Fingermark quality assessment, a transversal study of subjective quality scales

Teneil Hanna, Scott Chadwick, Sébastien Moret

PII: S0379-0738(23)00233-5

DOI: https://doi.org/10.1016/j.forsciint.2023.111783

Reference: FSI111783

To appear in: *Forensic Science International*

Received date: 5 April 2023
Revised date: 24 June 2023
Accepted date: 2 July 2023

Please cite this article as: Teneil Hanna, Scott Chadwick and Sébastien Moret, Fingermark quality assessment, a transversal study of subjective quality scales, *Forensic Science International,* (2023) doi:https://doi.org/10.1016/j.forsciint.2023.111783

Fingermark quality assessment, a transversal study of subjective quality scales

Authors: Teneil Hanna [1], Scott Chadwick [1], Sébastien Moret [1,2]

Institution:

[1] Centre for Forensic Science, University of Technology Sydney, 15 Broadway, Ultimo NSW 2007, Australia

[2] School of Human Sciences, College of Science and Engineering, University of Derby, United Kingdom

Corresponding author: Teneil Hanna

University of Technology Sydney, 15 Broadway, Ultimo NSW 2007, Australia

Email: teneil.hanna@uts.edu.au

Abstract

Fingermark detection research aims to improve the quantity and quality of fingermarks detected through the development of novel techniques. Subsequently, there is a need to evaluate these methods to determine the quality of the developed mark. Since the 1980's there has been a significant number of publications, which utilise a variety of different quality assessment methods. The introduction of common practice methods from the International Fingerprint Research Group (IFRG) aimed to implement a more standardised approach. Although these schemes are recommended as common practice, they are only guidelines. Consequentially, there is currently no universally accepted method to evaluate the enhancement techniques implemented in research. Therefore, this study aimed to collate and analyse the published protocols being used within fingermark detection research in order to better understand their application and how research is currently analysing and interpreting fingermark quality.

This study comprised of manual and automatic searches of over 2000 published papers within the fingermark detection area. After a thorough analysis of the articles, 398 published papers were found to have used a scale within the years spanning 1998 to 2022. The number of publications that report the use of a scale to assess quality for fingermark detection research has considerably increased over the last decade. However, whilst the number of publications utilising scales has increased, it is not proportional to the number of papers using the IFRG scales. The choice of scale is often institution specific and even more specific to their location. There are also numerous different adaptations of the IFRG recommended scales, as well as novel scales, which do not associate with the IFRG recommended versions being introduced the more research continues to grow. One such reason for this is investigated here, as different quality parameters are utilised within each individual scale. There is underrepresentation of these quality parameters within some of the IFRG scales, in particular the Centre for Applied Science and Technology (CAST) scale. This correlates to the considerable number of tailored approaches as authors are forced to add these parameters within the descriptions. Until there is an introduction of clear guidelines surrounding all areas of fingermark quality, from definition to parameters chosen within phases, the research area will continue to face such issues. This article recommends areas of potential study, whilst also recommending procedures that may be employed to alleviate some of the issues seen with fingermark quality evaluation.

Keywords:

Subjective Scales; Fingermark analysis; Quality metrics; International Fingerprint Research Group (IFRG)

Funding:

This research is supported by an Australian Government Research Training Program Scholarship.

1. Introduction

Fingermarks are one of the most extensively utilised traces within casework [1]. Analysis of this trace is divided into two distinct but complementary fields: (i) fingermark detection, which focusses on improvement the quality of developed marks and (ii) comparison and identification, which focusses on comparing fingermarks recovered as part of an investigation to a known suspect or exemplar in casework [2-6]. Research in fingermark detection is an active counterpart to comparison and identification methods. However, research focuses on developing novel techniques or advancing current fingermark detection methods that are applied prior to the eventual use of fingermarks in comparison and identification. Whilst some level of comparison analysis may be done within this detection area, the focus is primarily on increasing the number of successful good quality fingermarks produced. The current research methods thus utilise a wide variety of techniques and methods in order to achieve this end goal. However, the original application and investigation of these methods was often inconsistent across studies [7, 8]. In order to address this, the International Fingerprint Research Group (IFRG) [2] released guidelines in 2014, which aimed to recommend procedures to standardise the experimental design for fingermark research. This created a more streamlined process for design of a new detection technique through first concept to casework implementation. Although this may be considered common practice, they are only guidelines and often authors will tailor these methods for their studies purpose. This is specifically true when considering the methods used to evaluate the fingermarks are not widely accepted and broadly adopted.

Fingermark quality assessments are commonly implemented in two broad categories of subjective (typically is completed by a person that gives an estimate of quality from provided criteria) and objective evaluation (performed using an algorithm that provides quantitative data). The most common approaches are often subjective and are utilised due to their widespread application and easy availability. Subjective assessments are inherently subjective and often involve a significant level of criticism surrounding their reliability [8, 9]. This is often because they are poorly accepted, proficiency levels for using them are undefined and it is unknown if they allow repeatability or cross-comparison between studies [8]. Objective assessments were introduced to minimise these disadvantages, but their application is often thought of as support tools or are utilised alongside subjective measurements [10, 11]. These methods also have their own weaknesses with reliance on software, narrow-metrics that have difficulties assessing a fingermark as a whole and still involve a level of subjectivity [8]. As such, subjective means are still one of the most favoured mechanisms to assess the fingermarks produced in research.

In early subjective assessments, fingermarks were often classified as operationally useful or useless [12]. These definitions were eventually created into descriptive numerical representations that used specific descriptions to indicate the ‘usefulness’ of a fingermark [13]. The first formal introduction of a scale came from the New Scotland Yard (NSY) or Godsell scale [3, 14]. However, the scale descriptions used in the original ‘1 to 6’ scale are not officially published outside of internal reports. The Home Office Internal Police Scientific Development Branch (PSDB) was the next institution to introduce a scale in the early 1980’s. There was evolution of scales within this time frame but record

of such is less detailed and likely part of internal Home Office reports. Some scales can be found through memorandums, with non-numeric versions [15] and throughout 1975 to 1976 different variants of the 1 to 6 scale [16, 17]. This is where grading schemes significantly evolved and became more than just counts of number of marks developed.

Past the 1980s scales have continued to develop and are now more routinely used within research. These scales have become more specialised, having specific roles to determine different levels of quality or even compare marks against each other. These include those recommended within the IFRG [2]. The first being the Centre for Applied Science and Technology (CAST) scale [18] (**Table 1**) that focuses on the areas of developed ridge detail in a whole fingermark. Similarly, the University of Lausanne (UNIL) [19] (**Table 2**) introduced a whole fingermark scale that focuses on the clarity of level 2 ridge details. A comparative scheme by the University of Canberra (UC) [20] (**Table 3**) is also indicated, which alternatively uses half-marks to compare techniques directly against each other. Despite this, since the 1980's there has been a significant number of publications, which utilise a variety of different quality assessment methods. Consequentially, there is currently no universally accepted method to evaluate the enhancement techniques implemented in research.

Table 1: *CAST absolute grading scheme for the assessment of developed fingermarks [18]*

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

Table 2: *UNIL assessment for reagent performance [19, 21]*

Grade	Definition
0	No ridge, no fingermark visible
1	Ridges are visible over a small area (or over the whole mark), but it is extremely difficult to retrieve Level 2 characteristics (such as minutiae) because of extremely poor ridge details.
2	Ridges are visible on almost the whole mark; Level 2 characteristics can be retrieved. Nevertheless, the quality is not optimal because of a low contrast, strong background staining, or faint ridges.
3	Ridges are very well defined on the whole mark. Level 2 characteristics can easily be retrieved. The contrast is optimal with no (or extremely faint) background staining

Table 3: *UC comparative scale used to assess the relative performance of two detection methods [20]*

Grade	Definition
+2	Half-impression developed by method A exhibits far greater ridge detail and/or contrast than method B
+1	Half-impression developed by method A exhibits slightly greater ridge detail and/or contrast than method B

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

Creating a consistent grading method that relates to a universal and refined definition of fingermark quality would allow for a more streamlined process and easier cross-collaboration. However, there are numerous current methods of fingermark quality analysis that one singular definition cannot be established. In particular, no one 'best fit' scale can be recommended as each study, institution and even country utilise a wide variety of scales to represent a fingermarks quality. Therefore, this study aims to investigate the current published protocols being used within fingermark detection research to better understand the application of these quality grading methods. This will in turn allow for a better understanding of how quality can and is being assessed. This systematic critical review will identify and present literature on subjective fingermark quality assessment methods in research. The objective is to summarise existing research on fingermark assessment methods whilst critically analysing their uses and trends, as well as proposing different perspectives on the positive and negatives associated with these approaches. This study will not recommend a universally accepted method, but rather give an insight into the current approaches used.

