single fingermark.

The application of desorption electrospray ionization - mass spectroscopy (DESI-MS) was described (365). A solvent was electro-sprayed on the surface bearing the sample to be analyzed, generating secondary scattered droplets that are further evaporated and analyzed by MS for each point of the surface (spatial resolution: 150 µm, scanned area: 19.2 x 14.8 mm²). This method gives chemical information, associated with the ridge pattern of the fingermark. For this study, fingertips were contaminated with drugs and explosives in solution, before being pressed on glass, paper and plastic. Good ridge details were obtained, also on tape-lifted marks that were analyzed by the same technique.

Time-resolved luminescence imaging of cyanoacrylate-fumed fingermarks stained with an europium-based dye could be used to circumvent the problems caused by luminescent substrates (366). This technique took benefit of the long-lived europium-based dye luminescence (micro- to milli-seconds) compared to the short-lived background luminescence (nanoseconds). The recording of the image has to take place a short time after the excitation source has been shut down. As a result, the unwanted background luminescence (or security features) is no more visible, and fingermarks can be visualized with a good contrast. Illustrations are given for latent fingermarks left on aluminium foil and plastic with security features.

A diffractive glossmeter sensor is presented as a new imaging technique to visualize latent fingermarks left on glossy, curved objects (364). This technique gives information about the local gloss of the ridges, depending on the local surface roughness and refractive index. By rotating the item (i.e., a ballpoint pen in this case) in front of the light source, it was possible to analyze the reflected light coming from the scanned area. As a result, latent fingermarks were imaged and coloured according to the strength of light reflection.

Time-of-flight - secondary ion mass spectrometry (ToF-SIMS) was applied to image and analyze drug-contaminated fingermarks (368). For this study, washed fingertips were contaminated with drug powder (i.e., amphetamine, methamphetamine, and ecstasy) before being pressed on four different substrates (i.e., steel, aluminium, brass and glass). Secondary ions mass spectra were recorded from a 500 x 500 µm² area, and further coloured according to

the emission intensity of particular ions. This window size was insufficient to image a ridge pattern, but sufficient to detect and identify the contaminants.

Matrix assisted laser desorption / ionisation - mass spectrometry (MALDI-MS) was used to image the endogenous lipids present in latent fingermarks, as well as their degradation products as the marks aged (370). For this study, sebum-rich and eccrine-rich fingermarks were left on pre-coated aluminium sheets (thin-layer chromatography plates from which the silica coating was scraped off with acetone). Ageing of the fingermarks was simulated by placing the samples at 4 °C, 37 °C and 60 °C for seven days before being processed (i.e., spray-coated with a matrix) then imaged. This technique permitted to scan an area of 150 x 150 μm² that can be extended to the size of a fingermark (ca. 1.7 x 2.0 cm²) through mosaics, in ca. 44 minutes. The advantage of chemical imaging being the possibility to visualize specific compounds according to their distribution in the sample, many endogenous lipids were observed (e.g., cholesterol, palmitoleic acid, stearic acid, or oleic acids). Aged fingermarks were imaged by retrieving the oleic acid and its degradation products. The authors showed that the matrix used to coat the fingermarks prior to their imaging can be eventually removed, while keeping the ability to detect the fingermarks using magnetic powder (on aluminium and glass).

Surface assisted laser desorption / ionisation - time of flight - mass spectrometry (SALDI-ToF-MS) was used to image fingermarks from smokers, and more particularly by retrieving the peaks related to nicotine and cotinine (258, 259) or drugs (260). This study has been described in the *"Nanoparticles (nanopowder and nanocomposites)"* section.

