Institut de Police Scientifique et Criminologie
Fingermarks, shoesole and footprint impressions, tire impressions, ear impressions, toolmarks, lipmarks, bitemarks

A review (Sept 1998 – Aug 2001)

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INTRODUCTION

N.B. In literature a general confusion exists between the term print and mark. We have taken the option of using a uniform terminology: prints are standard (known) impressions, marks are recovered traces.

The purpose of this paper is to review the scientific literature from September 1998 to August 2001. The review is focused on published papers in scientific journals or proceedings and on personal communications (complete reports) transmitted to our laboratory. The review will not cover information coming from international meetings available only in abstract form. Regarding this later material, we invite you to consult the individual programs of :

- **the annual meetings of the American Academy of Forensic Science (AAFS) ;**
- **the annual educational conferences of the International Association of Identification (IAI) ;**
- **the annual conferences of the Fingerprint Society ;**
- **the annual conferences of the Biometric Consortium ttp://www.biometrics.org/) ;**
- **the 15th meeting of the International Association of Forensic Science (IAFS) August 22 – 28, 1999, Los Angeles, USA ;**
- **the 2nd European Meeting of Forensic Science, September 12 – 16, 2000, Cracow, Poland. During this meeting, the European Fingerprint Working Group (EFP-WG) was created.**

The state-of-the-art and a general information about the different fields covered in this report can be found in the Encyclopedia of Forensic Science edited by Siegel, Saukko and Knupfer, published in 2000 [1]. A review covering fingerprints and fingermarks individualisation and detection methods can be found in "Dactyloscopic identification" of Meuwly and Margot [2].

FINGERMARKS

Friction ridge individualisation process

A general information about the field of friction ridge individualisation process can be found in "Standards of proof" of Champod [3] and in "Identification and classification" of Dalrymple [4].

The identification procedures are regularly discussed in literature or other forums. David Ashbaugh [5] has written a valuable book that discusses the scientific basis of ridge skin identification, describes three successive levels in the identification process going from pattern (level one) to minutiae (level 2) and ridge details such as pores, shapes, path, etc (level 3). Ashbaugh was the first to propose a model to express pores variability [6]and this model has been refined recently by Roddy and coworkers [7, 8]. However, at present the amount of structured data relative to pores and edge structures is limited.

This quantitative – qualitative friction ridge analysis perspective is coined "ridgeology" by Asbaugh [5, 9, 10]. The aspect of mark and print as a source of uncertainty is also considered in this work where the author highlights the clarity bridge that exists between the three dimensional nature of friction ridge with its two dimensional representation in prints or marks and the consequent loss in information. Tackling theses issues requires that the examiner having a detailed knowledge of the circumstances in which the mark has been secured. The mark observed will not only depend upon the ridge friction that came into contact with the receiving surface but also upon the medium (latent, bloody, other contaminants), the surface (smooth, rough, contaminated), the pressure, the distortion and the development medium. In the comparison process, the ability to distinguish between distortion and dissimilarity is essential and rely mainly on the examiner's experience [11]. An ideal way of gathering reliable experience for interpreting differences is through setting up controlled experiments where marks of known donors are deposited and revealed under various conditions. The study of such sets allows a calibration of the examiner and could even lead to an assessment of his proficiency.

The ultimate question is often expressed as follows: "how many similarities are required to conclude to the identification?" This question was explored by Champod, by reviewing in detail international views and practices and to update earlier reviews [3, 12]. When a fingerprint expert concludes to an identification, he indeed reaches a decision threshold, but this threshold is highly subjective whether the criteria is a minimum number of concordant minutiæ or, in addition to this quantitative element, qualitative factors are taken into account. As Ashbaugh stated: "The opinion of individualization or identification is subj ective" [5, p .103].

The contribution that Ashbaugh [5] has made to the establishment of fingerprint identification as a science is to be applauded. These are the kind of studies and arguments that form the basis of a corpus of scientific knowledge that any expert can draw on in explaining fingerprint individuality in court. However, when it comes to the core issue of drawing inference from a comparison, Ashbaugh says:

> ***"Finding adequate friction ridge formation in sequence that one knows are specific details of the friction skin, and in the opinion of the friction ridge identification specialist that there is sufficient uniqueness within those details to eliminate all other possible donors in the world, is considered enough" [5, p. 103].***

Here it gets to the core of the matter. It is the expert who forms the opinion that there is "sufficient uniqueness....to eliminate all other possible donors in the world". Ashbaugh is not clear on how this inference is to be drawn. This is specifically discussed and disputed by Champod.

It has been argued that it must be inductive [12-14] as already underlined earlier by Kwan [15]. The expert is, however imprecisely, forming a view about the entire world when he cannot possibly have considered more than a sample. So the quotation from Ashbaugh illustrates two points according to Champod: first, the opinion is based on inductive reasoning (it follows inevitably that it must be probabilistic) ; second, the process by which the expert arrives at his opinion is ultimately obscure. The point is that he evokes the need to eliminate all other possible donors in the world, but does not say how it can be done – essentially this is because it cannot be done. Certainly it cannot be done by scientific means but even leaving science to one side, no one person can attain and retain comprehensive knowledge of the prints of every person in the world. It has to be an inference, be it scientific (which it cannot be) or otherwise. The conclusion has to be, as Stoney [16] eloquently put it "a leap of faith": as such, it is ultimately obscure.

The conclusion of certainty derives from the examiner's personal conviction that the chance of a match between the crime mark and any person other than X is so small that it can be ignored. Effectively, the expert sets a personal threshold that rounds the probability assigned to the identification to 1. This position appears, through custom and practice, to be acceptable to courts in all situations where statistical analyses are not possible: fingerprints ; handwriting ; toolmarks ; footwear ; etc. The fingerprint expert's reasoning is based on the idea that the probability that another person would match the mark (we will call this the match probability) is so small that it can be discounted. Greater transparency in this process is afforded if a match probability were assigned by means of a database that has been constructed from a suitable survey. But in the fingerprint field dominated by categorical opinion and the refusal of any corroborative statements, any discussion about a probabilistic approach is, on principle, rejected by the fingerprint profession [Stoney, 1997 #396 To progress towards transparency our duty is twofold: first we need to explore the framework of conclusions used in the field and second to discuss probabilistic data pertaining to fingerprints.

The present state of affairs, then, is that fingerprint experts refuse to report opinions in terms of probabilities. This has been termed the doctrine of "positivity" – see, for example Knowles [17]. All comparisons that fall between the extremes of definite inclusion and definite exclusion are classified as 'inconclusive'. In a case where, perhaps because of the limited quality (or clarity) of a mark, the weight of evidence is not sufficient to convince the expert of a categorical opinion, there may be corroborative evidence of less weight that might provide useful guidance to a court argues Champod. A report concluding with 'inconclusive', 'consistent with' or 'points consistent' lacks to offer an expression of the value of the evidence. If for the sake of the argument a practice based on a numerical standard of 16 is adopted, it is clear that an inconclusive conclusion for a comparison showing 14 concordant minutiae (and no discrepancy) provides stronger evidence than an inconclusive conclusion regarding a comparison with 3 concordant points. Champod claims that the phraseology used by the expert should render explicit these contrasted values in a more efficient way than 'inconclusive'. This concept is recognised to be central to the reporting of other fields of forensic science, such as handwriting, toolmarks, footwear and so on [18].

There appears to be three arguments that are constantly used by practitioners in support of the "positivity" stance. The first argument stipulates that probabilities cannot be used in the field because of the individuality of friction skin arrangements. It takes the following [19, 20]: *Any probabilistic statement would imply a possibility for duplication. But individuality prevents any duplication. Hence probabilities does not apply to fingerprints.*

The second argument is that probabilistic opinions should be avoided until a dedicated tool for assessing match probabilities is made available to the examiner [5]. Whereas a cautious approach is to be commended, it presents a peculiar state of affairs. An opinion of individualisation means that the known individual is singularised in regard of the World population. But paradoxically, a fraction of second before in the process, when the information gathered is judged by the examiner as insufficient to individualise, it is suggested that the examiner cannot give any opinion. Champod thinks that this transition from no knowledge to certainty is not compatible with the logic of the inference of identity of source. If examiners are able to provide opinions regarding individualisation, they should also be able to provide answers regarding the value of possible associations.

The third argument is that the admission of probabilistic statements would weaken the concept of positivity. The perception is that the pursuit should be seen to be exact, with no shades of grey. But this is more a cultural view than one that has derived from any process of scientific reasoning. No doubt, most fingerprint experts see those arguments as a threat that could undermine the profession. That is not the intention of the debate since there is no dispute with the power and utility of fingerprint examination. Indeed, it sought to expand the potential of the pursuit.

One of the most frequent questions to statisticians regarding fingerprints is of the kind: "If a comparison between a mark and a print shows a given set of features in agreement without discrepancies, could you demonstrate statistically the identity of source?" The quick answer is *"no"*, as Stoney puts it: *"you cannot achieve individualization through statistics."* All that statistics can do is provide a model for assigning a match probability in a given case and provide guidance on setting that match probability in some kind of relevant population framework: the latter leading to some kind of inference to the probability of the mark and print being from the same person. But statistics can do no more than provide a probability. It is for others to decide on whether that probability is small enough to conclude identity of source (for a complete discussion, see [12]).

But some may argue that the random match probabilities for fingerprints are so small that, whatever the framework, the probability of the identification will be so close to 1 that there is no need to disclose to the court any number. During the recent *Daubert* hearing in the *U.S. v Mitchell* case, the FBI provided calculations based on experiments done carried out on an AFIS system. For complete fingerprints, a random match probability of 10^{-97} was claimed. For partial marks, the match probability was given as 10^{-27}. Such figures, at first sight, appear to relegate the argument to the status of nit-picking. The figure of 10^{-97} transcends reality that one can be amazed that it was ever admitted into evidence. This extraordinary number was obtained by a model-based formula that took the probability density of extreme points of a known distributional assumption. Wayman pointed out the weakness of this argument [21]. Grieve [20, 22] discusses also this "search for science" in the identification process.

