Special Feature

Guidelines for the Assessment of Fingermark Detection Techniques

International Fingerprint Research Group (IFRG)

Scope & Purpose

The purpose of this document is to provide "best practice" guidelines for the evaluation of new or modified fingermark detection methods, from initial concept through to final casework implementation. These guidelines are not meant to be prescriptive; however, where research is conducted that is relevant to the scope of these guidelines, *it is expected that significant deviations will be clearly indicated and justified in any associated presentations and publications*.

This document has been prepared in consultation with members of the International Fingerprint Research Group (IFRG) and has been endorsed by the IFRG Steering Committee.

1 Introduction

A survey of presentations at recent meetings of the International Fingerprint Research Group (IFRG) and journal publications by fingermark research groups over the last 10 years has illustrated significant variability with respect to the evaluation protocols employed, including significant variability in the number and types of fingermarks collected for testing purposes. In order to strengthen fingermark research and ensure that proposed new methods can be readily adopted by other research groups and operational forensic laboratories, it is crucial that we standardise research and validation methods

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in a manner that reflects agreed minimum requirements. The aim is to promote rigorous and objective evaluations of fingermark detection methods, with such assessments performed and reported in a manner expected by the international fingerprint research community. Two recently published journal articles have brought this complex but necessary task to the attention of the global fingermark research community [1, 2] and much of the discussion in this paper takes a similar approach.

Four main research phases consistently appear throughout the literature. These phases provide a solid, overarching framework for discussing research methodology, as illustrated in Appendix I.

- **Phase 1** (*Pilot Studies*; Section 3) involves initial pilot or proof-of-concept investigations of novel fingermark detection methods (reagents or techniques) or major modifications to existing methods. These projects are often the domain of universities and dedicated government research facilities. Example of a Phase 1 publication: Jelly *et al.*, 2008 [3].
- **Phase 2** (*Optimisation & Comparison*; Section 4) is a more detailed investigation and evaluation of a method. The optimisation of relevant parameters is generally a first step in this phase. The relative performance of the new or modified method then needs to be compared to that of established operational techniques and the performance of the method across a number of variables (substrates, donors and aging periods, for example) assessed under reasonably controlled conditions. Consideration may also be given to how the new method performs in sequence with relevant routine detection techniques. Phase 2 projects may be undertaken by universities, government research facilities, or operational casework facilities. Example of a Phase 2 publication: Porpiglia *et al.*, 2012 [4].
- **Phase 3** (*Validation*; Section 5) studies are designed to introduce successfully optimised techniques to more realistic, pseudo-operational scenarios using simulated casework material. This phase is a rigorous evaluation of the performance of the new technique against current methods in order to assess suitability for potential operational use. The position of the new method in relevant detection sequences must also be thoroughly tested as part of the validation.

Phase 3 research may be done by universities or government research agencies but should at least be undertaken in close collaboration with an operational casework facility. Example of a Phase 3 publication: Downham *et al.*, 2012 [5].

- **Phase 4** (*Operational Evaluation & Casework Trials*; Section 6) focuses on eventual casework implementation via inclusion into standard operating procedures (SOPs). Phase 4 must be undertaken as a live casework trial by an operational facility intending to introduce the method. For accredited facilities, Phase 4 evaluations should be undertaken in a manner that will facilitate the subsequent formal method validation processes required to meet relevant international standards (e.g., ISO 17025). Examples of Phase 4 publications: Hewlett and Sears, 1999 [6]; Merrick *et al.*, 2002 [7].

Subject to acceptable performance, the progression of a new method from Phase 1 research to its inclusion in SOPs (Phase 4) is dependent on the resources available to both the research and operational laboratories concerned, but often occurs over a period of several years. Some proposed methods may not progress past Phase 1 if, for example, they are impractical, perform poorly compared to routine techniques, or have other deficiencies such as high cost or safety concerns. However, there may also be instances where a proposed method is unviable and cannot advance past Phase 1 until associated instrumentation improves. The equipment required may need to become more portable, more sensitive, less expensive and/or faster, for example, before a method can progress to Phase 2 and Phase 3 testing. An example of this is fingermark enhancement via mid-infrared chemical (hyperspectral) imaging [8].

The maturity of an evolving technology may also be assessed against a scale typically used by government agencies, such as the military, that is referred to as the *Technology Readiness Level* (TRL) [9]. This scale has been reinterpreted by the UK Centre for Applied Science & Technology (CAST) so that it can be applied to the evaluation and implementation of new or modified fingermark detection processes [10]. The CAST definitions for each TRL are provided in Appendix II. The relationship between the four research phases summarised above and the TRLs is indicated in Appendix I.

The requirements for designing a rigorous research methodology and the associated challenges faced differ for each evaluation phase. While large scale studies involving the sampling of multiple donors and substrates are suitable for Phase 2 and 3 research projects, the application of these sampling techniques for Phase 1 research can quickly transform the project into a cumbersome, potentially futile, data production exercise. Likewise, while standard solutions and synthetic secretions may give useful indications for the initial study and characterisation of interactions between fingermark deposits and a new reagent, their use is not appropriate in subsequent optimisation and validation trials.