2. Review Methods

2.1 Search Strategy

The search strategy comprised of an automatic and manual search as visualised in **Figure 1**. General keywords derived from known terminology under fingermark quality were utilised in different publisher databases. These identified relevant papers based on study titles and abstracts. All possible permutations of fingermark quality assessment were utilised in this search, including, "grading", "scoring", "scale/s", and the titles of commonly found scales within research such as "CAST", "UC" and "UNIL" (both their abbreviation and unabbreviated names). Once the primary data was obtained, the data analysis phase of the papers and consideration of their relevance began. EndNote X9 was used to store all relevant research articles for referencing purposes. This also allowed removal of duplicates.

A manual search was also conducted using the referencing within Interpol reports [22-29]. Interpol reports are an extensive collection of published papers performed every three years and providing an overview on a various number of topics within fingerprint and fingermark detection. The references in these reports were imported and extracted for manual search, otherwise known as snowballing, which is an iterative process in which references of references identify further literature in order to extract more relevant studies.

2.2 Selection Process

1280 research studies were found in the automatic and manual search. Initial keyword searches found 632 research articles, which either inferred analysis of fingermark quality or included an assessment scale. After a thorough review of the articles, those studies that were not associated with measurements of quality (an example of general exclusion criteria can be noted in **Table 4**) or used objective computer software to conduct analysis were excluded. Articles were also excluded for duplicity or non-availability. 250 were duplicates from automatic searches and were eliminated. Inclusion and exclusion criteria (as visualised in **Table 4**) removed 612, leaving 418. A further 22 were eliminated due to access (fingerprint whorld articles, which ceased publication in the mid 2000's has

limited access to previous publications), which left 396 studies. This can be visualised in **Figure 1** below.

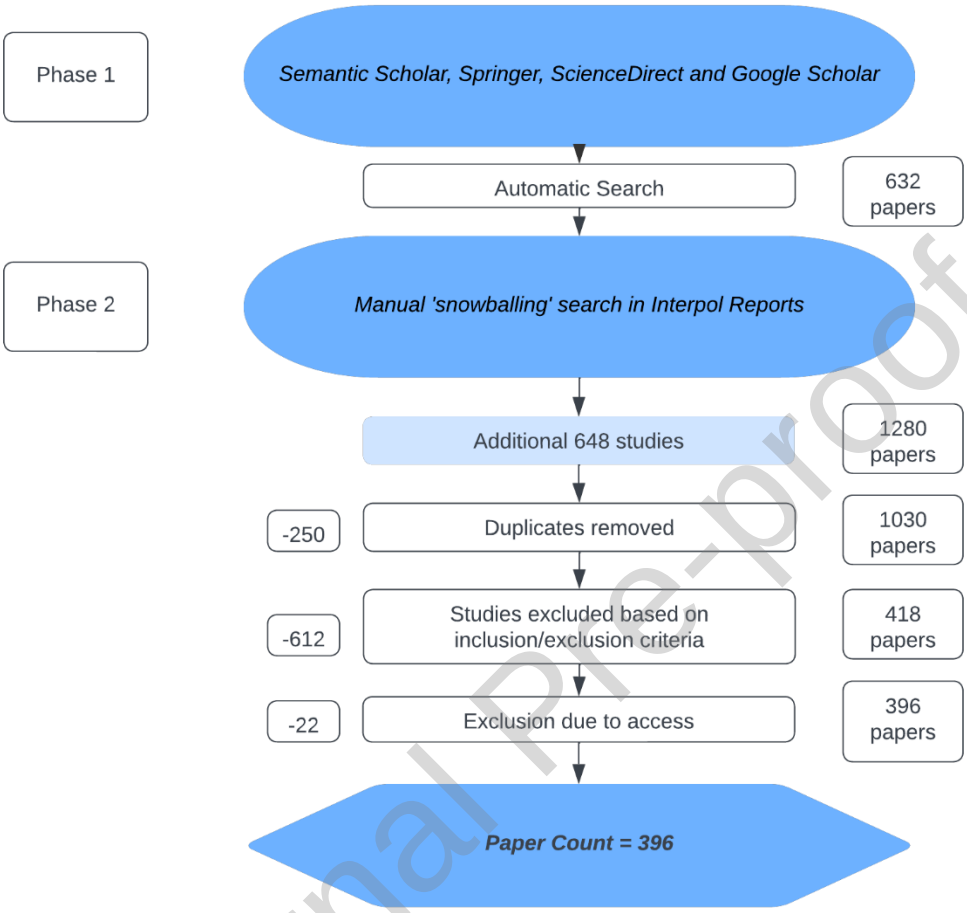

Figure 1: *Overview of studies selection process*

2.3 Inclusion and Exclusion Criteria

An inclusion and exclusion criteria were implemented to ensure only articles of relevance were considered. The criteria included only peer reviewed publications and excluded conferences, symposiums, and workshops as well as thesis papers. Studies from any country could be included only if there was a translation to English. In this critical review, studies published from January 1998 to October 2022 were considered.

It was acknowledged that for laboratory accreditation or quality assurance, verification or validation studies may require the use of a qualitative system. Only if the findings were published were these quality systems included in this analysis, any assessment system which was internal to an organisation and not shared more broadly was not included.

Table 4: *Representative exclusion criteria for publications*

Exclusion Criteria
× Objective software used without an accompanying subjective scale used to assess quality
× Scales associated with comparison/identification casework analysis – e.g., utilise an examiner to score yes or no if a mark is suitable for comparison in order to investigate the efficiency of said examiner
× Papers using specific chemical analysis as a form of fingermark quality assessment
× Case studies unless they specifically performed research on questions created from the case
× Papers that focused solely on DNA extraction from fingermarks and no analysis was performed on impact on mark quality from DNA testing
× Scales used within newsletters or local internal validation studies

2.4 Data Extraction and Synthesis

The data from each of the 396 studies were extracted. MS Excel was used to record information pertaining to areas of interest in each study. The data contained ID (identifiers for each study, including study title and DOI when applicable), publication platform, authors name, location of first author (unless an institution was provided), publication year, and study context (those being the scales utilised and their parameters). These were extracted via reviewing the methods and results of the papers and sorting the studies into categories within MS Excel. **Table 5** shows the fields of extracted data. The scale type was classified based upon the scale utilised, in order to determine which category these sat within, their references were analysed to determine where the scale was either formed from or if no reference was used a manual determination was conducted where choice was made by analysing the descriptions used. Then the scale used was individual assessed by its scale parameters, and number of scales used. This also included analysing and collating data from the descriptions within the scale. The scale parameters can be further noted in **Table 6**.

Table 5: *Extracted fields of selected studies*

Selected Features	**Description**
Study identifiers	Identification for research article including DOI and study title
Reference	Authors, title, publication, publication year, phase of study
Scale Type	IFRG scale, novel as well as absolute vs relative (meaning whole mark or half-mark analysis)
Original or tailored	Indication if the scale had been tailored from the IFRG recommended versions or not
Number of scales used	Number of scales presented within each individual study
Quality parameters	Those variables used within each scale description (**Table 6**)

Table 6: *Quality parameters, general description for fingermark quality parameters, which were extracted from each scale within the study*

Quality Parameter	Description
Ridge Detail	The level of ridge characteristics (level 1,2,3) and/or minutiae within a mark (e.g., the core or delta is present)
Ridge Visibility/ Continuity	The visibility and how continuous they are (line, dotty, smudged) within a mark
Development Level	The level at which a technique has developed
Background Development	The level of noise or technique development on the substrate other behind or on top of the mark
Contrast	The difference between the ridges and furrows as well as the ridges and substrates
Fluorescence	The fluorescence of a technique
Clarity of Images	How sharp an image is, whether the mark is blurry or distorted
Identification/Comparison	Definitions used based on suitability for comparison within casework – is the mark suitable to be compared against a suspect print and make an identification
Added Grades	Adding a sub-grade or another grade within a scale (e.g., +1, 0, -1 becomes +1, 0, 00, -1)
Qualitative Grading	Instead of numbers to grade marks, words or symbols are utilised
Number of Marks Developed	The number of marks a technique is developing, usually a count of any quality of mark as long as something is produced

All sorting and visualisation were performed on MS Excel and Tableau 2022.4. A scale was classified as a word, number or description with multiple choices, which was used to indicate a marks quality. Each identified scale was separated into four categories: CAST, UNIL, UC and novel. The first three denote the scales associated with the IFRG Guidelines [2] as noted in **Table 1**, **2** and **3**. Each were then sub-classified as either the original iteration or a tailored version, which has changed either numbers or descriptor classifications. The final category is the novel scales, which indicate those that are not associated with the IFRG guideline recommended scales and are newly introduced. Often the novel scales could be used more than once in separate papers but did not warrant classification as a scale name as they were not utilised more than four isolated times. A fifth separate category was introduced as visual examination, representing the studies that only analysed fingermarks by images with written

comments about quality rather than any scale equivalent. These papers only required sorting for study identifiers, reference, and phase of study (**Table 5**).