The Internet is also a valuable source of information regarding the identification process. Edward German's site (http://www.onin.com/fp) is a reference on these matters, covering the basic concepts and a discussion of some known cases of wrong identifications. Finally, the acceptability of fingerprint evidence as scientific evidence in the above Daubert hearing in the United States (U.S. v. Mitchell, US District Court for the Eastern District of Pennsylvania, Criminal No. 96-00407) is also discussed. This hearing lead both parties to present their view on the underlying principles of fingerprint identification. All the documents associated with this hearing can be found on German's internet site. The outcome of the hearing was that fingerprint evidence passed the *Daubert* test. Moenssens [23-25] similarly reacts on court cases by asking the question on whether fingerprint identification is a science and describes the validation studies being set-up by the National Institute of Justice (NIJ) in the US. As of this writing, these studies have not been initiated or financed.

A thesis by Cole [26] was discussed in the previous report [27]. Main arguments on the development of the methodology of identification arising from the thesis have been published in the scientific literature [28, 29]. Grubska [30] discusses the inheritance of ridge patterns, whereas gender studies seem to have found a research ground on fingerprint asymmetry [31] and ridge density measurements [32], these are of anecdotal interest in the identification process.

Ridge skin structure of palms: pelmatoscopy

The Bundeskriminalamt (BKA) has produced a complete review under the authorship of Tietze and Witthuhn, with case notes and research, on the structure of palm ridges and lines. This is justified by the observation that between one third and one quarter of all ridge skin marks on scenes of crime are palm marks. They define a method on how to approach palm marks and give a clear insight in their classification and in the frequency of appearance of specific features [33].

Fingermarks in crime analysis

Problems linked with the quality of the traces are compounded because each trace can suffer from all the faults that a single trace may have. Depending on position and types, it may be possible to determine whether one or more authors were committing the crime, which part of the action may be identified with one author and partial reconstruction of the events. This is the usual primary observation made on the scene. More importantly a trace may be identified on more than one scene of crime thereby creating a link between two events, and giving one of the strongest information one could think of in the analysis of serial and high volume crimes. Trace to trace comparison has therefore a very high operational value when investigating such crimes (see [34] for application in burglary series) and should be seen as an essential and priory investigative tool.

Fingermarks detection methods

The state-of-the-art in the field of fingerprint detection can be found in the second edition of the handbook " Manual of Fingerprint Development Techniques " edited by Kent in 1998 [35, 36] describing the operational application of the methods used for the detection of the latent fingermarks, in " Sequential treatment and enhancement " of Hardwick and co-authors [37], in "Visualisation" of Almog [38].

Optical detection techniques

The components of the fingermarks responsible for the inherent visible fluorescence are investigated by Jones and co-authors [39]. In this compositional study, thin layer chromatography (TLC) has been performed on sebum-rich fingermarks laid directly onto TLC plates with an argon ion laser used to visualise the separated components. Investigations into their nature have also been made. A technique that exposes these fingermarks and TLC separated residues to a gaseous electrical discharge in nitrogen, followed by treatment with ammonium hydrogen carbonate vapours to produce visible photoluminescence is investigated. Fluorescence is observed from previously non-fluorescent fractions of the fingermark residue and TLC separated residues point towards lipid derivatives as a possible source for the fluorescence [40].

A pseudo real-time (one second delay) system composed of a mercury-xenon lamp and a CCD camera, both water-cooled and computer controlled was designed to study the short ultraviolet luminescence and the behaviour of latent fingermarks and stains of body fluids such as blood semen and saliva [41].

The concept of utilizing photoluminescent semiconductor nanocrystals for latent fingermark detection, especially in concert with phase-resolved imaging for background fluorescence suppression, is described by Menzel and co-workers. Cadmium sulphide (CdS) nanocrystals that are capped with dioctyl sulfosuccinate [42, 43] are being used in practice. The nanocrystals are applied on articles pre-fumed with cyanoacrilate and also on the sticky side of electrical tapes without pre-fuming [44]. Since CdS can form a photoluminescent nanocomposite with dendrimers, CdS/dendrimer nanocomposite solutions are applied the for detection of cyanoacrylate fumed und unfumed fingerprints on polyethylene and aluminium foils [45].

Physical detection techniques

The morphology of the polymer developed separately on clean and oily fingermarks after cyanoacrylate fuming has been studied by scanning electron microscopy (SEM). The moisture in the mark prior to fuming is found to be more important than the moisture in the air during fuming for the development of a useful latent mark. The optimum polymerisation time depends upon the concentration of cyanoacrylate vapours within the enclosure [46]. The quality of the cyanoacylate deposition has been studied by Fourier transform infrared spectroscopy (FTIR) ; the greatest degree of polymer deposition on latent fingermarks is obtained by prior exposure of the marks to ammonia followed by fuming with methyl cyanoacrylate monomer [47]. A new method to enhance visualisation of latent fingermarks is proposed by sublimating a blue and a red purple dervitative of anthraquinone [48]. These sublimates adhere to the polymers created from the fuming of cyanoacrylate ester and are therefore also useful for enhancing cyanoacrylate-developed prints.

An improved system to fume cyanoacrilate in a vacuum chamber is proposed by Harvey and colleagues [49]. Vacuum fuming works well on firearms, and may be the preferred method for blue-steel firearms ; atmospheric cyanoacrilate fuming efficiently enhances latent marks developed by the vacuum technique, and may be the preferred method for polished, light-coloured finishes [50]. Using a heater inside a vacuum chamber is suggested to accelerate the polymerisation of cyanocrylate [51]. A portable case is proposed by Tissier to fume cyanoacrylate in cars ; the car itself serves as the fumigation chamber and cyanoacrylate vapours are being fed into the passenger compartment via a hose, connected to the vapour source [52].

Cantu discusses fully what is known of physical development and makes a number of hypotheses on how silver physical developers work in the visualisation of latent fingermarks on paper. Hypotheses regarding the identification of components in the latent mark residue that cause physical development and why such developers work better on porous surfaces than on non-porous surfaces are investigated. Five physical developers are compared and it is shown that the development rate of such developers depends on its cell potential, the temperature, the maximum amount of silver deposited and the magnitude of [Fe^{2+} / Ag^{+}] [53].

Vacuum metal deposition (VMD) is used to visualise latent fingermarks on polyethylene substrates. Factors affecting normal and reverse development have been investigated, the critical factor being the structure and thickness of the gold film [54]. Ishizawa and co-workers [55] have developed a new small particle reagent (SPR) which will not fade even during a rainstorm and which is not influenced by the ambient temperature. This reagent is composed of a developer and a fixer. A black (45% carbon black and 55% carbon graphite) and a white (80% agalmatolite, 10% lithopone and 10% zinc oxide) developer have been tested. The fixer is mainly composed of silicone and propyl alcohol.

Chemical detection methods

In a guest editorial, Menzel exposes the dark situation of the research funding he perceives in the field of fingerprint detection in the USA. He estimates that R & D in this specific area has largely been neglected and that the spending is of the order of $100'000/year at best, nation-wide, this mostly on part-time in-house projects of agencies [56].

The state-of-the-art and a general information about the chemistry of sweat and latent fingermark residues have been published by Bramble and co-authors [57] and Ramotovski [58]. A bibliographic overview has been presented by Rosset [59]. Bohanan has conducted a study revealing significant differences between the fingermarks sweat chemical compounds of prepubescent children and adults [60], similar results were found by Mong and co-authors [61].

Maceo and Wertheim [62] propose the use of ninhydrin in the recovery of latent marks on evidence involving adhesive surfaces attached to porous surfaces. The incomplete reaction of ninhydrin with amino acids of the fingermark residue can be optimised when the sample is post treated after the developing process with the blank solvant. An increase in both the rate of development and the final dye density colour can be obtained, and the background coloration can be decreased [63].

Efficient syntheses of 5-substituted ninhydrin analogues by aromatic nucleophilic substitution as potential fingermark reagents was proposed by Della and co-workers [64]. Computational design of ninhydrin analogues has been explored by Elber [65]. The authors explain why past attempts to improve ninhydrin gave relatively small improvements, referring to colour only, and propose new analogues of ninhydrin with a significant potential such as thiono derivatives. The scope and limitations of another ninhydrin analogue, the benzo[f]ninhydrin has been investigated by Almog and co-authors [66]. The low solubility and high cost of the benzo[f]ninhydrin does not justify to prefer this product to the DFO or other ninhydrin analogues.

A comparative trial [67] was carried out to determine the operational effectiveness of two ninhydrin formulations based on new non-ozone depleting hydrofluorocarbons (HFC) solvents, the HFC-4310 and the HFE-7100. The results establish that the HFE-7100 is both an effective and safe, but expensive, replacement for CFC-113 in the ninhydrin detection process.

The reaction mechanism between 1,8-diazafluoren-9-one (DFO) and the amino acid L-alanine in methanol was studied by Wilkinson. Particular attention was paid to the possible part played by the solvent which seems to react with DFO to give a hemiketal that is the reactive species. On the basis of the data collected, a potential reaction pathway is proposed [68]. A study was carried out to determine if there is an enhancement of the luminescence, when the fingermarks developed with the DFO are enhanced with a metal salt post-treatment. There is very little, if any, enhancement of luminescence with Zn, Cd, Ru or Eu-treated DFO-developed latent prints [69, 70].

Hauze and co-workers describe a new class of reagents based on 1,2-indandiones for visualisation of latent fingermarks on paper [71]. A number of vicinal cyclic diketones, most of them belonging to the 1,2-indandiones series, have been prepared and tested as potential reagents for latent fingermark development [72]. 1,2-indandione and 5,6-dimethoxy-1,2-indandione are claimed to give fluorescent developments superior to DFO, when the carrier solvent is HFE-7100 [73]. Zinc salt treatment further enhances the sensitivity. These new reagents can be obtained from inexpensive starting materials in a short reaction sequence [71]. The study of 1,2-indandione dissolved in methanol using nuclear magnetic resonance spectroscopy (NMR) and mass spectrometry (MS) show formation of a hemiketal similar to that proposed for DFO when it is dissolved in methanol. In contrast to DFO where reactivity with amino acids appears to be enhanced by hemiketal formation with alcohol solvents, the reactivity of 1,2-indandione towards amino acids is diminished by hemiketal formation. Following Wilkinson, alcohols should be avoided in 1,2-indandione formulations [74].