Not all projects that produce promising results in Phase 1 will be suitable for casework validation in Phases 3 and 4 as Phase 2 results may indicate that there are no advantages – in terms of sensitivity, specificity, speed, cost-effectiveness, reduced toxicity, etc. – over existing methods. However, these projects are still crucial for the continual advancement of the fingermark detection discipline and the development of techniques that could substantially enhance the prospects of recovering usable fingermark evidence in casework. The vast body of research dedicated to the 1,2-indanedione/zinc chloride reagent (IND-Zn) is one of many examples of proper and collaborative implementation of the four research phases, resulting in an invaluable detection method that has improved operational success rates worldwide.

Publications reporting results from the assessment of fingermark detection methods need to disclose all relevant experimental parameters and any limitations that may restrict the conclusions that can be reached.

Researchers need to be aware of any local requirements regarding responsible research practices, including the potential need for obtaining human research ethics approval before collecting fingermark samples from volunteer donors.

2 Key Variables

2.1 General

Fingermark research groups and operational laboratories are encouraged to optimise and evaluate enhancement reagents under local conditions, using a variety of locally sourced test substrates and visualisation equipment. Despite the fact that research occurs in a global environment and typically in climate-controlled laboratories, fluctuations in laboratory temperature and humidity plus outdoor climate can have significant effects on fingermark aging and fingermark development processes. Added to this are variables such as substrate chemistry and the health, age and diet of the fingermark donors. Yet another layer of complexity is added when solution preparation, varying development conditions, and parameters associated with light sources and visualisation systems are considered.

While a summary of the more relevant variables is provided here, a number of journal articles are available that include more detailed discussions of the research parameters that need to be considered [1, 2, 11, 12].

2.2 Environmental Conditions

Anecdotal and peer reviewed evidence from forensic practitioners and academic researchers indicates that the performance of fingermark enhancement reagents can be affected by local climate. For example, 1,2-indanedione, ninhydrin and cyanoacrylate fuming are often reported as being highly effective methods for fingermark enhancement in temperate, subtropical and tropical coastal regions. However, in arid climates there is often a need for pre-treatments or adaptations to development procedures in order to achieve comparable results (e.g., rejuvenation/rehumidification of dried latent marks prior to cyanoacrylate fuming). Laboratory conditions during collection, storage and development of samples may also be a contributing factor that needs to be taken into account when interpreting the results obtained during the initial testing or later validation of new or modified fingermark detection techniques.

2.3 Fingermark Composition & Fingermark Age

The chemical composition of fingermarks will have a direct effect on development quality. Amino acid composition, for example, will impact on the results obtained with reagents such as ninhydrin, DFO or IND-Zn. Similarly, the amount of sebaceous material present will directly correlate with the inten-

sity of development obtained with lipid stains. When validating methods for casework use, it is important that the fingermarks collected for assessment are representative of those likely to be encountered operationally.

Fingermark composition will vary depending on factors such as the donors employed, substrate and environmental effects, and the amount of time between deposition and the application of a detection method. Operationally, it is unlikely that fingermark processing will be performed less than 24 hours after the incident under investigation has occurred. Therefore, as suggested by Kent [2], the aging of test fingermarks for 24 hours is a good starting point. Then, depending on the technique being evaluated, the substrate, and the evaluation phase, subsequent timescales may include 1 week, 1 month, 3 months and 6 months, for example, to assess changes in performance with increasing fingermark age. (Note that there may be specific circumstances, such as the detection of fingermarks on human skin or the covert detection of fresh fingermarks, where test impressions only a few hours old need to be employed.)

The choice of latent fingermark storage conditions, prior to treatment, also needs to be carefully considered and should take into account the particular detection method being evaluated and its proposed scope of application. For the proper evaluation of some processes, storage inside or outside and sheltered or exposed (to air currents, moisture or sunlight, for example) can be important experimental parameters. In all cases, the actual storage conditions employed should be recorded and reported appropriately.

2.4 Substrates

Due to differences in manufacturing processes, available raw materials and end-use, substrates within the same class may exhibit different physical and chemical properties, which may affect fingermark enhancement. For example, the texture of a substrate and the presence of electrostatic interactions are known to affect physical methods such as powdering. The presence of fillers and additives in recycled plastics and papers have also been observed to substantially affect the results obtained using physico-chemical methods such as vacuum metal deposition (VMD), multimetal deposition (MMD) and physical developer (PD). Furthermore, the pH of paper substrates (e.g., alkaline archival papers versus acidic non-archival papers) can affect the performance of amino acid reagents, with such reagents typically requiring a slightly acidic environment

(generally around pH 5) to react effectively with the fingermark deposit, while reaction products (e.g., Ruhemann's purple and Joullié's pink) tend to be more stable in slightly alkaline environments. Many of these factors are noted as incidental observations during research projects but are not completely understood. Therefore, performing optimisation experiments with locally sourced substrates is an essential part of the validation process.

2.5 Development & Visualisation Conditions

One of the major variables encountered in fingermark detection research is the equipment used for promoting detection reactions (e.g., heating or fuming system), and for visualising and recording developed fingermarks. Each jurisdiction may be using different equipment for these purposes due to budgetary restrictions or a preference for a particular manufacturer, supplier or user interface. However, the type of equipment and the conditions used for development and visualisation can be significant factors, for example:

- The use of a humidity-controlled oven or a direct contact heat press for developing marks on paper after treatment with IND-Zn or DFO. While DFO generally gives suitable development in both instances, IND-Zn tends to produce the best results using short, direct contact heating via a heat press.
- Performing cyanoacrylate treatment in a fuming cabinet with programmable humidity control compared to ambient humidity cabinets or improvised cabinets.
- The use of different light sources, filters and image capture systems. Each forensic light source on the market will have different wavelength bands and intensities depending on the technologies employed, the detection methods the light source was designed to be most compatible with, and the generation/model of the unit. The optical filters supplied with imaging systems, or purchased separately, will also differ in their wavelength cut-on/cut-off characteristics and filtering efficiencies.