3. Systematic Critical Review Results

The number of publications that report the use of a scale to assess quality for fingermark detection research has considerably increased over the last decade (**Figure 2**). The increase can be explained by the ability for these scales to allow quick and precise analysis of multiple fingermarks at once as well as create the possibility of cross-comparison between studies. Additionally, these scales created an easier method to reveal deviation in results, such as in studies that examine donors or substrates variations [30]. The popularity of using a scale to assess quality is thought to originate from their recommended use by the IFRG in 2014 [2]. This is supported by the increase seen from 2014 to 2022. However, this excludes any indication of how many of these scales are actually the ones that are recommended by the IFRG.

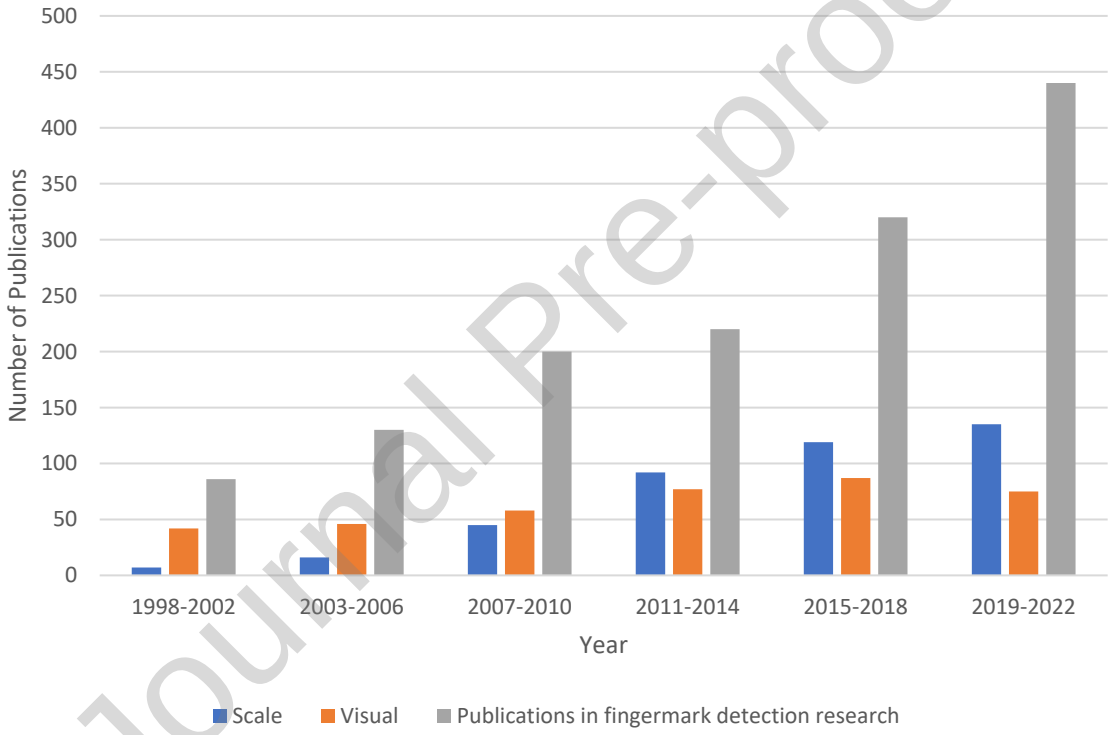

Figure 2: *Total number of publications that reported the use of a scale or fingermark quality assessment method (blue) or visual examination of a fingermark (orange) against number of publications in fingermark detection research (extracted from Scopus search using 'fingermark' to remove any publications involved in comparison/identification research or IR area - grey) from January 1998 to October 2022.*

3.1 Overall Analysis

The novel scales within this study were found to have the most accumulation of use (**Figure 3**) [8, 31-216]. The CAST scale follows closely to this at 164 of the 412 studies [3, 10, 18, 30, 35, 50, 217-374]. The UC and UNIL scales have the lowest representation respectively [19-21, 50, 249, 287, 291, 316, 318, 324, 357, 375-424]. The UC is likely to have less representation as it only performs comparison of marks, meaning it cannot determine other quality variables excluding if one technique is better than

another, however, the same cannot be said for the UNIL scale. It is expected the novel scales would show some level of higher frequency as the data ranged from 1998 and the closest scale to this date is from the CAST's introduction in 2004 [218]. When classified by year, the novel scales are never the least represented. As noted in **Figure 4**, there are never less than 5 novel scales being used each year from 2006.

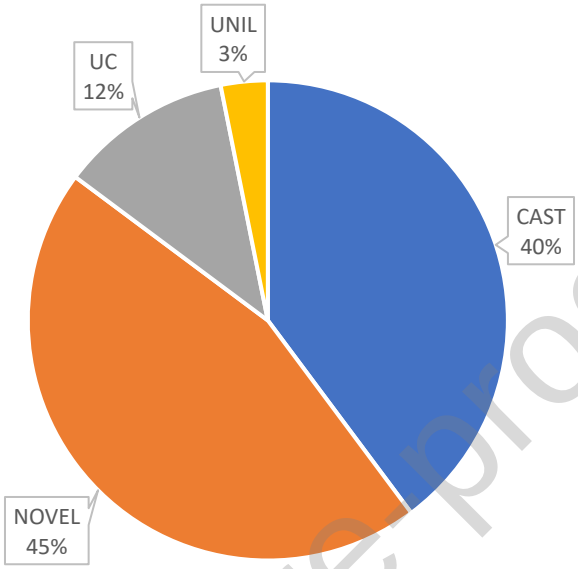

Figure 3: *Number of each scale category (CAST/UNIL/UC denoting the IFRG guideline scales and novel being those scales introduced by authors that do not have any connection or reference to the IFRG scale) within this study.*

Looking at the overall frequencies of the scales, it is clear that the highest utilised method are the novel scales. These assessment methods have been created by the authors for that particular study. These scales create issues around cross collaboration and are often subjective to not only the individual assessing the marks but the study as well. More often than not these scales are only used in singular studies, with exceptions [8, 56, 68, 77, 81, 84, 91, 92, 104, 107, 108, 114, 115, 128, 131, 144, 145, 186, 320, 425, 426]. Those that are utilised in more than one study often are being used by particular research groups or are authors utilising their own scale multiple times in different studies, but not being utilised outside of these instances. It is easy to validate this by stating the subjective nature of measuring fingermark quality is unclear and undefined. However, one might conclude the IFRG guidelines should have corrected this issue. The CAST scale is utilised 40% of the time overall. However, whilst the IFRG scales are being used, there are still novel scales being employed in other studies (**Figure 4**).

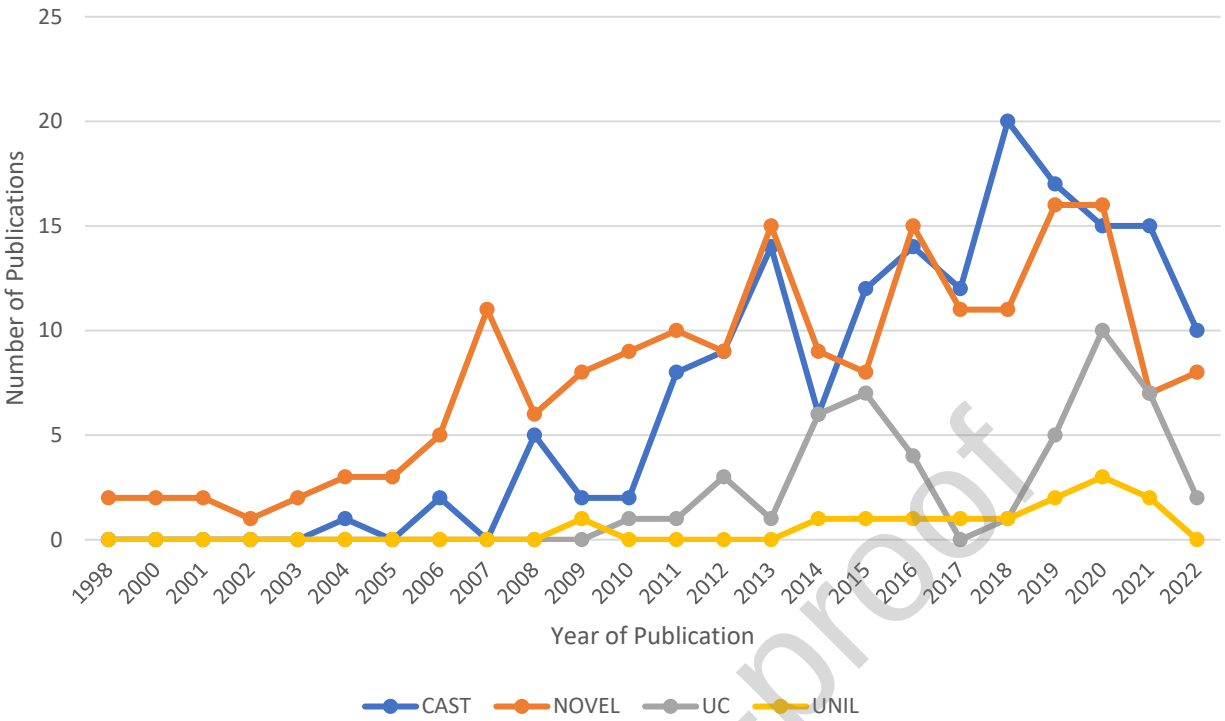

Figure 4: *Total number of articles published per year linking to their scale category (CAST/UNIL/UC denoting the IFRG guideline scales and novel being those scales introduced by authors that do not have any connection or reference to the IFRG scale).*