Schnetz presents operational details and optimisation of the colloidal gold or multimetal deposition technique (MMD) of Saunders [75] for the detection of latent fingermarks on porous and nonporous surfaces to improve the method [76]. The gold particle size and homogeneity, the effect of the pH of the colloidal gold solution, the gold and surfactant concentrations in the solution, the temperature of development have crucial effects on the effectiveness of the technique, as well as the use of deactivated (siliconised) glassware and bidistilled water for all solutions [77].

In a letter to the editor of the journal of forensic identification, Blackledge [78] informs on the danger for the health of the ruthenium tetroxide reagent (RTX) proposed by Mashiko [79]. The editor of FJI, Grieve, [80] and the proponent of the method [81] answered to Blackledge [78], this question remains open as of this writing.

Finally, Price and Stow [82] propose a method for stopping over development of silver nitrate treated finger and footwear marks and developed a technique using eosin blue dye together with a phase transfer catalyst for the detection of latent fingermarks on porous and non porous surfaces.

Fingermark detection in blood

Since both the water and methanol-based formulations of amido black (acid black 1) are not exempt of problems when used to enhance fingerprint in blood, an alternative ethanol/water based solvent system has been developed [83]. Following this study, a systematic evaluation of seventeen protein dyes for the enhancement of bloodstained fingermarks on various surfaces that may be encountered on crime scenes was undertaken. Of these protein dyes, acid violet 17 may serve as an alternative to amido black and benzoxanthene yellow can be used on non porous surfaces. Further trials are required before such dyes can be recommended for operational use [84]. Warrick reports a case of bloody finger and palm marks developed on cotton fabric using amido black followed by digital image enhancement [85]. Caldwell and co-authors have investigated an effective and safe non-carcinogenic, but more expensive, alternative to the presently used 3,3'–diaminobenzidine (DAB) for the development of fingermarks in blood [86]. The 2.2'-azino-di-[3-ethylbenzthiazolinesulfonate(6)] diamonium salt (ABTS) when oxidized, gives a bright green colour. ABTS can be use before the DAB treatment and after the ninhydrin treatment. Huss and co-workers have investigated the question: *"Which was first – Fingermark or blood?"* [87]. The results are as follows: blood will not visualise previously deposited eccrine fingermarks, blood will visualise previously deposited greasy fingermarks but the ridge structure and furrows are reversed because the blood is repelled. A fingermark left by a bloody finger can be distinguished from a light blood smear over a grease mark and a fingermark left by a bloody finger can be distinguished from a mark left in grease or oil and detected by brushing it with blood.

Fingermark detection on normal and mummified human skin

Sampson and co-authors have collected their publications discussed in the previous report [27] in a book entitled " Recovery of Latent Fingerprint Evidence from Human Skin: Causation, Isolation and Processing Techniques" [88]. Fortunato and Walton [89] propose a review of several techniques for development of latent fingermarks on human skin, they include the lifting technique, the cyanoacrylate/magnabrush technique, the Rhodamine 6G dye staining technique and the concentrated cyanoacrylate/magnabrush technique, which was determined to be the most effective technique, but the effectiveness of these techniques in practice remain to be seen!

Two quick and accurate methods to obtain fingerprints from mummified hands are proposed by Saviano [90]. The first consists in photographying the mummified fingers and the second involves the use of casting to produce impressions of the fingerprints. Schuliar and co-authors propose an improvement of the acetic acid method, often used for the phalanx re-hydration of mummified, putrefied or burnt human remains. Fingers may be immersed in an ultrasonic container in which there is a 20% acetic acid solution. The ultrasonic waves accelerate the re-hydration process, detaching the epidermis and cleaning ridges and inter-ridges within hours.

Although the tested samples were in poor condition, excellent results were obtained using this method [91]. Schmidt and co-workers successfully applied a solution found in the archeological literature to re-hydrate dermal tissues to the extent that fingerprints from a recently deceased, unidentified female could be taken. The method is simple, affordable and the ingredients are readily available and consist of Sodium carbonate, ethanol and distilled water [92].

Fingermark detection on metal surfaces and cartridges

Tests were conducted by Freeman to determine if magnetic powders or regular powders should be used on ferrous metal firearms and cartridges to develop fingermarks. The magnetic powders produced the best defined marks, but latent fingermarks were not, or only partially, developed on some of the cartridges [93]. Several commercial brass or aluminium blackening solutions were successfully applied on metal surfaces to visualise latent fingermarks by Smith and Kauffman [94]. The efficiency of the etching and blueing processes used to reveal fingermarks on cartridge cases was tested on five types of cartridge cases (brass, nickeled brass, aluminium, copper and lacquered steel) and compared with multimetal deposition (MMD). Seven techniques were tested on each cartridge case : MMD, two etching techniques and four blueing techniques. Results show a greater efficiency for blueing techniques, particularly for treatment marks contaminated with sebaceous components. Etching or MMD offer, in some cases, a better quality of fingerprint details, but care has to be taken to avoid over-development, especially for etching. Concerning MMD, it appears that only the physical developer contributes to the detection of fingermarks. Cartridge cases made of aluminium or lacquered steel remain problematic surfaces for detecting fingermarks deposited on their surfaces [95].

Fingermark detection on sticky surfaces

Two water-based solutions containing a surfactant and a fluorescent dye, the TapeGlo™ of LumaChem and the Liqui-Drox (composed of Ardrox and Liquinox) [96] have been proposed to detect fingermarks on the adhesive side of sticky tapes. A limited efficiency of these two methods is reported, principally because the solutions do not develop fingermarks consistently [96].

A comparative study of the current methods used to visualise fingermarks on the adhesive side of the tapes (TapeGlo, sticky-side powder, Saunders and Schnetz formulas of MMD and iodine fixed with 7,8-benzoflavone) has been completed by Marquis [97]. The results on 10 adhesive tapes, of which 3 were transparent, confirm the limited efficiency of TapeGlo™ ; the Schnetz formula of the MMD gives better or equivalent results than the Saunders formula MMD and the sticky side powder gives better result than the MMD, except on the transparent adhesive tapes. Several combinations of these detection techniques have been tested on the 10 adhesive tapes, but no sequence was found to be applicable in routine.

Sneddon and Parisi reports that the replacement of the Kodak Photo-flo 600 detergent by the Liquinox as surfactant in the sticky-side powder improves the sensitivity of this method [98, Parisi, 1999 #184].

Stimac indicates that a commercially available heptane-containing adhesive "neutraliser" named UN-DU®, was assessed in terms of its ability to successfully and consistently remove different pressure-sensitive adhesive tapes from surfaces, whilst not inhibiting the development of latent fingerprints [99].

Fingermarks detection on miscellaneous surfaces

Polymer banknotes were first introduced in Australia in 1988 ; unfortunately, they have proven to be a difficult surface on which to develop latent fingerprints as observed by Flynn et *al.*. Latent fingerprints less than one week old could be detected by suitable fluorescent powders or by cyanoacrylate fuming for up to 10-12 hours followed by cyanoacrylate enhancement techniques (i.e., fluorescent staining or powdering). Vacuum metal deposition proved to be the best technique for the development of latent fingerprints, at least up to six months of age on polymer banknotes. However, this technique requires considerable experience and is not available to all laboratories [100] Shinozuks reports a case in which visible fingerprints present on the white powder-covered underside of a banana leaf, known as wax "bloom" were discovered and used for identification [101].

Compatibility of fingermark detection techniques, DNA typing and other scientific examinations

DNA quantification and PCR amplification of D_1S_{80} and VWA have been realised from blood and saliva samples after porous (DFO – ninhydrin – MMD – PD) and non-porous (cyanoacrilate – dyes – MMD) fingerprint detection sequences. On porous surfaces, Brignoli reports that DFO, ninhydrin and MMD do not damage the DNA material, but PD does. On non-porous surfaces, saliva samples are damaged by the detection techniques applied, and MMD seems to seriously damage the DNA material. However the observed degradations of the DNA material do not prevent the PCR amplification [102].

Roux and co-authors investigated the effect of common and well established fingerprint enhancement techniques on the subsequent DNA analysis of items potentially bearing both fingerprints and biological evidence. Bloodstains of varying ages were prepared on different surfaces and various fingerprint enhancement techniques were applied to the samples. DNA typing was performed using PCR amplification (D_1S_{80} and CTT system). The results showed that magnetic powder, multimetal deposition (MMD) and ultraviolet (UV) radiation are not recommended for use in a sequence of analyses involving DNA typing. Strong white light, white and aluminium fingerprint powders, physical developer (PD) after 1,8-diaza-9-fluorenone (DFO), PD after ninhydrin with cadmium (Cd) salt treatment, and cyanoacrylate with gentian violet or Ardrox stains may be used successfully in a

sequence of analyses involving DNA typing. Ninhydrin with secondary metal salt treatment, DFO, amido black, diaminobenzidine (DAB), black powder, Stickyside Powder, cyanoacrylate with rhodamine stain, and luminol may be used before DNA analysis but care must be taken to ensure that sufficient DNA is extracted and analysed [103].

The effect of seven blood enhancement reagents on the subsequent Profiler Plus™ fluorescent STR DNA analysis of fresh or aged bloody fingerprints deposited on various porous and nonporous surfaces. Amido black, Crowle's double stain, 1,8-diazafluoren-9-one (DFO), hungarian red, leucomalachite green, luminol and ninhydrin were tested on linoleum, glass, metal, wood, clothing and paper. Enhancement of bloodmarks using any of the chemicals selected, and short-term exposure to these same chemicals (i.e., less than 54 days), had no adverse effects on the PCR amplification of the nine STR systems surveyed [104].

Fingermarks age

The estimation of finger marks age has become a true discipline in Poland with results based on probabilities. This has recently been disputed by Marcinowski [105] who feels the absence of categorical conclusions creates doubts rather than clarification. A strong rejoinder by Baniuk [106] is rejecting this dogma that categorical opinions are the tenet of scientific discovery rather than probabilistic in nature.

In the US, fingerprint experts have been found to refer to the presence and detection of “fresh prints” without any scientific justification, thus implying a short time span to explain the presence of the traces. Starrs [107] considers a number of court cases and demonstrates the risks linked to such baseless determinations.