Associated research reports must clearly state the equipment and conditions employed for the development and visualisation of treated fingermarks. In addition, it needs to be made clear if performance assessments have been conducted via:

- Visual examination of marks *in situ*;
- Visual examination of unprocessed images, such as live or captured images viewed on a monitor; and/or
- Visual examination of processed images, with details provided on the modifications/ enhancements applied and the justification for this processing.

2.6 Research Implications

The parameters discussed in section 2.5 are the main controllable variables encountered during fingermark enhancement research. However, the effect of variables such as donor habits and substrate properties can be mitigated by the use of a large population of representative samples in late-phase testing and validation. Variations in local climate can be accommodated through the recording of temperature and humidity data, which may be required for the subsequent interpretation and discussion of the experimental results. Due to the many factors that play a role, it is imperative that research groups and operational facilities perform independent Phase 2, 3 and 4 assessments of fingermark detection techniques to establish that the methods are genuinely fit-for-purpose within their own jurisdictions (under local conditions and using local equipment).

3 Phase 1: Pilot Studies

3.1 General

Phase 1 studies may involve an analogue of a current fingermark enhancement reagent, an alternative approach for the application of a current reagent, or a proposed novel technique (including novel imaging methods), for example. Sample collection parameters need to be carefully considered to ensure that the initial results accurately reflect the feasibility of the technique under investigation. In addition to the treatment of collected fingermarks, chemical spot tests may also be useful to determine which components of the latent fingermark are being targeted by the process under consideration. It is also recommended that Phase 1 studies include at least a preliminary comparison against

relevant routine detection methods; for example, the use of split marks may give an initial indication of relative performance.

Note that there is also research dedicated to using quantitative analytical techniques to study the composition and persistence of latent fingermark residues. While such research is not specifically covered by these guidelines, it is still critical that such studies are undertaken on the types of fingermarks likely to be encountered in actual casework. Experimental parameters as summarised below need to be carefully considered to ensure that the results reported from the study have operational relevance.

3.2 How Many Donors & Substrates?

Typically, proof-of-concept projects utilise a small pool of fingermark donors (three to five) and a small pool of common substrates with low background interference, unless the overall aim of the project is to develop a technique for difficult substrates such as a particular substrate that poses problems with routine detection methods. If promising results are obtained from the initial pilot studies, these pools are then increased in Phase 2 to encompass a wider range of variables (discussed further in section 4).

While focusing on a small number of donors and substrates is not representative of reality, it can provide a reasonable starting point to assess the potential of a novel technique without resorting to cumbersome, possibly expensive, data collection experiments that are better reserved for optimisation (Phase 2) and validation (Phase 3) trials. The main concern regarding donor numbers in proof-of-concept research stems from the occasional study using fresh fingermarks from only one or two donors and naively overemphasizing the outcomes of the project. *The results of these projects should be carefully considered within the scope and aims of the research program; the conclusion from a successful pilot study should be that the method is worth further investigation, rather than it being a definite solution to a problem. Reviewers should be critical of research manuscripts where there are overstated conclusions from limited data (e.g., Phase 1 results reported as if Phase 3 studies had already been completed).*

It is strongly recommended that Phase 1 projects directed at latent fingermarks employ at least 3 donors to ensure that some degree of donor variability can be assessed (e.g., use of a good, an average, and a poor fingermark donor based on results from routine detection methods). Results obtained from only one

donor may not give a realistic indication of a method's general performance. Clearly, if the study is focussed on contaminants such as blood, rather than on natural skin secretions, then one fingermark donor may be sufficient.

Similarly, the testing of only freshly deposited fingermarks may give misleading results. The test impressions should be left to "age" for a minimum of 24 hours prior to development, unless there are particular circumstances that dictate otherwise, and the actual age prior to treatment should be recorded and reported. Consideration should be given to testing a range of fingermark ages, such as 1 day, 1 week and 1 month.

3.3 Collection of Fingermarks

The collection of fingermark samples for Phase 1 studies generally requires clear descriptive donor instructions (e.g., "touch the substrate with the same pressure you would use to pick up an object") or assisted deposition in order to ensure that there is some consistency across the sample set. However, provided that the deposition pressure is not so extreme that there is either insufficient contact with the substrate or significant ridge distortion (including complete ridge obliteration with excessive pressure), natural variation between samples is not a major issue.

However, maintaining deposition consistency across samples can be a crucial issue for some specialist studies; for example, studying detection techniques that exhibit reverse development under certain deposition conditions or analytical projects focused on studying latent fingermark residue composition. Parameters such as deposition force and contact time may need to be accurately controlled in such studies. The use of analytical balances or force gauges to standardise deposition force, for example, has become common practice for analytical projects to ensure that any inter-sample variation is due to the chemical composition of the donors' secretions rather than differences in deposition conditions.