Beresford & Hillman proposed a method based on the selective deposition of an electrochromic polymer (i.e., polyaniline) to image fingermarks left on a metallic surface (i.e., stainless steel) (362). The technique is based on the fact that the electrochemical deposition process is inhibited by the latent secretion (that masks the underlying metallic surface), leading to a negative image of the latent fingermarks. Sebaceous and eccrine fingermarks were left on stainless steel, aged from two hours to 39 days, before being processed and imaged (extraction of images from a filmed electrochemical process). It should be noted that even if this technique led to well-defined ridge details, a major drawback is to be reported: if the electrochemical deposition is too important, the polymer can overfill the grooves between fingerprint ridges, resulting in polymer growth extending across the ridges, modifying thus the third level details from the ridge borders.

An attempt to perform chemical imaging on fingermarks detected using sputtered gold and matrix assisted laser desorption / ionization – time of flight - mass spectrometry (MALDI-ToF-MS) was presented (367). If sputtered gold hits the secretion matrix, it is supposed that it prevents the gold aggregation, favouring the formation of gold nanoparticles of smaller sizes and pseudospherical shapes. On another hand, if gold hits the substrate (e.g., the grooves between the ridges), gold nanoparticles of irregular shape and larger size are created. Both kinds of gold nanoparticles exhibit different absorption bands in the visible region, leading to a visible contrast (this principle is highly similar to vacuum metal deposition). Chemical information was obtained through the MALDI-ToF-MS equipment. For this study, highly sebum-rich fingermarks from one donor were used by pressing the fingertip for ten seconds on a substrate. Contaminated fingermarks were also obtained by putting the fingertip in contact with drug powder for 20 seconds before pressing it on a substrate. Finally, experiments were conducted on superimposed fingermarks by artificially enriching each fingermark with a specific lipid (i.e., stearic acid for the first one and oleic acid for the second

one). Unfortunately, these protocols are far from being realistic and degrade therefore the quality of the observations made.

3   MISCELLANEOUS

Survival and transfer of bacteria has been tested on three biometric readers (Recognition Systems HandKey III, Crossmatch Verifier 300 LC and TechSphere VP-II S). Two strains of bacteria were tested independently of each other: *Escherichia coli* and *Staphylococcus aureus*. For the survivability test, a known concentration of bacteria was applied to the devices (after sterilization) and recovered by a single touch with a finger covered with a sterile finger cot after 5, 20, 40 and 60 minutes. For the transferability test, the device was touched 50 times with a finger, and contamination of the device occurred prior to touch number 11. The survivability study shows that at five minutes past contamination, 15% of the *Staphilococcus aureus* remain on the fingerprint reader (and 20% and 40 % for the vein and hand geometry readers, respectively); after 20 minutes, the survival rate was almost zero. For *Escherichia coli*, the percent survival after five minutes is 28% for the fingerprint reader (it is 40 and 50% for the hand geometry and vein readers, respectively). Again, after 20 minutes, the survival rate approaches zero. The number of cells transferred decreases over successive touches; most of the bacteria are transferred within the first ten touches (371)

The relationship between oiliness, humidity, elasticity of the skin and image quality has been investigated using 190 individuals, 6 impressions per individuals and 9 fingerprint sensors (4 capacitance, 4 optical and 1 thermal). The skin moisture, oiliness and elasticity were measured with a Triplesense device. While differences appear between the different sensor technologies, the relationship between skin moisture, oiliness and elasticity and image quality is not linear (372).

The important factors in fingerprint scanners with respect to image quality (quality being defined with respect to the accuracy of automated fingerprint recognition) have been investigated. The main quality parameters defined by the FBI are used, and images are acquired and then degraded with respect to each of these parameters. No significant drop in performance (with respect to the ideal case) was observed when all parameters were set to the IAFIS IQS minimum requirements (but acquisition area is not defined); The PIV IQS requirement for the acquisition area allows a drop in performance when the minimal requirement is used. The three most critical parameters are acquisition area, output resolution, and geometric accuracy. When these three parameters were degraded simultaneously, the drop in performance was larger than the sum of the individual performance drops. (373)

Saijo *et al.* propose ultrasound imaging of fingerprints for medical purposes. The proposed method allows obtaining clear 3D images of the finger surface, but also of the rear surface of the fingerprint (dermal papillae), in vivo (374).