Fingermarks forgery

Planting or fabricating evidence can completely change police conclusions about the scenario of a crime. Documented cases of fingerprint forgery are known since the beginning of the twentieth century. Now DNA is subjected to the same threat with the actual blind trust given to this type of evidence (however it was recovered) (USA Today, August 2000). There is an obvious resistance to admit the possibility of being fooled. Little research has been done to establish the extent of the phenomenon and how to detect it. Forgery implies reproduction, modification or alteration with the intent to deceive as well as counterfeit, that is imitating with the intention that the imitation is deceptively believed to be genuine.

Some fingerprint experts consider the phenomenon of fingerprint forgery only as an annoying curiosity ; others, however, see it as a serious potential problem. The cases that do exist are few and far between, and documentation is rarely comprehensive with many unsubstantiated allegations. When describing cases of this type of forgery, some sources omit important details, while the reliability of others sources raises questions. Information retrieval and evidence collection on this subject is not simple. Although the number of well-recorded and properly documented cases of fingerprint forgery is relatively small, there are reasons to believe that the real number of cases is higher and probably cannot be accurately estimated.

Cases of fingermark forgery fall into two main groups:
1. Forgery committed by law-enforcement officers, police specialists, fingerprint experts
2. Forgery committed by a criminal (or for the criminal)

In both instances, the intent is to frame or direct the attention on a person that has not left fingermarks were they were reportedly recorded. There is documentation of a third category of fingerprint imitations/modifications by scientists and experts attempting to reproduce alleged or admitted *modus operandi* by forger, for research purposes or in order to be able to detect forgery and ways to avoid being fooled by it.

With recent reports [19, 108 110] and the multiplication of documented cases, it is certainly difficult to know if more forgeries occur, or simply more are reported. What can be safely said is that technical evidence is required more and more. Pressure on officers/experts is thus increasing and a certain lack of ethics and control may lead the weakest to "prove" their worth - and demonstrate their efficiency in helping put "good" suspects behind bars (like the fireman setting up fire to be the first to demonstrate courage and abnegation). It makes rewarding statistics, promotion chances and "obvious bad characters" are kept checked. It may also be a (bad) response to the increased political pressure on police to obtain results and to "follow human rights principles" in their investigations resulting in fewer admissions.

Digital fingerprints and fingermarks images acquisition

Silicon based sensor chips

In this field, the main research efforts are focused on the reduction of the size, the price and the electrical consumption of the fingerprint sensor chips to meet crucial industry needs for rugged fingerprint sensor technology that can be easily integrated into space-constrained and battery-operated platforms [109]. Mainguet and co-workers present different types of fingerprint sensors with silicon-based sensors, being shown as the least expensive solution. The fact that lower area means lower cost for silicon chips is demonstrated by looking at 'sweeping' solutions such as the FingerChip™ [110].

Veridicom's offers an ultrathin 1.4mm package featuring a low power stand-by mode of less than 50 * 10^{-6} Amperes [109]. A low consumption complementary metal oxide semiconductor (CMOS) fingerprint sensor is presented by Jung and co-workers [111], with a self-biasing automatic local contrast adjustment technique for image binarisation realised with a passive capacitive network. Pixel-parallel cellular logic is embedded into the sensor array and extracts the characteristic features of the fingerprint image without any additional area consumption. A chip architecture that integrates a fingerprint sensor and an identifier in a single chip is proposed by [112]. The fingerprint identifier is formed by an array of pixels, and each pixel contains a sensing element and processing element. An identification is performed by the pixel-parallel processing of the pixels. The sensing element is built above the processing element in each pixel. The sensor area is 10.1 * 13.5 mm^2. The sensing and identification time is 102 ms with power consumption of 8.8 * 10^{-3} Watts at 3.3 Volts. Five hundred tests confirm an equal error rate (EER) of 1%. Lee and co-authors propose a 600 dpi high resolution sensor chip integrating a new detection circuit of charge sharing, which eliminates the influences of internal parasitic capacitances [113].

Finally, the Korean company PASS 21 has announced a mobile phone with an integrated fingerprint sensor due for commercial production in January 2001 [114].

3D surface topography system

De Kinder and Nys paper present a new technique for recording fingerprints on cartridges. Data recording are carried out using a UBM-profilometer, based on a 3D recording of the surface topography. This system uses a sensor head which can be positioned along a translational axis while the cartridge can be rotated by a rotational stage, making this system well suited to the analysis of cylindrical surfaces [115].

Confocal scanning-beam system

Roorda and co-workers describe a highly sensitive confocal scanning-beam system for time-resolved imaging of fingerprints. Time-resolved imaging is a relatively new forensic procedure for the detection and imaging of latent fingerprints on fluorescent substrates such as paper, cardboard, and fluorescent paint. Ordinary fluorescent imaging of latent fingerprints on these surfaces results in poor contrast. Instead, the specimens are treated with a phosphorescent dye that preferentially adheres to the fingerprint which allows time-resolved discrimination between the fingerprint phosphorescence and the background fluorescence. Time resolved images are obtained by synchronising the digital sampling of the specimen luminescence with the on-off cycle of the chopped illumination beam [116].

Fingerprints and fingermarks image processing

Analogue image enhancement

Two factors adversely affect the contrast in the photograph of fingermarks on glass bottles: the absence of a dark background and the reflection from the interior surface of the bottle. Levi and Leifer propose three methods to prevent these two difficulties: place the bottle on a black background, inserting a rolled piece of black paper into the bottle before photography or fill the bottle with a black liquid. The latter gives the best results and the second method provides better results than the first one [117].

Digital image enhancement

Digital image processing technology was applied by Moler and co-workers to restore fingerprints with non-uniform contrast. Whenever the results obtained by applying conventional optical enhancement techniques were not satisfactory, spatial domain as well as frequency domain techniques were combined in order to enhance the features that allowed later identification of a murdered victim who had remained unknown and unidentified since 1976 [118].

A critical step in automatic fingerprint recognition is to automatically and reliably extract features from the input fingermark and fingerprint images. However, the performance of a feature extraction algorithm relies heavily on the quality of the input images. Image enhancement algorithms ensure that the performance of an automatic fingerprint recognition system will be robust with respect to the quality of input images. Hong and co-workers propose a fast fingerprint enhancement algorithm, which can adaptively improve the clarity of ridge and valley structures of input fingerprint images based on the estimated local ridge orientation and frequency. Experimental results show the improvement of the accuracy of an online fingerprint verification system [119].

Digital image compression

Ersoy and co-authors propose a fingerprint image compression scheme using the essential steps of a typical automated fingerprint identification system (AFIS) such as enhancement, binarisation and thinning to encode fingerprint images. The decoding process is based on reconstructing a hybrid surface by using the grey values on ridges and valleys. In this compression scheme, the ridge skeleton is coded efficiently by using differential chain codes. Valley skeleton is derived from ridge skeleton and the grey values along the ridge and valley skeletons are encoded using discrete cosine transform. The error between original and replica is also encoded to increase quality. Features such as end points and bifurcation points can be extracted directly from compressed images even for a very high compression ratio. The algorithm has been applied to various fingerprint images and high compression ratios like 63:1 have been obtained [120].

A compression algorithm using wavelet packets and lattice vector quantisation, a new vector quantisation scheme based on an accurate model for the distribution of the wavelet coefficients is presented by Deriche and co-workers. In the new algorithm, no assumptions are made about the lattice parameters and no training and multi-quantizing are required. The proposed algorithms achieve the best rate-distortion performance by adapting to the statistical characteristics of the source image in each sub-image. Compared to other available image compression algorithms, the proposed algorithms result in higher quality reconstructed images for identical bit rates [121].

Hsu gives a review of the key issues of the holographic data storage for image recognition application to fingerprint recognition [122].

Automatic fingerprint recognition technology

Automatic fingerprint recognition technology covers the fields of feature extraction from fingerprints or fingermarks and the classification strategies of the feature vectors extracted. The development of these technologies are also a source of enhancement of the technology used in the AFIS systems. A summary of the state-of-the-art in the field of biometric use of ridge pattern can be found in two edited books published in 1999 : " Intelligent biometric techniques in fingerprint and face recognition " edited by Lakhmy Jain and co-editors [123] and " Biometrics, personal identification in Networked Society ", edited by Anil Jain and co-editors [124].

The proof of identity is given by the application of a fingerprint (usually a thumb or an index print) on identification documents such as passports, identity cards (there is always a legal base for these applications), or in the last few year as a morphometric or biometric means of identification in access control of computers, doors, safes, etc). Recent interest in automatic access control is leading to the creation of records or files whose legality is often not established. It is made on the basis of agreement or consensus decision. This may become the source of prints useful in identification in large scale disasters' victims identification or in specific computer crimes (unauthorised access, fraudulent file modifications, etc).

Feature extraction

The inherent properties of fingerprints allow a feature extraction and data reduction in the spatial frequency domain. The Fourier representation allows fingerprints to be distinguished from a small and spatially well defined area. Li and co-authors investigate the recognition of fingerprints from the Fourier spectrum. This suggests various schemes to detect the significant information in order to optimise the trade-off between sensitivity and robustness. The classification of fingerprints from their plane wave spectra allows the design of compact systems, where the Fourier transformation is performed optically, while detection and post-processing is done by electronics. This provides the advantage that both optics and electronics are used in an optimum way to minimise the physical size of the system as well as the computational load to interpret the detected signal [125].

Traditional automatic fingerprint identification systems (AFIS) are based on minutiae extraction techniques from binary or skeleton fingerprint images. Farina and co-workers present a set of algorithms for the extraction of fingerprint minutiae from skeletonized binary images. Besides classical methodologies for minutiae filtering, a new approach is proposed for bridge cleaning based on ridge positions instead of classical methods based on directional maps. Finally, two novel criteria and related algorithms are introduced for validating the endpoints and bifurcations. Statistical analysis of the results obtained by the proposed approach shows efficient reduction of spurious minutiae. The presented minutiae extraction algorithm performs correctly in dirty areas and on the background as well, making computationally expensive segmentation algorithms unnecessary. The results are confirmed by visual inspections of validated minutiae of the NIST sdb 4 reference fingerprint image database [126].