3.4 Natural vs. Groomed Fingermarks & Standards

The use of groomed or charged fingermarks remains the most contested aspect of latent fingermark enhancement research. The body of research recently published by Croxton *et al*. indicated that the increase in sebaceous content caused by grooming was highly donor dependent, with some donors exhibiting a ten-fold increase in sebaceous content compared to natural marks and

others demonstrating no significant increase in lipid content [13]. Consequently, the use of groomed fingermarks (particularly heavy sebaceous impressions) needs to be carefully considered before embarking on the evaluation of a new or modified detection method. It should be understood that deliberately touching the nose, face or hair immediately before depositing fingermarks will normally result in a fingermark with a totally different chemical composition to average uncharged fingermarks.

It is preferable to use ungroomed, "natural" marks as a method of studying and validating new fingermark detection methods. Such marks are more likely to mimic operational samples. Research groups new to fingermark enhancement research typically focus on groomed fingermarks as an initial starting point for their research with the theory being that a groomed mark is more likely to yield a positive result. However, this assumption does not always hold true. Very heavy, groomed fingermarks may actually give poor results using some techniques, typically due to overdevelopment and loss of ridge detail. As an example, physical developer (PD) is generally ineffective on fresh, heavily sebaceous marks on paper, but is an extremely sensitive method for weaker, aged impressions. Similarly, vacuum metal deposition (VMD) may not develop useful ridge detail for heavy fingermark deposits on plastic substrates. Very "sweaty" (high eccrine content) fingermarks generally suffer from a loss of ridge detail when developed with amino acid reagents such as DFO or IND-Zn. The skewed results that may be observed with some techniques when only very strong impressions are evaluated can be avoided by the use of a depletion series of fingermarks (see section 4.3), which provides a range of fingermarks from strong to weak.

It is acknowledged that the extreme climates experienced in some countries (e.g., very cold and dry conditions) may increase the need to employ some form of grooming in order to obtain results. However, the exclusive use of groomed marks needs to be justified and care exercised in terms of any conclusions drawn. Results from such studies may not be reproducible when the detection method being evaluated is applied to natural (uncharged) fingermarks.

Although amino acid solutions and synthetic eccrine perspiration can and have been used successfully as analytical standards for a variety of quality control and reaction elucidation studies [4, 14, 15], other components within latent fingermarks may affect reagent performance in a way that is not witnessed

with pure standards. For instance, during initial research into the use of aptamers as a fingermark enhancement reagent, it was observed that pure amino acid standards and eccrine groomed marks produced visible ridge detail with the reagent, while natural fingermarks failed to show any development [16]. Furthermore, as outlined by Kent [2], commercially available synthetic sebaceous materials and lipid standards do not behave in the same manner as sebaceous fingermark components so caution must be exercised if these are employed for evaluation purposes. In a recent study, Zadnik *et al.* [17] observed significant differences between commercial simulants and latent fingermarks in their response to a number of common fingermark development reagents.

It is acceptable to use a combination of standards, groomed marks and natural marks *provided that initial conclusions concerning reagent performance and sensitivity are drawn – where possible – from natural fingermark sets, not from groomed samples or standard solutions.*

Where relevant, negative controls should also be performed to ensure that the observed development is not due to unanticipated effects from "non-active" components of the new reagent or due to other phenomena such as thermal decomposition of the latent residue when heat treatment is employed. This can be done, for example, by applying the new development process to fingermark samples but with the exclusion of the presumed "active" component.

Pre-collection hand-washing procedures are another source of potentially misleading results. The effects of exogenous compounds such as liquid hand soap on latent fingermark luminescence and reactivity are anecdotes that are familiar to members of the fingerprint research community. A recent study involving the *in situ* growth of colloidal gold on fingermarks [18, 19], discussed at the 2011 IFRG meeting, also highlighted potential interference by solvents used to clean the donor's fingertips of skin materials, excess lipids and contaminants prior to fingermark collection.

While donor hand-washing procedures may be employed for both reagent assessment and quantitative studies of fingermark components, *if there is the potential for the wash procedure to interfere with fingermark enhancement then the collection of additional sets of samples from the unwashed hands of donors should be considered.* This would allow the researchers to eliminate any cross-reactivity between the enhancement technique and

any exogenous compounds introduced by the washing procedure. This is particularly important for physical and physico-chemical methods that are not designed to target a specific fingermark component (or class of compounds).

3.5 Reporting Phase 1 Results

As Phase 1 studies are designed to show the *potential* for a new or modified method to be useful for fingermark detection and to justify further research, a quantitative scale for assessing performance as a function of fingermark development quality may not be necessary for reporting the results. If researchers wish to use a quantitative assessment criterion, an absolute scale such as those developed and reported by researchers at the Centre for Applied Science & Technology (CAST) [1, 20, 21] and the University of Lausanne (UNIL) [22] is recommended (Appendix III).

Care needs to be taken when publishing the results from pilot studies. As the reagent has yet to be fully validated, reports from Phase 1 projects need to clearly indicate limitations such as the use of a small number of donors or test substrates, or if the method was tested exclusively on fresh or heavy fingermark deposits. Such reports should also acknowledge the need for optimisation and validation (i.e., Phase 2 and Phase 3 studies) before the new method can be proposed for casework use.