An author may choose to use specific quality parameters or qualifiers to determine the quality of a mark. For example, if they were looking to implement a new technique, they could simply indicate a fingermarks contrast and development level [1, 37, 87, 140, 148]. This would allow an understanding of if a technique can develop a fingermark with good contrast but lacks any further detail about ridge characteristics. This scale would then only be suitable for use in studies that are trying to introduce a new technique, it would have no place in casework implementation studies. To further this, if another study of similar technique indicates better performance using a different scale, which used both contrast and ridge characteristics, there could be no definitive correlation between which technique may perform better as both have designated different conclusions based on the quality of the marks produced.

This becomes more obvious when the scales are shown compared to one another. For example, a one-step fluorescent cyanoacrylate technique, presented an abundant amount of research during the 2010s. However, when evaluated against each other the way in which these studies evaluate the results varies. Jones et al. [175], in a multi-phase study utilised a scale which made a comparative assessment of development based on symbols of "+", "=" and "=" but indicated no descriptions against these qualitative grades. Sherriffs et al [325], then furthered this by optimising the technique but utilised a tailored version of the CAST scale that utilised ridge detail and development level. Beerman et al. [334] also adapted both the UNIL and CAST scales by adding mid-scores, which allowed further scores within each whole grade. This is then different to the study in 2016 by Bisotti et al [139] that scored based on comparison of Lumicyano vs a Lumicyano kit and exploited differences in development, contrast, and ridge detail. All four studies, whilst different in application, discuss the same technique. The question here being, would it be possible to directly compare their evaluations

against each other. It is currently difficult to assess if the explicit conclusions drawn about the techniques can be compared, but it could be implied the evaluation of mark quality is not equivalent within these studies. Research would benefit from implementing a universal method of evaluation to allow conclusions to be definitively compared, especially when comparing different studies utilising similar techniques.

3.2 Early Introduction of Scales into Research

During the earlier years examined in this study, most if not all fingermark research involved making generalised comments about level of development seen [427, 428] or gave quantitative representations of the number of marks or ridges present [37, 54, 57, 177, 277] or a mixture of both [429]. This also includes those studies that counted the number of marks present or how many could be used for comparison. A select few also utilised a scale, which often represented some form of ridge counting [41, 54, 55, 57, 59, 62, 69-71, 73, 76, 78, 82, 85, 90, 92, 124, 150, 177, 215, 277, 430, 431]. Looking specifically into the earlier scales from 1998 to 2004 they are frequently focused more on ridge characteristics and if the mark is suitable for comparison purposes. This can be seen in **Figure 5** where ridge detail, visibility and identification parameters are most frequently used within descriptions. Of the 12 scales represented in this time frame, half included a descriptor that was based around a mark being "a good trace for identification" [38, 52, 53, 70, 160]. There is a level of adaptability to these descriptors, and they are often subjectively bias, meaning they rely on a person's ability to know when a mark is suitable for identification. These initial scales are often thought of as the introduction of scales into research and represent the progress into streamlining the assessment of fingermark quality in research.

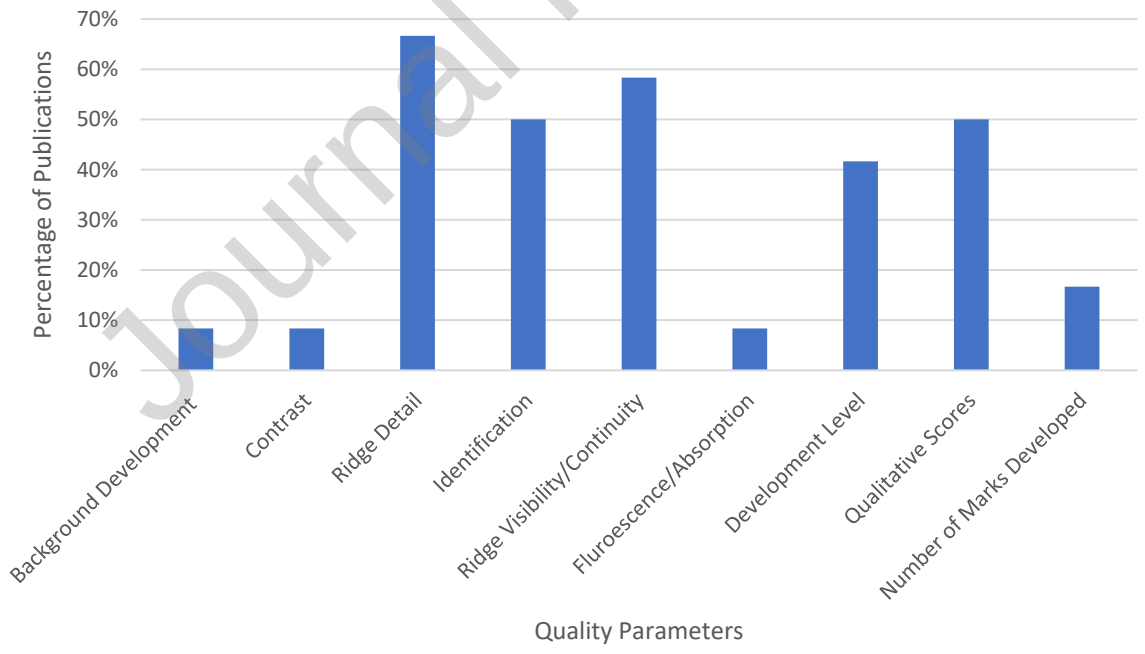

Figure 5: *Total number of each quality parameter used within the novel scales from 1998-2004.*

Many authors during this time often alluded to quality, with only a select few identifying parameters used to come to these conclusions. More often than not, these methods included understanding the ability of the mark to be used for comparison and identification. Ridge counting, and minutiae identification are complex and in order to be proficient in these methods in casework one has to go

through rigorous training in order to perform them [1, 432-434]. However, it's expected that a researcher could make an inference of these qualifiers for hundreds of marks at once. Ridge or minutiae feature counting is not an appropriate proxy for quality as it is dependent on the expertise and experience of the assessor, with a researcher often less trained than an examiner. Likewise, a numerical value of ridge counts is redundant unless it meets a specific count number. This leads to the question of if 20 minutiae in one mark can be compared to 10 minutiae in another. This is also complicated with how many ridges constitutes as different levels of quality. This is often why these older studies give basic descriptions to each mark instead of utilising a quantitative method to demonstrate quality as the number of ridges currently cannot be quantified to a specific quality level. This is where the highly subjective and often disputed terminology of "good" "poor" and "clear ridge detail" was introduced [47, 435]. The use of these highly subjective definitions in the analysis of ridge detail has created issues with current evaluation scales. Whilst the introduction and continued effort into using quantitative scales to determine quality has been beneficial, we are still using outdated and often disputed terminology to create them.

3.3 International Fingerprint Research Group Scales

Some of the complexity within those first scales was thought to be alleviated when 'common practice' scales were introduced. These involve a holistic look at the marks without having to give specific numbers of minutiae or visual descriptions to each mark. In 2004 the CAST scale was introduced, although notably its increase in application does not occur until 2011 [227, 232, 234, 235, 241-243, 248]. It could be said its introduction was created to streamline the process by which quality can be measured in research. It also would allow for collaboration between studies as assessment methods prior to this could not be compared to each other. Further to this the introduction of the UNIL and UC scales in 2009 [19] and 2010 [20] respectively created a more streamline introduction of these quality measures. This is particularly of note as the IFRG guidelines were released in 2014 which is where a notable increase in their use is seen (**Figure 4**).