Causin *et al.* (375) present the analysis of latex gloves using thermogravimetric analysis. This yielded a discriminating power of 99.5%.

Stature estimation from hands and phalanges is described by Habib and Kamal (376); these estimations show a good mean correspondence to stature. Right and left hand and foot lengths are investigated for a North Indian population. In particular, the goal is to be able to infer the size of a missing member for identifying the deceased; indeed, these measures are correlated and regression equations are proposed, where, for example, the right foot length is predicted

from the right hand length and breadth (377). In the same context of identification of human remains, a sex difference of the index to ring finger ratio is found (on 300 subjects of south Indian origin); this ratio is larger for females (378).

Packaging of objects for the protection of different kinds of marks, including fingermarks is described by Tietze and Heer (379); for porous surfaces, paper bags or cardboard boxes should be used, for nonporous surfaces friction should be avoided; generally again cardboard is privileged, but plastic containers are also mentioned (for example for weapons, that are also the object of special attention in this article).

The organization and fitting out of forensic laboratories has been analysed, and a basis for the conception of such laboratories has been presented. This concept is based on several modules that can be assembled according to the needs of a given laboratory. It emphasizes rationalisation, for example through shortening the distances to be covered in particular working sequences (380).

3.1 Knuckles

Both the inside and the outside of knuckles has been investigated for their use in biometric identification. The inside of knuckles, obtained from images of the whole palms, has been used by Nanni and Lumini. An equal error rate of a minimum of 0.3 is obtained for one knuckle, and when both knuckles from middle and ring fingers, the equal error rate obtained in the best scenario is of zero, but obtained on 72 users only (and 10 images of the right hand for each user) (381). The outside of knuckles has been investigated by Kumar and Ravikanth (382), as well as Zhang *et al.* (383) ; they demonstrate that finger knuckles can be used to distinguish same-source from different-source acquisitions in a biometric setting. Whether or not this discrimination could be achieved when marks (if such marks did occur) are compared to reference material is not the subject of these articles, and therefore remains unknown; however these are promising biometrics that could help in source attributions.

3.2 Barefoot impressions

An overview of research on barefoot impressions has been proposed (384). Maltais and Yamashita (385) present an operational trial where nine marks from bare feet and ninety inked impressions were sent to 15 specialists. There was one erroneous exclusion (but the examiner requested better standards). Also, current Canadian criteria do not allow positive identification of barefoot impressions ; therefore, several inked prints could be included for a given mark. Several examiners therefore included inked impressions other than that of the foot that had left the mark.
A study on an Indian subpopulation who customarily walks barefoot reports different measures, such as the frequency of the relative lengths of toes, the presence and number of humps in the ball line, creases, and the flatfoot condition (386).
Stature and weight estimations based on footprint measurements have been reported in different studies. Krishan (387) estimates stature from various measures carried out on 2080 footprints from a Gujjar population (an ethnic group from North India). Stature is also estimated from a different Indian subpopulation, and it is highlighted that the relationship between foot length / breath and stature diverges between populations (388). Finally, Kanchan *et al.* also estimated stature from foot measurements, based on a sample of 200 subjects belonging to a North Indian population (389), a follow-up from previous work (390).

The relationship between footprints and weight has also been studied. Here, 50 volunteers (again from the Gujjar population) left footprints normally, and carrying 5kg and 20kg additional weight (391). This kind of estimation is less precise than the estimation of stature from footprints.

Gait dynamics are the subject of (392). Measures of footprints left both on a flat surface and on sand are analysed, as well as the pressure of different foot regions, impulses, velocity and 3D kinematics. Finally, the footprint depth in different foot regions is correlated with body mass, functional leg length, foot type, velocity, pressure and impulse. Interestingly, body mass is not significantly correlated with footprint depth, in any of the considered regions. When stepwise regression is used by foot region, pressure, leg length, velocity and impulses are the only variables that appear (392).