3.6 Guidelines for Phase 1 Projects

While not being prescriptive, the following is a general guide for designing pilot studies aimed at an initial assessment of a novel fingermark enhancement method:

- 3–5 donors (preferably representing weak, medium and strong fingermark donors);
- 1–3 clean, low interference substrates (unless a technique is being proposed for specific, difficult substrates);
- Donors briefed on how to deposit fingermarks, with assistance provided as required;
- Natural marks preferred, with groomed marks avoided where possible;
- Fingermarks should normally be allowed to "age" for a minimum of 24 hours prior to development and the actual age prior to treatment should be recorded and reported;

The study should include at least a preliminary performance comparison against relevant routine detection methods (for example, the treatment of split marks can be used to provide an initial indication of relative performance);

Qualitative or holistic scales should be employed for assessing the quality of fingermark development; and

Reports must clearly indicate limitations and conclusions must be conservative.

4 Phase 2: Optimisation & Comparison

4.1 General

Once a novel reagent or technique has been deemed of interest as a result of Phase 1 research, it should be further scrutinised and optimised under a variety of experimental conditions. The objectives of Phase 2 research are three-fold:

- To determine the best reagent formulation, development conditions, and observation parameters;
- To rigorously assess the robustness, sensitivity and selectivity of the new reagent compared to existing techniques; and
- To give some consideration as to how the new reagent performs when incorporated into existing enhancement sequences.

It is important to assess the *sensitivity* of a new method in comparison with existing techniques (i.e., the capacity to develop weaker fingermarks), and also *selectivity* in terms of the method's ability to target components of the latent fingermark, or specific contaminants such as blood, rather than the substrate (or inversely), so that adequate ridge contrast can be obtained.

The value of a new method when used in a detection sequence is an important consideration in all Phase 2, 3 and 4 projects. For example, a new method considered in isolation may be discarded if it is shown that, side-by-side with an established method, it exhibits reduced sensitivity and/or selectivity. However, the method has value if it can develop additional fingermarks when used in a sequence with established methods. Similarly, the best single development method may not necessarily form part of the best detection sequence. *Complementarity* and *compatibility* with other methods can therefore be critical components of the assessment process.

There are other considerations that may be relevant for Phase 2 assessments, including cost-effectiveness, practicality (e.g., ease of application for crime scene methods) and occupational health and safety (OH&S).

4.2 Substrate & Donor Pools

In order to perform a meaningful and comprehensive evaluation of a potential fingermark enhancement method, a greater number of parameters need to be considered. A pool of 5 to 15 donors – representing a variety of donor types (from poor to good) – is commonly used for Phase 2 evaluations, with the actual number of donors depending on the scope of the project. The donor pool needs to be representative of a range of donor types (i.e., good, average and poor fingermark donors). If the method being proposed is targeting contaminants such as blood rather than a latent fingermark component, then one fingermark donor may be sufficient.

The selection of substrates for optimisation and evaluation experiments should reflect a manageable set of commonly encountered surfaces relevant to the proposed application of the method. For Phase 2 research, the use of newly purchased or cleaned substrates is commonplace to control for variables such as substrate degradation (due to aging or weathering effects) or surface contamination (e.g., dust accumulation). Evaluation studies often start to include difficult substrates not tested in preliminary experiments, such as those that exhibit background interference.

It is acknowledged that, depending on the method being evaluated, the focus of the evaluation may be on donor variability across a reduced number of substrates. On the other hand, the focus may be on performance across a wide range of substrates using a reduced number of donors.

Anomalous results from particular substrates may need to be further investigated. This may require an analysis of the substrates concerned to determine what surface characteristics are playing a role with respect to fingermark detection using the proposed new method.

4.3 Fingermark Collection Procedures

As the purpose of Phase 2 research is to determine the suitability of a new or modified fingermark detection technique for further validation and eventual inclusion in SOPs, this evaluation stage should focus on the testing of natural marks (unless

the use of groomed marks is unavoidable for reasons discussed in section 3.4). There is a risk that groomed fingermarks may introduce unnaturally high levels of target components (or interfering components) for some reagents, resulting in inaccurate comparative performance against current techniques and/or optimisation of the new technique to the best-case scenario rather than the median or more typical scenario.

At this point in the development of a new technique, there needs to be a compromise between the reproducibility of fingermark deposition procedures or sampling, and producing a more accurate representation of the range of fingermarks encountered in actual casework. In this instance, no quantitative collection measures are necessary; however, providing clear instructions to the donor is a suitable means of ensuring relatively consistent deposition between donors and within fingermark sets for individual donors.

Split fingermarks are an essential tool for optimising formulations and development conditions, and for accurately comparing a new detection technique with existing techniques. Any comparative assessment should ideally be performed on two equal halves of the same fingermark impression taken from the same donor, which eliminates intra-donor variability as a source of perceived difference between two development techniques. For some substrates, such as paper and aluminium foil, the preparation of split fingermarks is quite simple and the marks can be divided using a scalpel or scissors prior to development. Difficult to bisect substrates such as glass, ceramics and laminates can still be used for split-mark studies by placing two pieces of substrate side-by-side and instructing the donor to place their finger in such a way that it is bisected by the join between the two substrates.