For low-quality fingerprint images, the pre-processing stage of an AFIS produces redundant minutiae or even destroys real minutiae. Minutiae detection algorithms in direct grey-scale domain have been developed to overcome these problems [127]. The first step of grey-scale minutiae detection algorithm is to determine ridge locations and then perform grey-scale ridge line following algorithm to extract minutiae. Xudong and co-authors report a minutiae detection procedure based on adaptive tracing the grey-level ridge of the fingerprint image with piecewise linear lines of different length. The original fingerprint image is smoothed with an adaptive-oriented smoothing filter only at some selected points. This greatly reduces the computational time. Each ridge in the skeleton is labelled with a number so that each detected minutia is associated with one or two ridge numbers, which is useful for post processing [128, 129]. A Gabor-filter-based method is proposed by Lee and Wang for directly extracting features from grey-level images without any other pre-processing steps such as smoothing, binarisation, thinning, and minutiae detection [130]. The proposed Gabor-filter-based features play a central role in the processes of fingerprint recognition, including local ridge orientation, core point detection, and feature extraction. Experimental results show that the recognition rate of the k-nearest neighbour classifier using the proposed features is 97.2% for a small-scale fingerprint database [131].

However, the existing grey-scale minutiae detection techniques can only work on partial fingerprint images due to the ignorance of image background. Moreover, the grey value variation inside a ridge also generates redundant ridge points. Jeng and Kuo propose a novel method, based on grey-level histogram decomposition, to locate the ridge points in complete fingerprint images. By decomposing the grey-level histogram, redundant ridge points can be eliminated according to some statistical parameters. Experimental results demonstrate that the correct rate can be over 95% even applied to poor-quality fingerprint images [132].

Apart from the algorithms focused on the extraction of second level features (minutiae), some algorithms have been designed to segment and extract the information held in the general pattern (first level features) or in the papillary ridges (third level features).

Jain and co-authors present a fingerprint classification algorithm which is able to achieve an accuracy better than previously reported in the literature to classify fingerprints into five categories: whorl, right loop, left loop, arch, and tented arch [133].

Tico and Kuosmanen propose a segmentation technique based on the topographic properties of the image surface. The digital image is treated as a noisy sampling of the underlying continuous surface which is approximated by orthogonal Chebyshev polynomials. Ridge and valley regions are discriminated by the sign of the maximum normal curvature of this continuous surface. Different approximation accuracies are used along the orthogonal and parallel directions to the ridge orientation. This determines a lower sensitivity to small irregularities along the ridge direction then along the orthogonal direction, resulting in a high quality segmentation [134]. Abutaleb and Kamel have developed a genetic algorithm to find the ridges in fingerprints. It is based on the fact that the ridges of the fingerprints are parallel. When scanning the fingerprint, line by line, the ideal noise-free grey level distribution should yield lines of black and white. The widths of these lines are not constant. The proposed genetic algorithm generates black and white lines of different widths. The widths change to get the best match with the original fingerprint [135]. The recognition methodology proposed by Bourbakis and Goldman for line segments with unevenness is based on a heuristic criterion, where the user hierarchically defines the levels of tolerance (or acceptance) whereby an unevenness is removed from a line segment (ignored) or not. The results of this line-recognition approach are used on a graph-based method for the recognition of handwritten characters, where the graph nodes are straight or curve line segments. In addition, the same approach is used on the recognition of line segments extracted from fingerprints to form the appropriate graphs, which represent a fingerprint [136].

There are two major shortcomings of the traditional approaches to fingerprint representation. For a significant fraction of population, the representations based on explicit detection of complete ridge structures in the fingerprint are difficult to extract automatically. The widely used minutiae-based representation does not utilise a significant component of the rich discriminatory information available in the fingerprints. Jain and co-authors proposed a filter-based algorithm that uses a bank of Gabor filters to capture both the local and the global details in a fingerprint as a compact 640-byte fixed length features vector, called FingerCode |. The fingerprint matching is based on the Euclidean distance between the two corresponding FingerCodes | and hence is extremely fast. The initial results show identification accuracy comparable to the best results of minutiae-based algorithms published in the open literature [137].

Classification strategies

Fingerprint classification provides an important indexing mechanism in a fingerprint database. An accurate and consistent classification can greatly reduce fingerprint matching time for a large database [133].

Filterbank based classification

Jain and co-workers propose an approach in which fingerprints are viewed as oriented texture patterns, textures which exhibit an inherent and well-defined sense of directionality. Given a fingerprint image, a reliable translation and rotation invariant representation can be built. This representation is a novel scheme for solving the problems of fingerprint classification and matching on large data sets of fingerprint images [138].

Optical correlation based classification

An optical correlation system was proposed using volume hologram for database of matched filter. Optical correlator has high speed and parallel processing characteristics of optics. Matched filters are recorded into a volume hologram that can store data with high density, transfer them with high speed, and select a randomly chosen data element. The multiple reference images of database are pre-recorded in a photorefractive crystal in the form of Fourier transform images, simply by passing the image displayed in a spatial light modulator through a Fourier transform lens. The angular multiplexing method for multiple holograms of database is achieved by controlling the reference directions with a step motor. Experimental results show that the proposed system can be used for fingerprint recognition [139]. Watson and co-authors examine the use of composite filters for improving the effectiveness of a Vanderlugt correlator when used for fingerprint identification. Using the composite matched spatial filter, the Vanderlugt correlator is getting 70% correct identifications with no false positive [140].

Eigen features based classification

Kamei and co-authors propose a new distance measure and describe experiments on fingerprint preselection using eigen features of ridge direction patterns. The distance is defined by likelihood ratio of error distribution of feature vectors to the whole distribution of feature vector differences. Experiments show that the proposed distance is much more effective than the Mahalanobis distance. By combining the eigen features and traditional classification features, 0.06% false acceptance rate at 2.0% false rejection rate and one million cards/sec pre-selection speed on a standard workstation have been achieved [141].

Directional image partitioning

Cappelli and co-authors introduce a new approach to automatic fingerprint classification. The directional image is partitioned into 'homogeneous' connected regions according to the fingerprint topology, thus giving a synthetic representation which can be exploited as a basis for the classification. Experimental results have been given for the most commonly used fingerprint databases and the new method has been compared with other approaches known in the literature : the method gives the best performance and exhibits a very high robustness [142].

Ballan and co-authors present a method for fingerprint recognition based on principal component analysis (PCA), to compress fingerprint data, and minutiae extraction obtained from the directional histograms of a fingerprint. The process continues with directional image formation, directional image block representation, and fingerprint matching, respectively. The method gives the same performance as that of the uncompressed data, but reduces computation [143].

Wavelets based classification

In the recognition of fingerprint, pre-processing such as smoothing, binarisation and thinning is needed. Then fingerprint minutiae features are extracted. Some fingerprint identification algorithm (e.g. FFT) may require so much computation as to be impractical. Lee and Nam present a fast and effective wavelet based algorithm to identify fingerprints that would operate on a small computer [144].
Pohit and Singh outline a method, using simulated annealing algorithm, to optimize the dilation factor of the wavelet function, from a number of images. The optimized dilation factor has been used to obtain wavelet matched filters (WMFs) for different fingerprint images. A single WMF instead of a bank of filters can be used for identifying each image. The filter performance was tested in terms of discrimination ratio, peak-to-correlation plane energy ratio, peak-to-sidelobe ratio and average similarity measure with digitally degraded fingerprints [145].

Neural Network based classification

Curbelo has proposed and tested neural networks methodology on noisy fingerprint identification. Identification system performance depends heavily on image quality and the ability of the pre-processing software to obtain reliable minutiae in spite of image noise. Fingerprint identification using fingerprint coding based on minutiae direction turned out to be successful only with a small set of fingerprints [146].
Willis and Myers have developed and investigated a robust algorithm allowing good recognition of low-quality fingerprints with inexpensive hardware. A threshold FFT approach has been developed to simultaneously smooth and enhance poor quality images derived from a database of imperfect prints. A number of neural net and statistically based classifiers are evaluated for the recognition task [147].

Wilson and co-authors presents results on direct optical matching, using Fourier transforms and neural networks for matching fingerprints for authentication. Direct optical correlation and hybrid optical neural network correlation are used in the matching system. A matching accuracy of 90.9% can be obtained on a test set comprising 200,000 image pairs. The results obtained are on images which use 512-pixel resolution. The effect of image quality and resolution are tested using both 256- and 128-pixel images, yielding an accuracy of 89.3% and 88.7%, respectively. These results show that FT matching and neural networks can be used for the matching of fingerprints with insufficient image quality to be matched by the comparison of minutiae [148].

Fuzzy logic classification

A fuzzy bipartite weighted graph model is proposed by Kuo and co-authors to solve fingerprint verification problems. A fingerprint image is pre-processed first to form clusters of feature points, which are called feature point clusters. Twenty-four attributes are extracted for each feature point cluster. The attributes are characterised by fuzzy values. Attributes of an input image to be verified are considered as the set of left nodes in a fuzzy bipartite weighted graph, and the attributes of claimed template fingerprint images are considered as the set of right nodes in the graph. A matching algorithm is proposed for the fuzzy bipartite weighted graph model to find an optimal matching with a goodness score. Experimental results reveal the feasibility of the proposed approach in fingerprint verification [149].

Automatic Fingerprint Identification Systems (AFIS)

A general review about AFIS systems can be found in “Automated methods, including criminal record administration” of Dalrymple and MacKillian [150].

Performance evaluation

Large numbers of fingerprint software companies dropped out of a recent fingerprint verification competition, worried that differences between preliminary test results and their own published performance statistics were unacceptably high. Up to 25 algorithms were originally volunteered for the FVC2000 (http://bias.csr.unibo.it/fvc2000/) tests, but according to the competition organisers this quickly decreased to 11, probably due to "misalignments that some participants found between the performance measured on the FVC2000 training sets and their internal test sets". The organisers explained that the competition results were a measure of relative technology performance and would not predict performance in a real environment. But they did concede that "the misalignments...could play negatively for a company releasing accuracy numbers significantly different from those measured at FVC2000" [151].