3.3   Ears and earmarks

The ear is receiving attention from both biometric and forensic perspectives. The advances in the use of ear image in biometric systems are covered by Hurley *et al.* (393) as well as in another review (394). Attarchi *et al.* (395) propose a new mechanism for biometric recognition. Some entries of the *Encyclopedia of Biometrics* (396-398) are also dealing with the biometric analysis of ear marks and shapes.

Ear length and breadth, as well as a classification of the type of ear (long and narrow, short and broad, long and broad), position of the ear with respect to the head, whether the ear is vertical or oblique, and the ear lobe types (free, attached, absent) have been investigated on a sample of Kanyakuja Brahmin male subjects (399). While this data, which is collected from direct measurements and from photographs of the ears, cannot be directly applied to casework, variation is shown in these different measures. However, the frequencies of the different classes are reported separately.

The efficiency of 20 observers to associate ear photographs has been shown by Asirdizer *et al.* on a database of 120 ear images. The error rate reported varies between right and left ear and lies between 12% and 15% (400).

An investigation of the analysis of DNA obtained from earmarks shows that DNA can be obtained from these marks, but also that a large number of non-donor alleles are obtained. Full donor profiles were obtained from 10 swabs of ears. However, out of these 10 analyses, 6 were contaminated with non-donor alleles, the source of some of which is not identifiable (401)

Automated ear identification is proposed and has been tested on two databases; one containing four images per person of 77 persons and one containing six images for each of 17 persons. On these databases, recognition rates of 90.50 and 95.05% are obtained, using 2 and 3 images for training, respectively; in the second database, when 4 images were used for training, the recognition rate is of 97.05% (402).

Using pairwise comparison of 700 ears by measuring 12 distances between landmarks defined on the ear and computing the Euclidean distances between these measures, it is demonstrated that there is variation between different ears. The measures were taken directly on the ear, not on impressions, and 3 of the measurements are depths. The repeatability of measurements was tested on 20 ears (from 20 volunteers) by repeating the measures 10 times. An intra-pair distance of 0.251 was therefore defined. All distances for comparisons between different ears from males (350 ears) were above this distance, while for female subjects, out of 61075

paired combinations, 21 pairs of right ears and 26 pairs of left ears yielded distances that were inferior to this limit. Comparisons between the right and the left ear for all volunteers were also carried out and only few of these comparisons yielded distances smaller than the within-variability threshold (1 male or 0.3% and 7 females or 2%). For the pairs of ears with distances below the threshold, images were superimposed; the pairs could be distinguished on this basis (403).

Measurements carried out on ears (left and right, 414 individuals) showed symmetry between left and right ear for height and width. A difference between males and females was observed for the mean axis of the pinna, and a decline in anti-helical take-off angle was observed with increasing age for male and female Caucasians (but not for the Afro-Caribbean or Indian subcontinent ethnic groups). Length and width of ear increased for all ethnic groups with age. Also, volunteers from India had the longest ears, followed by Caucasians and Afro-Caribbeans ; the relationship is only significant for males (404). Differences between males and females as well as between age groups (linear distances, areas and symmetry increase with age, while sagittal angles of the auricle and width to length ratios decrease with age) was also found in a study on 843 volunteers (405).

3.4   Lip marks

A historical review of lip print studies, a description of the anatomical aspects of lips, the different classifications of lip prints, methods of recording lip prints (including latent marks), and problems with the comparison of lip prints are presented by Caldas *et al.* (406). The problems in the comparison are essentially linked to the intravariability of such impressions, due to the mobility of the lips, and various pathological conditions that render impossible this comparison. In the same article, the study of palatal rugae is also reviewed in the same way. A study on the patterns of lip-prints of 966 Saudi subjects, including 13 identical twins, has been carried out. They were then classified according to the Renaud classification system, which was slightly modified. No two patterns were found to be identical, including in the identical twins (although twins showed some similarity in the groove types). Detailed frequencies of the different classes of lip patterns are reported, by sex and for each of six regions of the lips (407). Direct measurement of the lips of 532 male and 386 female subjects has been used to investigate the variability between the dimensions of the mouth and lips of male and female subjects, and the age-related differences. A relatively large number of measures were carried out in the course of this study; it was shown that all volumes and the total lip area, as well as mouth and philtrum widths and total lip heights were larger for men than for women. The vermillion height to mouth width ratio is larger for girls than for boys and for women than for men, but larger for adolescent boys than for girls. All measurements significantly changed with age, and there were significant interactions between age and sex (408).