The use of fingermark depletion series – sequential impressions from the same finger to produce increasingly weaker marks – is highly recommended for assessing sensitivity and can be examined as whole or split impressions. Some reagents may perform similarly on strong fingermarks but have vastly different limits of detection (LOD), which may be the limiting factor in deciding whether a novel method is suitable for further trials or casework implementation. Conversely, some reagents may perform poorly on very strong marks, due to saturation of the deposit, physico-chemical factors limiting development or luminescence quenching, but exceed the performance of current techniques on weak samples.

Collected fingermarks should be aged over realistic timeframes given that, operationally, it is rare that the fingermarks of interest were freshly deposited. The age brackets considered will depend on the methods and scenarios being investigated; for example, very short timeframes would be used for fingermarks on skin whereas an assessment of amino acid reagents on paper would require older marks. Age categories for relatively "fresh" fingermarks would include 1 day and 1 week. On the other hand, "aged" fingermarks would include 1 month, 3 months, 6 months, etc. The storage conditions for the aging process must be recorded.

Standard solutions may be useful for determining a quantitative LOD or sensitivity measure, but this approach is generally limited to eccrine marks and may not provide a comprehensive sensitivity measure due to the lack of matrix effects that may exist between the target components and the other natural secretions in the fingermark deposits. Synthetic sebaceous standards are of limited value in these studies as natural sebaceous secretions do not behave in the same manner as in-house or commercially available simulants [2].

4.4 Assessing & Reporting Results

There is no best scoring system for the assessment of the results from Phase 2 projects; the three basic scoring systems (CAST, UNIL and University of Canberra (UC)) [1, 20, 21, 22, 23], summarised in Appendix III, each have different purposes, strengths and weaknesses. For example, the UC scale was developed as a means of directly comparing two halves of a split impression, with the experimental technique being given a score based on the quality of development (ridge detail and/or contrast) relative to the control method [23]. However, the two absolute scales – CAST and UNIL – provide a means of assessing the overall performance of a technique across a multitude of different samples. While the CAST scale focuses on the surface area of developed ridge detail relative to a full fingermark, the UNIL scale focuses on the clarity of level 2 ridge detail.

The particular scoring method chosen will be dependent on the aims of the research project and must be fit-for-purpose. As an illustration of this, the UC scale should only be used in conjunction with split marks as too many variables are introduced in comparisons across different impressions. In some instances, the assessment scheme may need to be tailored to the specific focus of the project, or two assessment methods may need to be used in tandem to best represent the results. For

example, differentiation between uniformly poor development, no development or equally good development using the comparative UC scale can be achieved by the addition of an absolute score for each half-impression.

Comparison of a new technique against an existing method should be done with a reasonable number of repeats to account for natural variations, with split-mark development performed on alternating sides of the mark to remove any pressure bias during deposition as some donors will favour one side of the fingers or hand over the other. In addition, the geometry of the imaging system, particularly the positioning of the light source, can favour one side over the other. Basic statistical analyses can also be used to process the scores obtained using the chosen assessment system; however, if the standard deviations are large, caution must be exercised when drawing conclusions from the data. Advice from a statistician may be required in terms of determining an acceptable number of repeats and how the data should be treated and interpreted.

4.5 Guidelines for Phase 2 Projects

Generally, the key experimental design aspects to consider when optimising a new fingermark enhancement technique and investigating its suitability for further consideration include:

- 5–15 donors (preferably displaying different concentrations of fingermark secretions via the use of depletion sets);
- ≥ 3 typical substrates of varying difficulty or background interference;
- Donors briefed on how to deposit fingermarks, with assistance provided as required;
- Natural fingermarks only (unless extreme climatic conditions or the particular focus of the research dictates otherwise);
- Fingermarks collected and stored for a reasonable selection of time periods, depending on the project length and the method/scenario being considered; and
- Quantitative absolute and/or comparative assessment scale(s) employed for assessing the quality of fingermark development.

5 Phase 3: Validation via Pseudo-operational Trials

5.1 Designing Statistically Significant Donor & Substrate Sets

Designing a Phase 3 validation project requires substantial planning, and close collaboration between research institutions and operational laboratories if the work is being performed by academic researchers, to ensure that the validation trials are operationally relevant. As previously mentioned, these studies should ideally be performed on a jurisdictional or national basis to account for differences in climate, substrate properties and laboratory equipment that may influence the performance of the fingermark detection technique under investigation.

Pseudo-operational evaluations should involve a large, statistically significant donor set to cover as many donor types as possible to represent the range of fingermarks likely to be encountered in casework. Most published Phase 3 studies have used donor pools consisting of at least 20 individuals, either known volunteers or anonymous donors depending on how fingermark samples are sourced. In order to obtain relevant results, the substrates chosen for these studies should be representative of common casework examples. As the technique under investigation has been optimised in previous research phases, the donor and substrate variables can be increased without producing an insurmountable number of samples. The ultimate aim of these studies is to determine whether the method performs consistently across all targeted donor types and in the situations most likely to be encountered when it is integrated into casework. The performance of the new or modified process, *as a single detection method and in sequence with other methods*, is compared to the performance of current techniques and sequences.

Note that, for some projects, it may be important to consider a significant number of different substrates (e.g., different types of paper or plastics). In such instances, to keep the study manageable, a smaller number of fingermark donors may need to be considered.