Despite the concerns of many commercial companies, however, the perceived risk proved well worthwhile for the French supplier. Its algorithms shone in the competition, consistently beating off the other entrants in all the tests performed (see Table 1). Another top performing algorithm was supplied by Singaporean entrant CSPN (Centre for Signal Processing, Nanyang Technological University), which displayed a good trade off between accuracy and efficiency. Of the algorithms entered into the competition, seven entries came from academia and four entries came from three commercial companies.

Algorithm	Average EER (%)	Average enrol time (sec)	Average match time (sec)
Sag1	1.73	3.18	1.22
Sag2	2.28	1.11	1.11
Cspn	5.19	0.20	0.20
Cetp	6.32	0.95	1.06
Cwai	7.08	0.27	0.35
Krdl	10.94	1.08	1.58
Utwe	15.24	10.42	2.67
Fpin	15.94	1.22	1.27
Uinh	19.33	0.71	0.76
Diti	20.97	1.24	1.32
Nsmi	47.84	1.44	1.71
Note: In order of performance, algorithms were supplied by : Sagem SA ; Sagem SA ; Centre for Signal Processing, Nanyang Technological University ; CEFET-PR/Antheus Technologia ; Centre for Wavelets, Approximation and Information Processing, National University of Singapore ; Kent Ridge Digital Labs ;University of Twente, Electrical Engineering ; FingerPin AG ; Inha University ; Ditto Information &Technology Inc ; Natural Sciences and Mathematics, Institute of Informatics.			

Table 1. Average performance of the fingerprints recognition algorithms over all four database

In order to cover recent advances in fingerprint sensing techniques the algorithms were tested on four different fingerprint databases. The first two databases were collected using two small-size and low cost sensors (an optical sensor from Keytronic and a capacitive sensor from ST Micro-electronics), the third database was collected using a higher quality, large area optical sensor from Identicator Technology, while the fourth database was synthetically generated. Each database had 880 fingerprints from 110 different fingers.

Surprisingly the first two databases proved easier to match than the third, despite the fact that the third sensor was of higher quality! This suggests that acquisition conditions and volunteer population can have a stronger impact on performance than sensor quality. The first two databases were made up of 20-30 year old students, while the third database had volunteers ranging from 5-73 years of age. The fourth, computer-generated database, proved to be adequate for the purposes of the competition, and according to the organisers was very adjustable and cheap.

The competition's organisers were the Biometric System Lab at the University of Bologna, the US National Biometric Test Centre at San Jose State University and the Pattern Recognition and Image Processing Laboratory at Michigan State University. The organisers are considering performing another benchmarking test in the future and intend to investigate further the feasibility of using synthetic databases for future technology evaluations [152].

Specific uses

Latent fingerprints developed by photoluminescence techniques can be entered into AFIS directly, using the AFIS fingerprint reader. The reader's illumination sources are turned off and replaced by fingerprint illumination with a portable laser or 'alternative light source', with the usual filter for fluorescence observation placed in front of the reader's computer- interfaced camera. Coloured fingerprints can be read with substantially improved contrast in the standard absorption/reflection mode as well when the reader's white light illumination is replaced by suitably chosen colour illumination. No camera filter is then needed. Alternatively, white light and band-pass filters can be employed [153].

A new method for searching latent palm marks and processing inked palm prints utilising Automated Fingerprint Identification Systems (AFIS) is described. The system has been devised by two fingerprint experts of the Cambridgeshire Constabulary. Application and usage of the system is outlined as well as a description of the method whereby the AFIS matches the palm prints of convicted criminals with those of latent palm marks recovered from crime scenes [154].

Smart cards related fingerprint identification

Smart cards show a remarkable facility for working synergistically with biometrics. Smart cards provide an offline method for storing biometric templates, where access to an online central database of templates is not possible or desirable. Equally biometrics can also be used to protect access to information stored on smart cards or in combination with a smart card to provide access to network services. The inclusion of biometrics in any public key infrastructure (PKI) architecture would not replace the use of certificates, cards, or tokens ; instead, biometrics would operate in conjunction with such devices to make them more effective. The International Biometric Industry Association (IBIA) suggests that the use of a biometric, as opposed to a PIN or password, will positively establish trust between the candidate and the machine. Once trust has been established, a secured session can proceed, private keys can be generated, and the recipient of a requested transaction can have full confidence in the authenticity of its contents as well as its sender. In the near future, the security bar will be raised even further as fingerprint sensors are placed on the smart cards themselves [155].

A consortium of Nordic companies, Precise Biometrics (Sweden), Miotec (Finland) and iD2 Technologies (Sweden), has launched a means of providing digital signatures in which PIN codes are replaced with fingerprints carried on a smart card, and the leading French smart card supplier Oberthur Card Systems is moving along similar lines [156]. The smart card-based fingerprint authentication solution applies biometrics to PKI architectures and is designed to create digital signatures once an individual has been successfully authenticated through fingerprint matching. Comparisons between reference and sample biometric templates traditionally occur outside of the smart card chip – exposing the template to possible alteration. But with this product, matching takes place inside the smart card's chip using a proprietary matching algorithm. The stored template is normally between 100-300 bytes, while the total software package is around 3 Kbytes. The chip capacity is 16 Kbytes and verification typically takes under two seconds [157]. The user inserts in the reader their smart card (which carries their previously encrypted fingerprint) and places their finger on the reader. The fingerprint is then captured and verified against the fingerprint template stored on the card [158].

Precise Biometrics, Miotec and iD2 Technologies, demonstrated a biometrically signed transaction, where fingerprint matching took place within a smart card chip. The solution could be used to secure emails or ordinary office documents ; Precise Biometrics supplied its fingerprint matching software and integrated smart card and fingerprint reader, while Miotech integrated the matching functionality onto its smart card. iD2 Technologies' PKI-based software provided encryption and digital signature creation [158].

The Taipei County Government in Taiwan has placed an order for approximately 100 combined smart card and fingerprint verification units, supplied by the Swedish producer Precise Biometrics, in an effort to tighten up its IT security. Initially, the project focussed purely on employees in the IT department, but a decision on whether to extend the project to include all 2,000 employees is imminent. According to a company spokesman, the government is often seen as a pioneering force in Taiwan. The biometric aspect of the project is only a small part of the overall IT security overhaul. Eventually, Taipei County wants to produce platform-independent accounts, a single sign-on environment and secure transfer of electronic documents between different units using the internet and a PKI solution [159].

Integrated Automatic Fingerprint Identification Systems (IAFIS)

Systems integrating the simultaneous recognition of several biometric data, called Integrated Automatic Fingerprint Identification Systems (IAFIS) in [160], retain the attention of the security agencies, particularly in the USA. At the Biometrics 2001 Conference, the Pentagone announced its desire for the new Biometrics Fusion Center in Bridgeport, West Virginia to become a "repository for all department of defence (DoD) biometric databases (fingerprints, DNA, iris, face)" [160]. The fusion of the results given by the different biometric recognition systems used by the police forces represents without doubt the future in the field of forensic biometric identification.

Hong and Jain have developed a prototype biometric system which integrates faces and fingerprints. An automatic personal identification system based solely on fingerprints or faces is often not able to meet the system performance requirements. Face recognition is fast but not extremely reliable, while fingerprint verification is reliable but inefficient in database retrieval. The system overcomes the limitations of face recognition systems as well as fingerprint verification systems. The proposed decision fusion scheme enables performance improvement by integrating multiple cues with different confidence measures [161].

Shoesoles and footprints impressions

Bodziak proposes the state-of-the-art and a general information about the forensic use of shoesole evidence [162].

Shoesole impressions detection methods

Theeuwen and co-authors propose a comparative study of 28 chemical methods for the enhancement of muddy footwear impressions in order to differentiate between utilisation at the scene of crime. A differentiation can be made between methods having a reaction with metal ions : alizarine, ammonium pyrrolidinedithiocarbamate, ammonium thiocyanate, arsenazo, dipyridil, hydroxyquinoline, phenanthroline hydrosulfite, potassium ferrocyanide, potassium thiocyanate and tetramethylbenzidine ; having a reaction with amino acids : bromophenol blue, bromocresol green, DFO, DFO / gelatinelifter, ninhydrin and ninhydrin / gelatine lifter and having a reaction with other components : cyanoacrylate, gentian violet, iodine, iodine-naphtoflavone, physical developer, safranine, safranine / gelatine lifter, silver nitrate, small particle reagent (molybdene disulfide) and sticky side powder [163]. Shor and Vinokourov propose the use of a white adhesive lifter to remove footwear imprints in dust and their subsequent enhancement with a pH indicator. It was found that this method is superior to that of gel lifting in two cases in which shoemarks were recovered using this method [164].

Shoesole and footprint impressions individualisation process

Shoesole impressions interpretation

There have been major discussions and concerns among footwear examiners from around the world as to whether there should be an established number of characteristics in order to provide a positive identification. This study addresses the possible direction of a footwear examination by year 2000 that should integrate an understanding of the four basic components of a successful examination : the anatomy of the human foot ; the outsole-making process ; the comparison/decision process and the presentation of the final conclusion within a courtroom [165]. Shor and Weisner have conducted a survey with two sets of shoeprints from actual crime scenes and the corresponding suspect's shoes. Experts from seven countries were asked to give their opinion, based on the scale used in their country, on the probability that the suspect's shoe made the shoeprint impression at the crime scene [166]. The variance in the conclusions came out as a problem needing to be addressed if consistent results are to be offered for Courts.

In a first round pilot Delphi study of podiatrists' experiences of shoe wear marks made by Vernon and co-workers, considerable lack of agreement had been noted among participating podiatrists, suggesting the need for caution in the use of wear marks [167]. A second Delphi round showed a moderate move towards consensus among participating podiatrists in the context of overall wear interpretation [168].

Evett and co-authors describe an attempt to formalise the interpretation of footwear marks. First, the definitions of identification and individualisation which were given by Kirk are discussed and formalised, then a Bayesian analysis is presented in which the assumptions made are clarified. The analysis is broken down into components which reflect different interpretative issues. Application of a formal expression for the likelihood ratio is then illustrated by means of examples from casework in New Zealand and the United Kingdom [169].