3.3.1 Geographical Analysis

The CAST scale has the greatest representation followed by UC and then UNIL. Age could play a factor, with the CAST scale published 6 years prior to the UNIL scale. However, if this was the case, we would see a more dramatic rise in its use post introduction. Its steady incline occurs from 2011 onwards, with a further increase following its release within the IFRG guidelines in 2014. There is likely a point where these assessment methods gain traction outside of their institutions from popular publications. Therefore, they gain a wider audience, often through references of references of publications. The CAST system is often the most circulated outside of its country of origin, however the UNIL and UC are yet to achieve this acceptance. Over 50% of the CAST scale is used within the United Kingdom (UK) alone (**Figure 7**) [57, 220-225, 227-230, 232-235, 237, 239-241, 243-248, 255, 256, 258, 259, 261-264, 266, 267, 274-276, 278, 280, 284-286, 292-294, 298, 300, 302, 306, 313, 317, 319, 321, 325, 327, 328, 332-336, 338, 339, 379-381, 383, 436-441]. Considering the scale originated from the UK it's likely the scale was easier to access and considered 'common practice' there. Similarly, the UNIL scale within Switzerland, its place of origin, is used 50% of the time within these studies (**Figure 9**) [19, 21, 375, 385-387, 424]. This is further strengthened with the UC scale, which was developed and is most frequently used in Australia (**Figure 8**) [20, 50, 177, 316, 324, 397, 399-401, 408, 413, 415, 423, 442, 443].