5.2 Fingermark Collection Procedures

Natural fingermark samples, collected with minimal interference from the researchers, are essential for pseudo-operational trials; grooming or pre-collection washing procedures should be avoided. The resultant sample set should be representative of the various scenarios in which fingermarks can be deposited and the natural variation in latent fingermark quality

observed across donors. Blind studies can also be implemented in Phase 3 research prior to casework trials (Phase 4) to assess the ability of the technique to perform on unknown samples with no initial input from the researchers during the collection stage. This can be done through the collection of discarded items or with volunteer donors providing samples on unmarked substrates in the absence of the evaluation team. With the former method, the donors and the handling history are unknown, which is not the case with the latter method. De-identified university examination booklets that have surpassed their retention window, typically once students have graduated, are also a popular method for obtaining pseudo-operational samples on paper substrates. Given that it is unknown what fingermarks may be present on randomly collected items, a sufficient number must be processed to ensure that the results are statistically significant. What constitutes a "sufficient number" needs to be considered on a case-by-case basis and advice from a statistician may be required. As an example, studies of this type have typically involved the processing of 100+ items per method or sequence being considered.

5.3 Assessing & Reporting Results

The assessment of development results during Phase 3 evaluations is limited to the use of absolute scales (e.g., CAST grading scheme or similar) due to the nature of the samples collected. In these instances, comparative scales are not useful as performance is measured based on the overall quality and number of potentially identifiable marks developed on different substrates that have typically been collected in an uncontrolled manner, rather than split marks collected under controlled conditions. The reporting of assessment scores may need to be modified, either by combining score brackets or adapting score definitions. As an alternative to the use of a grading scale, a threshold can be set for the counting of marks. This threshold could be based on the surface area of continuous ridge detail developed (see, for example, Downham *et al.*, 2012 [5]) or on the number of minutiae visible in the developed mark (see, for example, Hewlett and Sears, 1999 [6]).

The involvement of fingerprint identification practitioners in the assessment of developed fingermark quality and the potential for identification is strongly recommended in these studies. Highly visible fingermarks are of no use if the development quality is inadequate for identification (e.g., highly diffused ridge detail). Conversely, some fingermarks that are suitable

for identification purposes may be ranked as poor quality by researchers who do not have expertise in fingerprint identification. As such, a fingerprint identification expert should be involved in the assessment or should, at the very least, check a subset of the assessments to "calibrate" the process.

5.4 Guidelines for Phase 3 Projects

In order to properly assess and validate the performance of a fingermark enhancement technique, the following experimental parameters should be considered:

- ≥ 20 donors, preferably randomly selected from the population (e.g., via the processing of anonymous, randomly handled objects);
- Several substrates that are representative of common operational samples (actual number will depend on the scope of the project and the technique being evaluated);
- Natural fingermarks collected in a blind manner;
- Samples aged for a variety of time periods representative of casework scenarios;
- The use of an absolute assessment scale for assessing the quality of fingermark development (with practitioners involved in this process if possible); and
- New technique assessed in terms of both *individual performance* and *performance in a sequence with relevant established methods*.

For some Phase 3 and Phase 4 studies, the compatibility of a novel method with other forensic processes – such as document examination and DNA profiling – may also need to be considered.

6 Phase 4: Operational Evaluation & Casework Trials

If the Phase 3 pseudo-operational trials yield promising results, the final phase of fingermark enhancement research involves an evaluation of the method under operational conditions on casework items. This typically involves an initial evaluation followed by extensive casework trials. Phase 4 projects utilise the optimised formulations and development techniques from Phases 2 and 3 and, for operational laboratories involved in these earlier phases, is often a continuation of, or integrated with,

Phase 3. This final assessment phase is essential for determining whether a new technique is truly fit-for-purpose when applied to actual casework samples under casework conditions, and is therefore suitable for integration into the laboratory SOPs. For accredited facilities, Phase 4 evaluations should be performed and documented in a manner that will facilitate the more formal validation processes required to satisfy relevant international standards (e.g., ISO 17025). Careful planning is required to successfully undertake and complete such trials.

A typical Phase 4 project includes the assessment of a new technique across a large number of cases – and possibly across a large number of laboratories in the case of national agencies or geographically broad jurisdictions – during a designated trial period. During this period, the performance of the new technique is compared to the performance of current methods. For studies undertaken across multiple locations, the ambient laboratory conditions can differ significantly and may impact on the results. Where this may be an issue, it is recommended that the temperature and humidity in each laboratory and storage conditions be recorded. If field-based methods are being evaluated, environmental conditions should be recorded to determine if these may be impacting on the results achieved. This information can be invaluable for assessing and documenting the robustness of a new technique.

The comparison and assessment of each technique should be measured by the participating practitioners based on the average number of useable fingermarks developed on each exhibit by each technique. If the techniques are part of a sequence, the number of useable marks developed by the experimental method can be reported as a percentage of the total number of marks developed by the sequence. An absolute scoring system may also be implemented as an indicator of overall fingermark quality but is not a requirement at this stage of the research.