Champod and Voisard propose a statistical study of the air bubbles, among other manufacturing or acquired characteristics of the shoesoles. The assessment of the evidential value of air bubbles coincidences relies currently largely upon the examiner's experience and/or follows sometimes a verification based on the examination of a small number of analogous pairs collected for the case at hand. Statistical data related to the occurrence and characteristics of air bubbles on shoesoles in an attempt to model the potential variability have been gathered. Seventy-one pairs of shoes with the same design, brand, model and size were obtained and soles were photographed. An image-processing algorithm was developed to allow the systematic acquisition of data such as: (1) the number of air bubbles on the sole and around given structural elements ; (2) the measure of air bubbles characteristics such as their surface and position. These data allow a discussion of the assessment of the probability of finding on shoesoles (same design, brand, model and size) a certain number of air bubbles on a surface with the same positions and morphology [170].

Footprint impressions

The state-of-the-art and a general information about the forensic individualisation of bare foot marks is proposed by Kennedy [171].

Nakajima and co-workers propose a new method of personal recognition based on footprints based on the pressure distribution of the footprint measured with a pressure-sensing mat. In this method, an input pair of raw footprints is normalized, both in direction and in position for robustness image-matching between the input pair of footprints and the pair of recorded footprints. In addition to the Euclidean distance between them, the geometric information of the input footprint is used prior to the normalisation, i.e. directional and positional information [172].

Walczynski reports an experimental study based on podometric apparatus used to establish a link between shoesoles impressions and suspects feet, when the footwear at the origin of the trace is lacking, either destroyed or concealed. At the moment, it is difficult to predict whether this method will be applicable in casework, but the study is currently pursued [173]. Two cases where latent footmarks were recovered from a homicide scene are reported by Donnelly [174]

Tire impression

Bodziak makes a review of measurements of tire tracks and vehicles tire marks [175]. Thali and co-workers report a case in which a soft-tissue injury to the face was caused by being run over by a car tire. They have used the CAD-supported photogrammetry for a detailed 3-D reconstruction to investigate the objects, injury and surface of the tire in virtual space. The RolleiMetric multi-image evaluation system has been used to measure and calculate the spatial location of points shown in the photo sequences, and create 3-D data models of the objects. The model of the injury was then compared against the model of the possible injury-causing instrument, and the perfect 3-D match between the tire tread and the facial injury has been shown [176]

Ear impressions

A general information about the field of ear impressions can be found in " Earprints" of van der Lugt [177].

Ear impressions detection methods

This paper provides a detailed description of the lifting and examination of earprints found at crime scenes. The information may be particularly useful for less experienced criminal evidence technicians and for police officers investigating burglaries. Some of the medical principles behind the use of earprints as identification evidence are also explained [178].

Ear impressions individualisation process

Interpretaion

Feenstra and van der Lugt describe some aspects of the normal human auricle. As the physiognomy of the auricle is, they claim, different for every individual, it leads to the possibility of identifying people based on their auricles. Indeed this has even led to the surmise of earprints as akin to fingerprints, a fact not generally known amongst specialists. This highly specialised knowledge has been developed within a special branch of forensic medicine and criminalistics, called 'earology' or 'otomorphology' [179].

The individualisation process of ear impressions is presented by Champod and co-authors [180]. They note that the use of earmarks as evidence in criminal trials appears to be expanding, but that there is something of a dearth of peer-reviewed scientific publications to support the pursuit. After a comprehensive review of the literature, literature in which they emphasise the weaknesses of the present state of knowledge, they describe the differences of nature of the identification and individualisation processes, previously explained by Kirk [181]. Some research directions are proposed to gather statistical knowledge of the within source and between sources variability of earmarks and earprints. Its ultimate goal permitting to assess likelihood ratios in relation with this type of evidence [180]. This point of view is supported and emphasised by Moenssens, in the numerous papers available on his website (http://www.forensic-evidence.com)[182]

Toolmarks

N.B. This review will not cover information related to the firearms individualisation process following from the examination of the marks left by weapons on cartridges and bullets.
A general review was published about the forensic examination of toolmarks by van Dijk in "Tools" [183]

Toolmarks detection methods

Petterd propose a state-of-the-art and a general information about the recovery of obliterated serial numbers in "Serial number" [184].

Roux and co-authors present a standard protocol including optical examination, UV-visible and Fourier transform infrared spectrometry to analyse common plastic drug packaging material to determine whether there are significant differences between different sources, to establish the evidential value of these examinations, and to build a database of common packaging material. Visual examination was the most effective means for discriminating samples. Thickness and weight measurements provided useful information. Visualisation of machining marks using crossed polarised light was found to be useful in the comparison process. UV-visible spectrophotometry has some value for distinguishing samples. It is concluded that the properties of plastic packaging materials can be excellent indicators for identifying the specific brand or origin of the packaging [185, 186].

Rydz proposes a comparison protocol, with stereomicroscopy, to observe toolmarks resulting from the mass production of illegally manufactured and distributed CDs with a quality comparable to the source. The mass character of this activity resulted from low costs forged CDs containing among others, music and computer software. Considering technological processes of CD matrix and CD production, one cannot, basing upon the secured material only, identify equipment which is used for their production by means of record sides, which bear impression of matrix surfaces. On the other hand, in situation where matrices were secured along with CDs, one may identify equipment used for their production [187].

Toolmarks individualisation process

Computer assisted individualization

Jones and co-authors describe a study conducted to investigate the reproducibility of toolmarks left by drill bits. They focus on the automated analysis aspect of the study, and particularly the advantages of using decision fusion methods in the comparisons. To enable the study to encompass a large number of samples, existing technology was adapted to the task of automatically comparing the test impressions. Advanced forensic pattern recognition algorithms that had been developed for the comparison of ballistic evidence in the DRUGFIRE™ system were modified for use in this test. The results of the decision fusion architecture closely matched those obtained by expert visual examination. The study, aided by the improved pattern recognition algorithm, showed that drill bit impressions do contain reproducible marks. In a blind test, the DRUGFIRE™ pattern recognition algorithm, enhanced with the decision fusion architecture, consistently identified the correct bit as the source of the test [188].

Bayesian interpretation

In the forensic science of firearms and toolmarks identification, examiners traditionally have drawn conclusions of identity from subjective criteria. Bunch critically explores the general validity of one proposed objective-criteria regime – that of counting consecutive matching striations on fired bullets. Practical considerations are discussed, as well as theoretical ones, with both discussions viewed from the perspective of Bayesian logic. It is concluded that drawbacks exist for this particular objective-criteria regime, but that research and logical analysis should lead to improvement in the field [189].

Case reports

Oz and co-workers report a rape case where no semen, hair, or fingerprints were left by the perpetrator, but rather uncharacteristic biological and physical evidence in the form of a lollipop and a pair of glasses. Three separate forensic laboratories collaborated using conventional forensic methods of PCR DNA typing, photography, and toolmarks comparisons to provide investigators with scientific evidence. The authors stress the importance of evaluating each item of evidence and realising its forensic value [190].

Lipmarks

Kasprzak makes a general review about the forensic investigation of the lipmarks, called "cheiloscopy" [191].

Lipmarks detection methods

Segui and co-authors have investigated the detection of latent lipmarks produced by permanent lipsticks. This cosmetic product, contrary to conventional lipsticks, does not leave visible prints and can thus be overlooked at the crime scene. As print supports, the study used ceramics, glass, cotton fabric and paper. Lip prints were left to dwell for different periods and were later developed using aluminium powder, cobalt oxide powder and magnetic powder. The results show that identifiable lip prints can be obtained up to 30 days after being produced [192].

Lipmarks individualisation process

Objectives of the study of Vahanwala and Parek was to test the durability of the lip-pattern of the same individual over a period of time, to check whether there were any peculiar patterns in relation to the sex of the individual, to discover the most common patterns in the Indian population. The labial wrinkles and grooves of each of the individuals was identical to the ones taken earlier. Type I and II were most commonly seen in the First quadrant. Lip prints behold a potential for individualisation and it can be used for sex determination according to the authors [193].

Bitemarks

The state-of-the-art and a general information about the field of bitemarks can be found in "Odontology" of Clement [194]. Bitemarks may be observed in skin, wax, from a dental model, indirectly from a photograph, a scanned image of a dental model or food and can be used for the individualisation of a person. Bitemarks constitute reliable evidence for personal identification. It was observed that a tolerance of approximately 1 mm existed between measurements of a wax bite, dental model, photograph and computer scanned image [195].

Bitemarks recovery

Optical methods

Photography is an important means of collecting and preserving physical evidence as it relates to bite mark and patterned injuries in skin. Wright explains the proper use and understanding of colour, black-and-white, ultraviolet and infrared photography and presents the techniques and equipment for the photo-documentation to aid the collection and preservation of this evidence. A case involving multiple bite marks is presented. The bite marks were photographed over a 31-day period to document the injuries and preserve their evidentiary value. The evidence recovered at each photography session is discussed and photographs are presented for review. Suggestions concerning the need for more research are presented [196, 197]. Clouser presents a flash illumination technique to obtain properly exposed bitemarks photographs [198].

Distortion of the bitemarks base

Low and co-authors have undertaken a study to analyse the dimensional stability of specimens of actual skin from deceased victims conserved to preserve of bitemarks evidence. Utilising a prefabricated template, marks approximating "bites" were made in post-mortem skin of Miniature Hanford pigs, producing imprints with distinct margins and indentations. Tissue samples were stored in 10% formalin after affixing an acrylic support ring with cyanoacrylate adhesive and sutures. Measurements of the six tooth mark analogues and cross-arch dimensions were taken at intervals of up to 38 days. Data from these measurements indicate a wide range of amount and type of distortion in preserved tissue. Although some samples were dimensionally stable, there was both contraction and expansion of bite mark specimens, even within individual skin samples. It appears that standard techniques for storage and preservation of bite mark samples will not produce reliable dimensional accuracy [199].

Sakoda and co-workers have explored an essential factor involved in distortion of bitemarks on the skin: that is the dynamics of biting related to the location on the body. This study describes the comparison between the identification of bitemarks left on different regions of the victims' bodies in two homicide cases. The findings indicated that a stepwise dynamic comparison of serial adjacent marks with a part of the dentition in consideration of movement of the jaws and distortion of the skin was useful in identifying matching points. The identification process indicated possible wounding dynamics of biting [200].