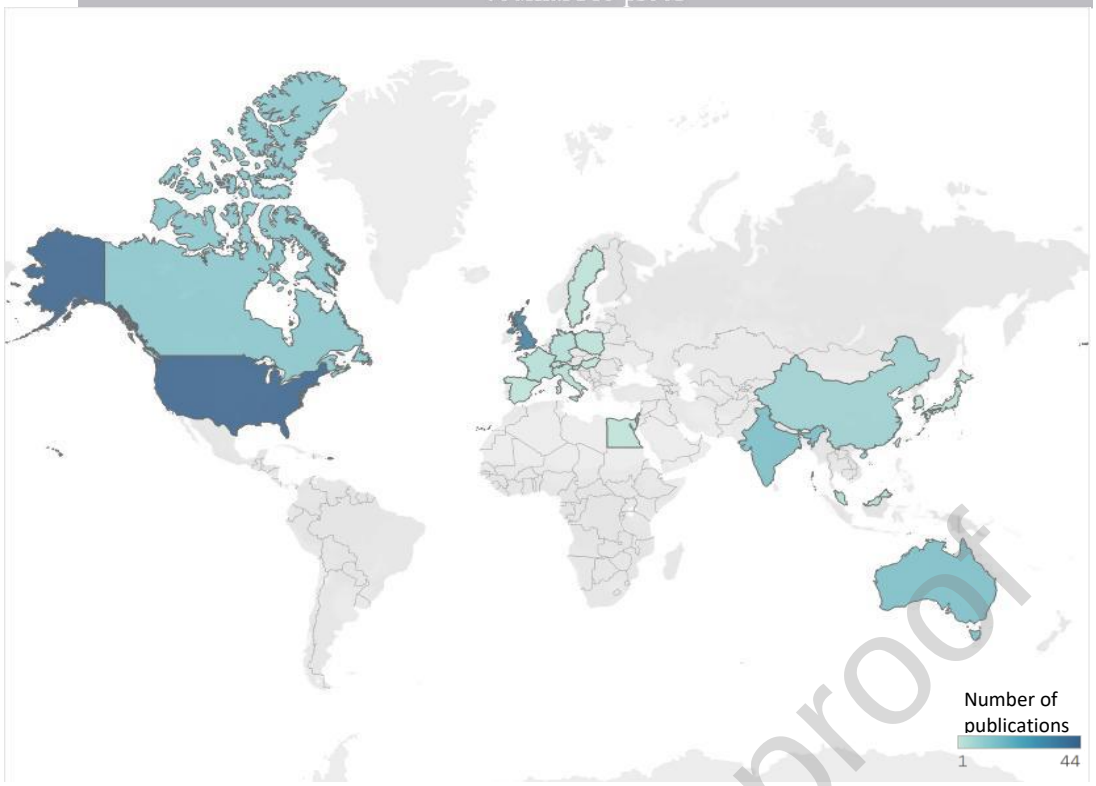

Figure 6: *Heat map of number of publications per country for the novel scales*

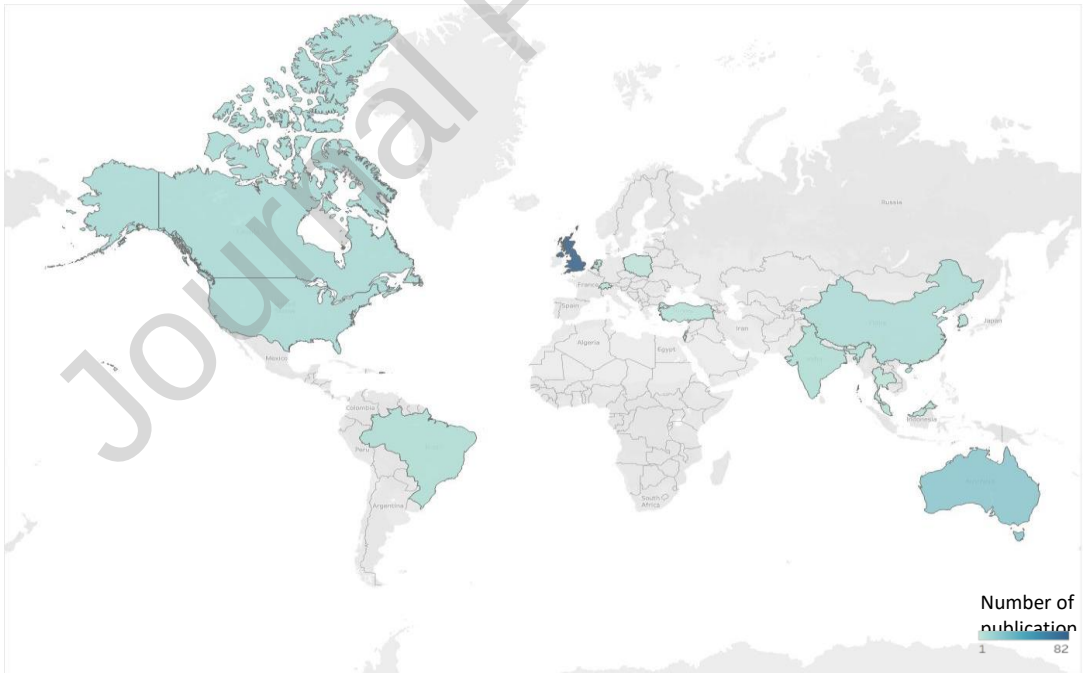

Figure 7: *Heat map of number of publications per country for the CAST scale*

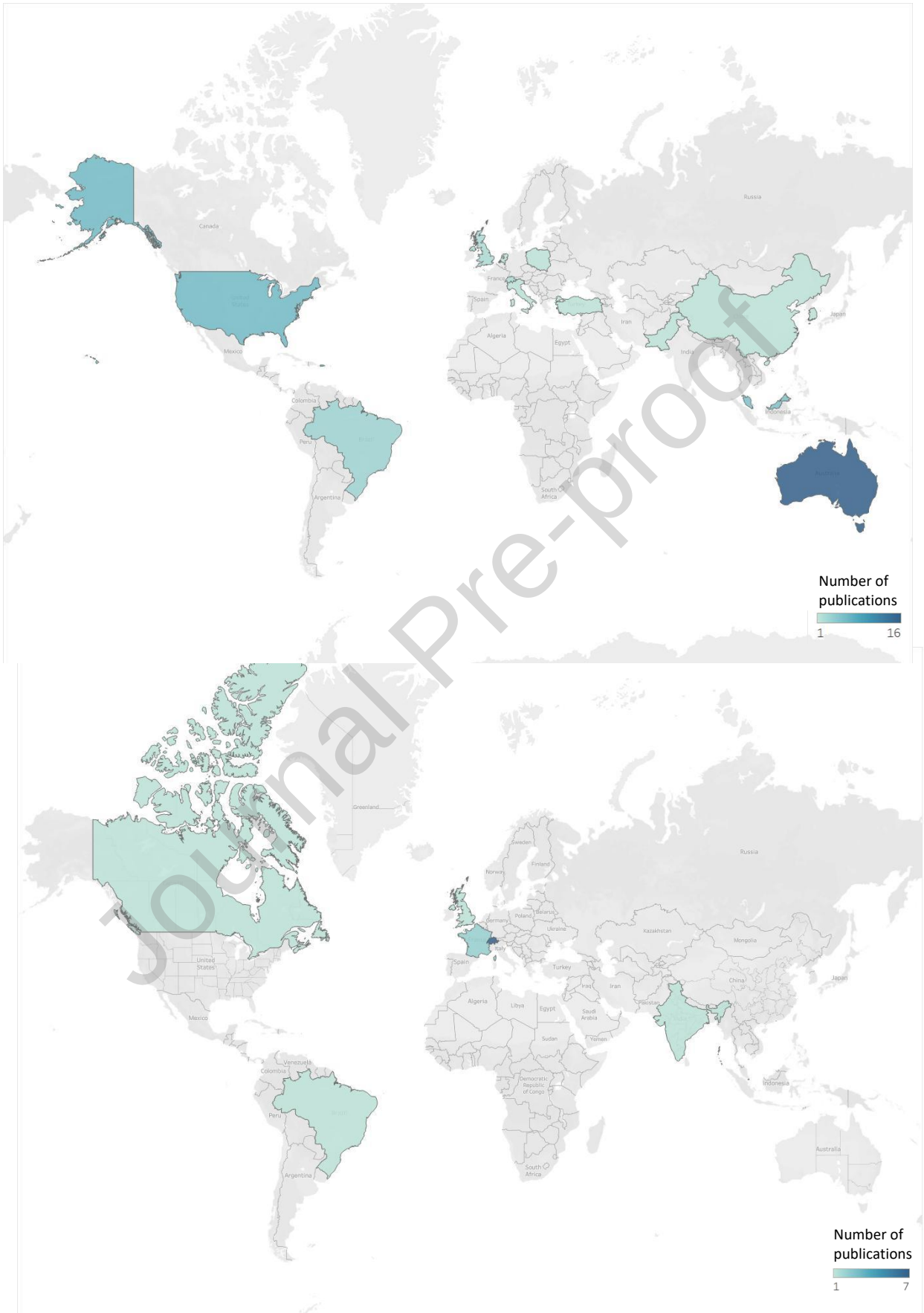

Figure 9: *Heat map of number of publications per country for the UNIL scale*

Whilst the IFRG scales seem to be dependent upon their location of origin, the novel scales seem to have no correlation to this. The United Kingdom and United States both hold the majority of novel scales, with Australia close behind. Considering the United Kingdom uses the CAST scale the most frequently and Australia sits both in the top two uses of the CAST and UC scales, it could be theorised that both these countries would show the smallest number of novel scales. Looking at the CAST and novel separated into years it's interesting to note that the novel scales are still being created alongside the CAST scale. In 2016 alone, there were more novel scales being used in the United Kingdom than the CAST (**Figure 6**) [8, 109, 112, 115, 118, 124, 128, 129, 132, 138, 139, 141, 156, 444, 445]. In the United States, excluding 2015, the CAST scale never out represents the novel scales [31, 38, 40, 42, 43, 51, 53, 58, 59, 62, 67-70, 74, 79, 81, 87, 90, 98, 99, 103, 109, 123, 127, 132, 136, 148-151, 155, 165, 166, 172, 179, 180, 189, 191, 203, 205-207, 209, 211, 215, 236, 238, 299, 307, 351, 360, 364, 444]. It could be speculated that perhaps geographical location has some correlation to the assessment method chosen by the authors, demonstrating that perhaps location plays more of a role in the common practice conditions we adapt in research.

3.3.2 Tailoring of Scales

3.3.2.1 CAST

One of the main issues that impacts the ability for cross-comparison and creates the largest variety in the distribution of the scales is the ability for the IFRG scales to be tailored. When spreading just those scales into tailored and original, the CAST scale has been tailored over 40% of the time when used in research (**Figure 10**) [3, 11, 30, 35, 50, 218, 219, 223-225, 228-231, 233-237, 244, 245, 251-256, 260, 261, 263, 265, 266, 268, 280, 281, 283, 287, 290, 291, 297, 299, 300, 302, 304, 307, 309, 313, 315, 316, 321-323, 325, 327, 331, 334, 338, 343, 344, 348-350, 358, 360-365, 367-369, 371, 372, 374, 376]. As noted in **Figure 11**, during 2012 to 2017 the tailored scales are being used more in these studies than the original CAST scale. This is complicated by the fact the IFRG guidelines not only gives the original indication of this scale but also represents a tailored version (**Table 7**). It is also interesting to note the scale they represent as the original version was released in 2006 and its tailored version was actually the one published in 2004. This could constitute some of the tailored classifications being classed as tailored prior to 2006 as the definitions within this study were produced from the guidelines. However, the IFRG tailored version is actually still the least utilised against other tailored versions, with most tailored versions being independent to the study.

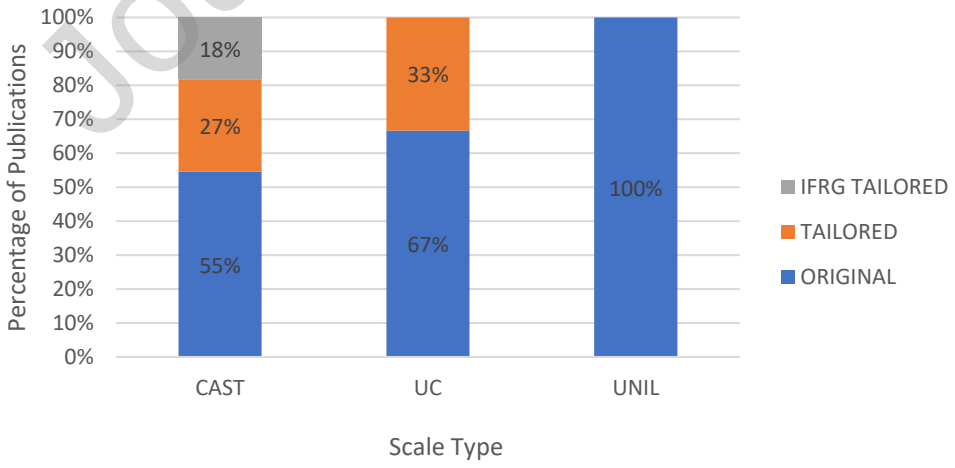

Figure 10: *Total percentage of tailored (IFRG tailored indicating the tailored version indicated by the IFRG and tailored indicating those changed by an author) and original versions of the IFRG scales.*

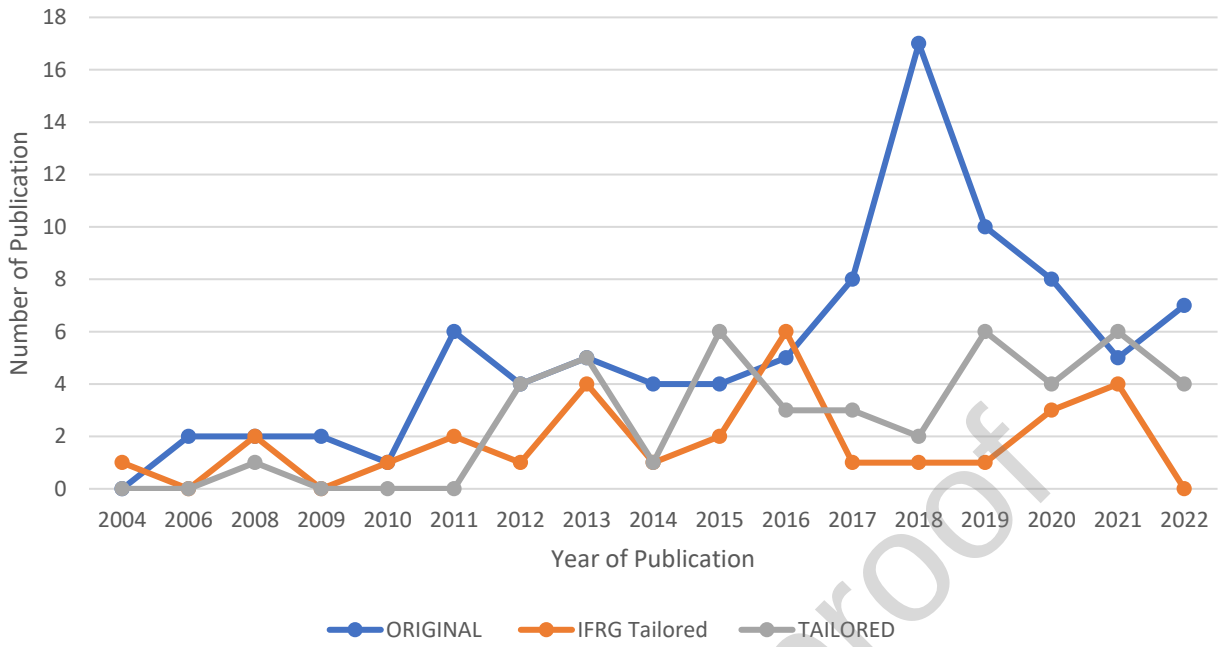

Figure 11: *Total number of CAST original and tailored iterations per year from 2004 to 2022*

As noted in **Table 7**, the original version of the scale showcases different qualifiers for different grades. The most obvious is a grade 4 where the original indicates over 2/3 clear ridge detail, but the tailored version gives this description in a grade 3. Changing the qualifiers each grade relates to infers differences in quality per grades. A grade of 3 and 4 are often associated with marks that are suitable for comparison [30, 325]. This could change based upon the descriptions chosen for grades 3 and 4. Having similar scales but different qualifiers for grades is a significant challenge, whereby each scale now classifies each parameter or qualifier and therefore changes the results. This would mean whilst one study showing a considerable number of grades 3's indicates the marks are still of 'good' quality, another could constitute those grades of 3 as only 'medium' quality. This is especially true where scales can adapt by adding grades, wherein a 5 is now considered the highest qualifier [224]. Considering the large number of tailored approaches still being utilised in research, it could be said that there is actually no agreed upon approach for measuring quality. The introduction of the IFRG scales showed a promising development of standard procedure in quality evaluation, but it is still relatively new and needs to mature and develop alongside the progress made in standardising technique processes. Research within this area should now focus on developing the definition of quality and adapting or creating methods that can be implemented to show overall fingermark quality without the need for adaptation.