The development of lipmarks left with lipstick on human skin has been investigated. A single type of protective lipstick has been used in this study, applied to a mould which was used to leave marks on the skin of 40 deceased individuals, on the right side of the neck and the anterior region of the forearm. Observation using a UV light source, dusting using REDescent Fluorescent Latent Prints Powder and Nile Red and observation under UV were used. Development was carried out 15 minutes after having left the lip mark. Observation under UV allowed locating the lip marks. Of the two reagents tested, REDescent Fluorescent Latent Prints Powder developed all marks, but not Nile Red (409).

Barbaro *et al.* investigated DNA typing from lipstick prints on skin. The sample consisted of four women, who kissed the face of one man, once with light protective and once with long-lasting lipstick. Overall eight swabs were collected. Analyses were carried out both using

Identifiler and Minifiler kits. Better recovery was obtained from light protective lipstick than from long-lasting; however generally a mixture between the female and male components was obtained, but both cases where only the male component was present and cases where only the female component was present were observed. In particular, the profile of one of the women never appeared (410).

Note also that lips have been suggested as a biometric modality as well (411).

4 CRIME SCENES AND CASE STUDIES

Reported case studies were dealing with: indented fingermarks under paint (412), the voluntary deposition of a toemark on falsified checks to mislead the investigation (413), skin removal and conservation (414), the role played (or not) by the deprivation level on the recovery of fingermarks and DNA (415), voluntary incorporation of "fingermarks" on some CD brands (416), fingermarks on a window frame that resisted a washing step (417), processing of a self-adhesive stamp using heat, Wetwop and ninhydrin (418), fingermarks on foldable items (419), fingermarks found on the floor after a bank robbery (420), and processing of corpses in bad state (421-424), crime scene processing (425), loss of fingerprint characteristics due to a cancer treatment (426), and the identification of a deceased individual through occupational marks (427).

The burglary of a clubhouse led to the detection of several fingermarks and palm impressions from the point of entry and other disturbed items (412). More particularly, a left palm and left little finger marks were recovered from an internal kitchen door and identified to an individual who claimed he had not been in this clubhouse for at least four years. In fact, it appeared that these marks were indented in the former paint coat (when it was not dry yet), and despite the fact that this kitchen door had been painted white 18 months ago and washed several times since, the marks were still visible and could be dusted / lifted due to the indented ridges.

During an investigation on counterfeit checks, unusually large *"fingermarks"* were found on the front of eight checks (413). As a conclusion, it appeared that these marks were actually corresponding to the right toe of the suspect, who left them to mislead the investigation.

The observation of a blood impression (i.e., fingers and palm) on the thigh of a dead body has been followed by the removal of the piece of skin. The difficulties related with its conservation were discussed (414).

A study has been performed to determine if there exists a relationship between the deprivation level of a neighbourhood in which a crime was committed and the recovery of fingermarks and DNA by crime scene examiners (CSEs) (415). Burglary and auto crime data for Northamptonshire (U.K.) during a three-year period has been used (ca. 25,000 crime activities). No statistically significant relationship was found between the deprivation level and the time spent on crime scene or the recovery of fingermarks from the crime scene. However, a statistically significant relationship has been found for DNA recovery, which is more frequently recovered from less deprived neighbourhoods. The authors emitted the hypothesis that in less deprived areas, the victims are more forensically aware and are,

therefore, more able to articulate to the CSEs which items from the scene may be of importance in the subsequent investigation.