Anatomical location of human bitemarks

101 bitemark cases were identified from the United States Courts of Appeal and included in the study of Pretty and Sweet, to obtain details concerning the bitemarks, such as anatomical location, number of injuries, and information concerning the victim. Information on 148 bites was collated. These data are presented in tabular and graphical form to allow comparisons between males and females, victims and perpetrators, adults and children, and the crime types associated with human bites [201]

Bitemarks individualisation process

Methodology

A review of the literature is presented by Pretty and Sweet, in which the major areas of contention within the field are assessed: including the accuracy of bitemarks on skin, the uniqueness of the human dentition, and analytical techniques. The review revealed a lack of valid evidence to support many of the assumptions made by forensic dentists during bitemark comparisons. The new level of judicial scrutiny of such scientific evidence is likely to emphasise this lack of knowledge upon which bitemark analysis relies. The authors call for a more scientific and evidence-based approach to forensic dental research [202].

Comparison methods

Physical comparison of a suspect's teeth to a bite mark injury using hollow volume comparison overlays is a common forensic odontology technique. Several methods are used to record characteristics of the size, shape and position of the teeth and to generate overlays. These include computer-based, radiographic, xerographic and hand-traced methods. Five common overlay production methods were compared using digital images of dental study casts as a reference standard. Area of the biting edges of the anterior teeth and relative rotation of each anterior tooth were measured and compared. The computer-based production method was determined to be the most accurate of those studied. It produced accurate representations of the biting edges of the teeth in an objective manner. The radiographic method was determined to be more accurate than the xerographic method with respect to tooth area measurement. The opposite is true with respect to tooth rotation. Hand-traced methods, from either wax impressions of teeth or directly from study casts, were determined to be inaccurate and subjective [203]. Sweet and co-authors have developed a method to generate accurate hollow volume overlays using computer-based techniques, to enable the odontologist to produce high-quality, accurate comparison overlays without subjective input [204].

Performance measure

Fifty colour prints of human bite marks were sent to 109 observers who were asked to decide using a six point rating scale, whether the marks had been produced by the teeth of an adult or a child. The observers consisted of accredited senior forensic dentists, accredited junior forensic dentists, general dental practitioners, final year dental students, police officers and social workers. The results were compared against a "gold standard" which was the actual verdict from the case. Comparison of the results between the groups of observers and the standard was made using Receiver Operating Characteristics (ROC) methodology. The best decisions were made by senior/junior experts or final year dental students. General dental practitioners and police officers were least able to differentiate correctly between adult and child bite marks. The effect of training is important and its effects need to be assessed in more detail in future studies [205].

Denture marking

A survey of denture marking in Europe and in the United States show that denture marking is, to our knowledge, regulated by law only in Sweden and Iceland. Since there is no international consensus regarding the issue of denture marking it is important to address it. A survey from the Nordic countries has shown that if denture marking was in general use, the contribution to the establishment of identity by forensic odontology in cases of fire would increase by about 10%. This means that about 25 more individuals could have been identified if their dentures were marked. Increased international collaboration is needed to solve the issue of denture marking for clinical and forensic purposes [206].

Case reports

Bitemarks left in foodstuffs

In a recent court case, a comparison was made between an impression of marks left in cheese at a murder scene and a set of study models of one of the suspects. The court was reluctant to accept the validity of the pattern-associated comparison that was used in the identification. This study compared marks made in cheese, butter and cooked potato with study models taken from volunteers. Pattern-associated comparison was the method used [207]. Kenna and co-authors report a theft in a chocolate factory in which the police recovered three pieces of chocolate with irregular fractured surfaces displaying a pattern of marks made by human teeth [208], and Nambiar and co-workers a case in which a wad of used chewing gum, recovered from the scene of a burglary, contained impressions of human teeth [209].

Physical evidence in the form of a high quality bite mark was discovered on a piece of yellow cheese found at the scene of a crime. The cheese had been frozen by police for 10 days after recovery and before submission to the laboratory for testing. The double swab technique was used to collect DNA samples. A sample of the suspect's blood was obtained. Using PCR-based DNA typing at ten STR loci, (Profiler Plus, Perkin Elmer-Applied Biosystems) it was determined that the DNA from the cheese originated from the suspect [210].

Animal bitemarks

Shark bitemarks

To examine the pattern of injuries in cases of fatal shark attack in South Australian waters Bayard and co-authors examined the files of the past 25 years, from 1974 to 1998. Of the seven deaths attributed to a shark attack during this period, full autopsies were performed in only two cases. Case 1 was a 27-year-old male surfer who had been attacked by a shark ; the main areas of injury involved the right thigh, which displayed characteristic teeth marks, extensive soft tissue damage, and incision of the femoral artery. There were also incised wounds of the right wrist. Bony injury was minimal, and no shark teeth were recovered. Case 2 was a 26-year-old male diver who had been attacked by a shark, the main areas of injury involved the left thigh and lower leg, which displayed characteristic teeth marks, extensive soft tissue damage, and incised wounds of the femoral artery and vein. There was also soft tissue trauma to the left wrist, with transection of the radial artery and vein. Bony injury was minimal, and no shark teeth were recovered. In both cases, death resulted from exsanguination following a similar pattern of soft tissue and vascular damage to a leg and arm [211].

Leopard bitemarks

Autopsy, radiography, fingerprint analysis, microbiologic cultures, and dental impressions were used to evaluate the fatal case of a Persian leopard (*Panthera pardus*) attack in an animal sanctuary in Oklahoma. These techniques can be applied to similar cases involving wild and domestic animal attacks [212].

Rodents bitemarks

Tsokos and co-authors present five cases of postmortem bite-injuries inflicted by rodents ; three cases caused by mice, one case by rats, one case of possible mixed rodent activity by rats and mice. The majority of the injuries have a circular appearance. The wound margins are finely serrated with irregular edges and circumscribed 1-2 mm intervals within, partly showing protruding indentations up to 5 mm. Distinct parallel cutaneous lacerations deriving from the biting action of the upper and lower pairs of the rodents incisors are diagnostic for tooth marks of rodent origin but cannot always be found. Areas involved in the present study were exposed and unprotected parts of the body, such as eyelids, nose and mouth and the back of the hands [213]. Prahlow and Linch present a case initially thought to be a child abuse homicide that, after complete autopsy and thorough investigation, was determined to be caused by a viral infection and complicated by postmortem animal activity [214]. Any case presented as postmortem animal mutilation should be viewed with skepticism and undergo a full autopsy [215].

Immunodeficiency virus transmission by human bites

The risk of human immunodeficiency virus (HIV) transmission following a bite injury is important to many groups of people. The first are those who are likely to be bitten as an occupational risk, such as police officers and institutional staff. Another group are represented by the victims and perpetrators of crimes involving biting, both in attack and defense situations. The possibility of these bites transmitting a potentially fatal disease is of interest to the physicians who treat such patients and the legal system which may have to deal with the repercussions of such a transmission. Bite injuries represent 1% of all emergency department admissions in the United States, and human bites are the third most common following those of dogs and cats. A bite from an HIV-seropositive individual that breaks the skin or is associated with a previous injury carries a risk of infection for the bitten individual [216].

Marks as essential features in crime analysis

There has been much work dedicated to crime analysis and intelligence in recent times. Independently, physical evidence has shown great potential for linking crimes and bringing solid informative data through the increased use of multiple databases. However, their informative potential is still often underestimated and has been poorly integrated into police information systems. A framework that fully introduces this data into an intelligence based system has been proposed by Ribaux [34]. This framework is built on the study of inference structures extracted from investigators' every day implicit reasoning processes and the specific use of physical evidence found as marks in scenes of crime and recorded in accessible and organised databases. The use of shoemarks in linking burglaries committed by the same individuals is one example and demonstrates the need of combining evidence types which often belong to separate territories within forensic science for reasons of specialisation and loss of the perception of what forensic science should offer in terms of investigative power.

Meeting of the International Fingerprint Research Group (IFRG), Wiesbaden (14 – 17.08.2001)

Studies on the instrumental analysis of fingermark residue and on a standardised methodology for fingermark detection was presented by Jones [217, 218]. A new multispectral approach for the optical detection of fingermarks was proposed by Schwartz [219]. Several physical detection methods were presented : Brennan has shown the use of a polymer called Isomark, useful for the detection of the cyanoacrylate fumed fingermarks [220], Cantu has proposed several methods for the physical development of marks on dark or patterned backgrounds [221], and Ramotovski and Ruggiero have presented new investigations on powders [222, 223].

Hart has presented new chemical dyes for non-adhesive surfaces [224].]. The improvement of the DMAC reagent has been proposed by Azoury and Wiesner [225]. Several enhancement methods of the amino acids reagents have been proposed : an optimised formulation of indandiones by Hewlett [226], a dry application of 1,2-indandione by Meuwly [227], an improvement of the indandiones synthesis and production by Wiesner and Azoury [228] and the results of a Canadian field trial of DFO/indandiones by Wilkinson [229].

For the detection of the fingermarks in blood, Azoury and Wiesner propose a comparison for the sequence –LCV-Amido Black– [230]. Hilgert, [231] as Sears [232], have presented comprehensive studies about fingermark reagents in blood. Lenertz has proposed the results of an comparative study of reagents used for the detection of fingermarks on human skin [233].

Several studies on the detection of fingermarks on sticky surfaces have been presented : new reagents, the results of an attempt to find a detection sequence for the detection of marks on sticky surfaces by Anthonioz [234], a review of the techniques by Bandey [235] and the use of several powder suspensions, by Mevißen [236].

Several fingermark detection methods on miscellaneous surfaces have been proposed: on Semtex™ (explosive polymer) by Almog [237], the cyanoacrylate fuming technique of cocaine contaminated polyethylene-bags [238], on Molotov-cocktail by Limmer [239] and on passport foils by Nobel [240]. Wilkinson has presented the results of a comprehensive study for the recovery of fingerprints from chemically hazardous scenes [241]. Several studies on the compatibility of fingermark detection techniques with DNA typing techniques have been proposed : the DNA sequencing after fingerprint treatments and blood reagents by Barber [242], the recovery of mtDNA from partial, developed fingermarks by Ramotovski [243] and DNA typing after SPR and after the indandiones by Wiesner and Azoury [244]. Terry Kent has presented a tutorial on digital imaging of fingerprints [245].

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