Table 7: *A reproduction of the fingermark quality scales shown in the IFRG guidelines [2]*

Grade	Original CAST Scale Descriptions	Tailored CAST Scale Descriptions
0	No evidence of a fingermark	No development
1	Some evidence of a fingermark	Signs of contact but < 1/3 of mark with continuous ridges

2	Less than 1/3 clear ridge detail	1/3–2/3 of mark with continuous ridges
3	Between 1/3 and 2/3 clear ridge detail	> 2/3 of mark with continuous ridges, but not quite a perfect mark
4	Over 2/3 clear ridge detail	Full development – whole mark clear with continuous ridges

3.3.2.2 UNIL and UC

The UNIL scale and its descriptions were not modified enough to be considered tailored any of the 13 times it was used within these studies [19, 21, 375, 385-389, 391-394, 424]. Descriptions used within these scales had the most representation of multiple variables and can be utilised as either qualitative representation ('+', '-') or quantitative using a number to represent quality. The UNIL scale perhaps represents quality better than the other scales seen within this study. However, it is considerably underutilised, which could be the reason for the lack of changes made as it does not have the same influence as the other scales. This poor reach explains the lack of tailoring as it's reach is not broad enough, especially as its use is often location and institution specific to those that created the scale.

Tailored versions of the UC scale most often introduce identification definitions and contrast. They also represent 'added grades' whereby an additional grade is included to reach different qualifiers. In example, Chadwick et al. [401] has additional 0 grades where comparisons can be made between marks that are the same because of similar development levels or similar because there is no development present (**Table 8** and **Table 9**). These added grades are often associated with development levels and not any additional parameters. This change in scale is one of the most seen tailored iterations [400, 401, 408, 410, 411, 413-415] and may represent a beneficial amendment to an original scale. On the contrary, this could be a contentious, especially considering the number of tailored approaches found for the IFRG scales. One could say perhaps a tailored approach may be a better replication of the original scale and should be the recommended scale for use. Although, in order to consider this each individual scale would need to be utilised in comparison to each other and assessor agreement would need to be considered. However, it is recommended that the UC scale adapt this sub-classification, as this tailored approach shows the most beneficial use of any tailored approach to the IFRG scales. This is also under the consideration that it has the ability to show multiple levels of quality from the variable grade of 0.

Table 8: *The UC fingermark quality scale [2, 20]*

Grade	Description
-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

Table 9: *The UC fingermark quality scale supplementary scoring system for grades of '0' [401]*

Sub-Classification	Description
Good development	Developed fingermarks with clear ridge detail and contrast
Poor development	Developed fingermarks but very little ridge detail and/or poor contrast
No development	Neither technique produced ridge detail

In general, these tailored scales and the parameters they use point to the fact that the current scales within circulation, especially the IFRG scales, are not utilising enough quality parameters within their descriptions. If authors are introducing new quality parameters, perhaps research needs to implement those parameters within the scales that are currently being used. This would then lessen the considerable number of new scales being produced each year. In turn, this would improve cross-collaboration of research once there is a universal and refined set of quality parameters required to encompass fingermark quality as a whole. In particular, the introduction of image quality parameters of development level and contrast and likewise identification may benefit the current versions of the IFRG scales. Especially since the IFRG scale descriptions are currently seen to lack some or all of those parameters, which are required when considering marks that are difficult to qualify or sit in-between grades. However, it should be noted that introduction of new guidelines would require implementing both new parameters, but also consideration of the phases of research and ultimately give a definition of fingermark quality that the scales are trying to achieve. Only then, would there be a universally accepted method of practice for assessing fingermark quality.

3.5 Phases of Research

Within the IFRG guidelines, there are different phases that constitute the process of fingermark research. This divides the research into four phases: (i) pilot studies, (ii) optimisation and comparison, (iii) validation via pseudo-operational trials and (iv) operational evaluation and casework trials (descriptions of the phases can be noted in **Table 10**). The progression of a new technique flows through from phase 1 trials into Standard Operating Procedure (SOPs) and is dependent on the resources available and often spans several years [2]. Although there is no set guide as to the method with which each phase measures the quality of the performance of the technique being introduced.

Table 10: *Description of the phases of research as specified in the IFRG guidelines [2]*

Phase	Description
(i) Pilot Studies	Initial pilot/ proof-of-concept experimentation of novel fingermark detection methods or major modifications of any existing methods
(ii) Optimisation & Comparison	More detailed investigation which involves optimisation of parameters, performance of methods compared to current established techniques, and performance of methods across multiple variables (substrates, aging periods, donors etc.)

(iii) Validation	Designed to introduce optimised techniques to more pseudo-operational scenarios which simulate casework – also involves comparison to current methods to incorporate the technique into operational use
(iv) Operational Evaluation & Casework Trials	Focuses on casework implementation and usually done in an operational facility intending to introduce the method into casework scenarios

3.5.1 Visual Examination

Visual examination, meaning those studies that only examined marks via images and comments about their quality rather than any quantitative scale equivalent, are the most utilised method to assess quality (references for these studies can be found in supporting documentation). It is expected phase 1 will predominantly hold the highest distribution of visual examination as it's recommended by the IFRG that this phase is only required to show the potential for new or modified methods and to justify the steps into further phases which can be done visually. It is likely that the scales within these phases wouldn't need to show a great variety of quality, only if the marks are present and show a certain level of ridge detail. However, there is still a prominent number of studies using visual examination in further phases. This is predominantly from studies that focus on chemical analysis or utilise techniques that are not routinely used in casework. A clear example comes from the use of nanoparticles to detect fingermarks, with a majority of these studies failing to surpass phase 3. It is hard to see these techniques replacing conventional methods as most studies have issues considering the application within a sequence or the consequences of using such hazardous materials in operational setup [446]. However, it would be beneficial to understand the performance of these methods in contrast to other techniques already in casework trials. This could be easily achieved by some level of comparison between quantitative scorings.

Phases 4 also shows a higher level of visual examination (**Figure 12**). Phase 4 could be attributed to the fact that most scales currently in circulation do not solely focus on suitability for comparison. As casework implementation should focus primarily on those comparison definitions, where fingermarks should be considered useful for making an identification. Although, this would then suggest Phase 3 studies should also likewise show a greater distribution than the other two phases. Although, since a majority of studies that fit into the final phase are performed by operational facilities, they are less likely to adapt or utilise current research methods of quality analysis and adopt their own as per the facility. The papers using visual examination in phase 2 often focused more on pulling out individual ridge characteristics that can be noted on individual marks rather than giving a score equivalent. However, this can only be achieved when the sample size is small. This is most likely why those studies that utilise smaller sample sizes, which is more often than not those that involve analytical techniques, do not employ a scale when performing analysis. Similarly, it is likely why those studies that don't use scales often don't compare to other techniques until phase 3 and 4 pseudo-operational scenarios. Although this could stem issues from the assumption that each technique is not actually being validated for further study the same as another, as some are using scales to validate results and others simply use visual examination. Although, this then asks the question should there be a mandated quality analysis protocol, so all techniques must go through the same process in order to be considered sufficient enough for casework implementation.