Two strictly identical fingermarks were discovered on two different CDs, processed in the frame of two different crime cases (416). The explanation was that these marks were left by the music production company as part of their brand, and are thus digitally included on the CDs during the manufacturing process.

The same fingermark has been detected and lifted within the frame of two different burglary cases, which took place at the same apartment - but days after (417). The mark was initially lifted from the interior side of a kitchen window in an apartment. The damaged window frame has then been superficially cleaned by a repairman (apparently, it was sufficient to make the mark becoming latent again, but not to erase it), and the same fingermark has thus been dusted and lifted as another burglary took place at the same apartment, days after.

The use of heat (using a hair drier and tweezers) to remove self-adhesive stamps from an envelope was used to further process the sticky side of the stamp but also the paper underneath the stamp (418). The use of Wetwop on the stamp gave no results, but the processing of the envelope with ninhydrin led to the detection of a mark lying initially beneath the stamp. It then appeared that the mark was transferred from the stamp (after it had touched the palm of the suspect) to the paper, giving a mirror image of the print.

Three cases related to the detection of fingermarks on foldable or torn substrates have been reported (419). In one case, folding the ninhydrin-processed substrate allowed to join two fingermark halves, that was subsequently inserted as a whole in an AFIS search. In a second case, a torn paper sheet was reassembled to infer the cutting dynamics performed by the suspect. The last case was about the transfer of secretion residue that occurred between two paper substrates put in contact, which led to the detection of a pair of mirrored fingermarks.

The report of a bank robbery for which the suspect entered the bank from the roof, through the attic, down to a back room was made (420). When dusting the floor, using black powder to detect footmarks, the author found a very well-defined handmark (palm and fingers) left on the floor when the suspect supposedly crawled around the room.

Four case reports were related with corpses' identification. First, latex has been used to obtain a negative copy of damaged fingertips belonging to corpses in a bad state of preservation (e.g., mummy and carbonization) (421). Fingertips were first brushed with ether to remove the grease from the skin, before a thin layer (ca. 0.5 mm) of liquid latex was spread on the finger using a wooden rounded rod. Once dried (ca. after 10 minutes), the latex film was removed and placed over a finger-shaped support previously soaked in latex, to be finally used in a fingerprinting identification procedure (e.g., inked or photographed). It should be recalled that the record constitutes a negative picture of the original print, and will have to be reversed in colour and shape before using it for identification. The only restriction imposed by the latex technique is that the mummified or charred fingertip must not be previously treated with sodium hydroxide, because it prevents the rubber from vulcanizing. A second case reported the use of black powder on the skin (i.e., fingertips and palms) detached from a cadaver in bad state of conservation (422). The use of black powder had for effect to darken the ridges and to create a visual contrast enabling the photography of the skin, and its use as reference material. This solution has been chosen because an inking process would have caused detrimental effects on the fragile skin. Finally, the identification of 60-year-old

mummified remains (i.e., forearm and hand) using fingerprints and DNA was reported (423). Fingertips were rejuvenated by rehydration, before being moulded with silicone rubber, then casted to create positive impressions of each fingertip. The identification of a badly decomposed body is the subject of (424). A possible name of the deceased was available, and ten-print records of this person were on file. One of these ten-print records showed clear pore details in the palmprints. Only three level II characteristics were found to be in agreement, however, a lot of pore detail was visible on both impressions and allowed the identification. In a further approach, the skin was cleaned, and three more minutiae could be matched to characteristics present on the exemplar.

How to proceed on crime scenes for the preservation and further analysis of fingerprints and DNA has been described by Lauer (425)

The loss of fingerprint characteristics due to the use of Capecitabine (a treatment for breast cancer) is reported by Garcia-Saenz and co-workers (426).

A case where occupational marks were used for individualisation has been presented. In this case, unusual symmetrical skin lesions were present on the hands and the ankle joints of an unknown deceased individual. Based on these lesions, it was concluded that the deceased was a coconut tree or coconut palm tree climber; this allowed identifying the person (427).

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