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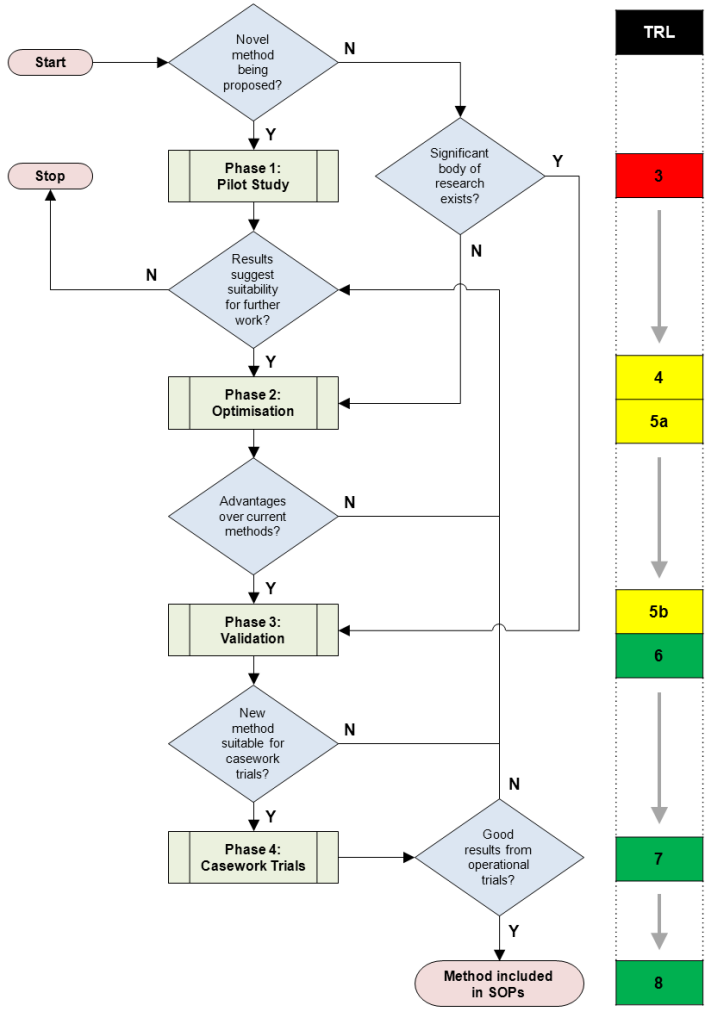
Appendix I

Flow chart depicting the evaluation phases for a new or modified fingermark detection method, with an indication of how these phases relate to Technology Readiness Levels (TRLs).



Appendix II

Technology Readiness Levels (TRLs) with definitions in the context of proposed new fingermark detection methods. Source: Centre for Applied Science & Technology [10].

Technology Readiness Level (TRL)	Fingermark Detection Context
1	Published papers reporting synthesis of new chemicals, or reporting principles of a novel optical technique, etc.
2	Published papers or other references reporting reactions of chemicals that are relevant to the environment of a fingermark, or physical interactions of optical techniques with surfaces.
3	Chemical spot tests using the process on individual fingermark constituents or on single marks to demonstrate feasibility, or trials to establish that the optical technique is applicable to the constituents within a fingermark.
4	Chemical formulation and/or process optimisation using real fingermarks, or trials to establish optimum optical environment for fingermark visualisation.
5	Extensive laboratory trials using the process on samples covering a range of donors, substrates, ages of mark. Testing in this phase may be conducted for several reasons and therefore experiments may vary according to end purpose. Information required at this TRL may include: • Whether the process detects fingermarks not found by other processes; • Whether the process is the single most effective process for a particular set of circumstances; • Whether the process can be used in a sequence and if so how it impacts on other fingermark and forensic recovery processes.
6	Pseudo-operational trials using marks on realistically handled, operationally representative items and surfaces.
7	Operational trials on items and surfaces encountered in live casework.
8	Publication of results obtained from tests covering TRL3–7 and issue of processing instructions. Inclusion in processing manuals (SOPs).
9	Provision of supporting data for process in operational use obtained by monitoring performance over several years.

Appendix III

Examples of Absolute Scales

CAST (Centre for Applied Science & Technology) grading scheme for the assessment of developed fingermarks [20].

Grade	Detail Visualised
0	No evidence of a fingermark
1	Some evidence of a fingermark
2	Less than 1/3 clear ridge detail
3	Between 1/3 and 2/3 clear ridge detail
4	Over 2/3 clear ridge detail

Note that the CAST grading scheme is intended to be adaptable depending on the focus of the associated study. To demonstrate this point, a modified version is provided below [21].

Grade	Detail Visualised
0	No development
1	Signs of contact but < 1/3 of mark with continuous ridges
2	1/3–2/3 of mark with continuous ridges
3	> 2/3 of mark with continuous ridges, but not quite a perfect mark
4	Full development – whole mark clear with continuous ridges

UNIL (University of Lausanne) assessment scale for reagent performance [22].

Symbol	Definition
+	Clearly visible ridges with sufficient quality to see minutiae
±	Ridges that are slightly visible but not sufficient to perform an analysis in terms of minutiae positioning
–	No visible reaction between the reagent and the ridges

Example of a Comparative Scale

UC (University of Canberra) comparative scale used to assess the relative performance of two detection methods A and B applied to split impressions [23].

Score	Definition
+2	Half-impression developed by method A exhibits far greater ridge detail and/or contrast than the corresponding half-impression developed by method B
+1	Half-impression developed by method A exhibits slightly greater ridge detail and/or contrast than the corresponding half-impression developed by method B
0	No significant difference between the corresponding half-impressions
–1	Half-impression developed by method B exhibits slightly greater ridge detail and/or contrast than the corresponding half-impression developed by method A
–2	Half-impression developed by method B exhibits far greater ridge detail and/or contrast than the corresponding half-impression developed by method A