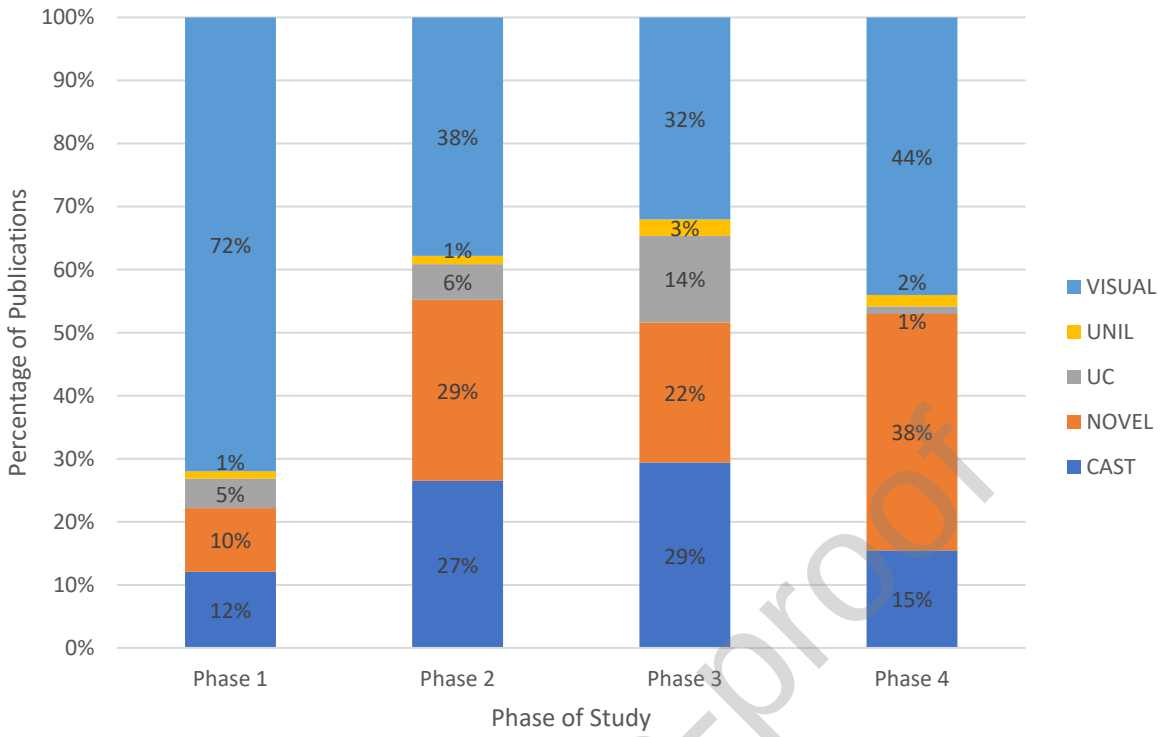

Figure 12: *Total percentage of publications within each phase of IFRG research phases (as noted in* ***Table 10****) in each scale category and visual examination.*

3.5.2 Scales

Scales are primarily utilised in phase 2 and 4 studies, as noted in **Figure 12**. Phase 2 uses comparison and optimisation of new techniques either with new variables or against existing methods, whereas the latter focuses on casework implementation. The novel scales show the highest percentage of representation in these phases. It is expected phase 4 studies would introduce new novel scales, especially considering the IFRG scales do not represent a level of identification/comparison. Phase 2 focuses on the area of assessing technique success and primarily involves looking at multiple techniques at once, or numerous amounts of fingermarks with varying external variables such as donors, depletions, aging times and so on. Hypothetically, this phase would require a comparison between current methods as well as an understanding of the variable that impact the detection methods. This is especially true where the CAST scale shows its highest frequency of studies within Phase 2. However, it is still out represented by the novel scales.

To further this, the quality parameters chosen within each phase gives a more specific look into what each phase is trying to show. Identification and comparison definitions increase their frequency from phase 1 to phase 4. Although, it should be noted ridge detail and ridge visibility are consistently the top parameters chosen for each phase (**Figure 13**). It is interesting to see that ridge detail and visibility are less frequent in phase 3 and 4 compared to phase 2. This could be that interchange between identification/comparison definitions being used and ridge characteristics. Possibly only specific parameters are needed per different phase. This might make the streamlining of scales easier if there was to be specific scales required for different phases of research. Phases 3 and 4 may require more identification/comparison definitions whereas the phase 1 and particularly phase 2 involves ridge visibility but also development level and contrast or clarity. Although it should be noted that number of minutiae cannot be equated to 'identification' as an examiner may be able to identify from a number below the threshold indicated, for example, a grade of 2 within the CAST system may also

show some marks suitable for identification. This should alleviate some of the tailoring or novel scales seen. This in turn would allow a more accurate description of the quality these phases are trying to achieve.

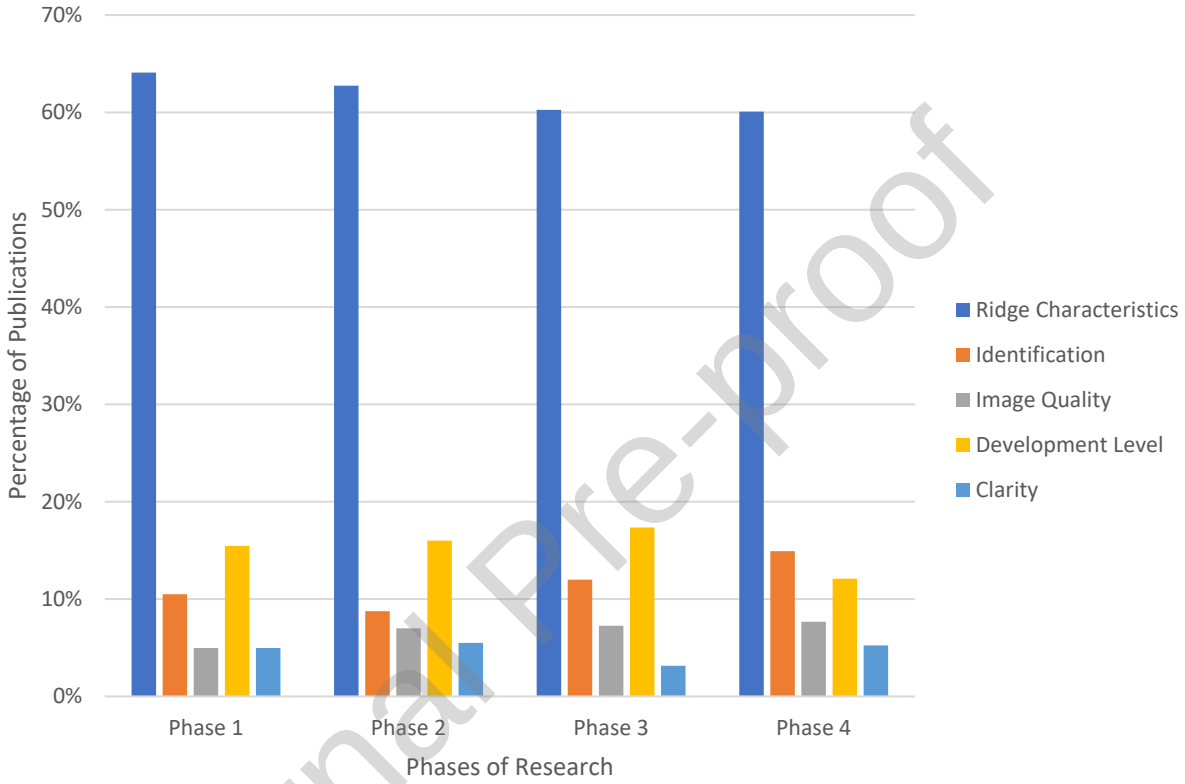

Figure 13: *Top parameters used within the phases of research. Ridge characteristics signifies ridge detail and ridge visibility, and image quality signifies contrast and background development.*

3.6 Influence of Quality Parameters

Most authors choose to introduce further parameters within their tailored IFRG scales [30, 35, 50, 225, 229-231, 245, 251-255, 260, 263, 265, 266, 281, 291, 302, 304, 307, 309, 313, 315, 316, 321, 323, 327, 331, 338, 343, 344, 350, 358, 360, 363-365, 367-369, 378, 381, 383, 384, 400, 401, 408, 410, 411, 413-418, 420]. The novel scales likewise introduce a wide variety of parameters, alone they represent the greatest number of parameters of any scales (**Figure 14**). The most consistent variable that was used in all scales included ridge detail, ridge visibility/continuity as well as development level. However, the novel scales introduced a higher level of identification/comparison definitions [1, 31, 34-36, 38, 50-53, 61-63, 70, 71, 73, 82, 86, 87, 91, 92, 95, 99-101, 103, 112-117, 119, 121, 123-125, 127, 130-135, 137, 144-146, 150, 151, 153, 156, 157, 159, 160, 162, 166, 169, 177, 179, 180, 182-184, 187, 188, 190-192, 195, 202-205, 208, 211-216, 447, 448]. These involved stating a fingermark was 'suitable for comparison' or the more temperamental 'identification assured' as a qualifier (an example can be seen in **Appendix Table 4**) [114]. These often were utilised as interchangeable

between ridge detail and identification. However, it should be noted these terms cannot technically be used in replacement of each other.

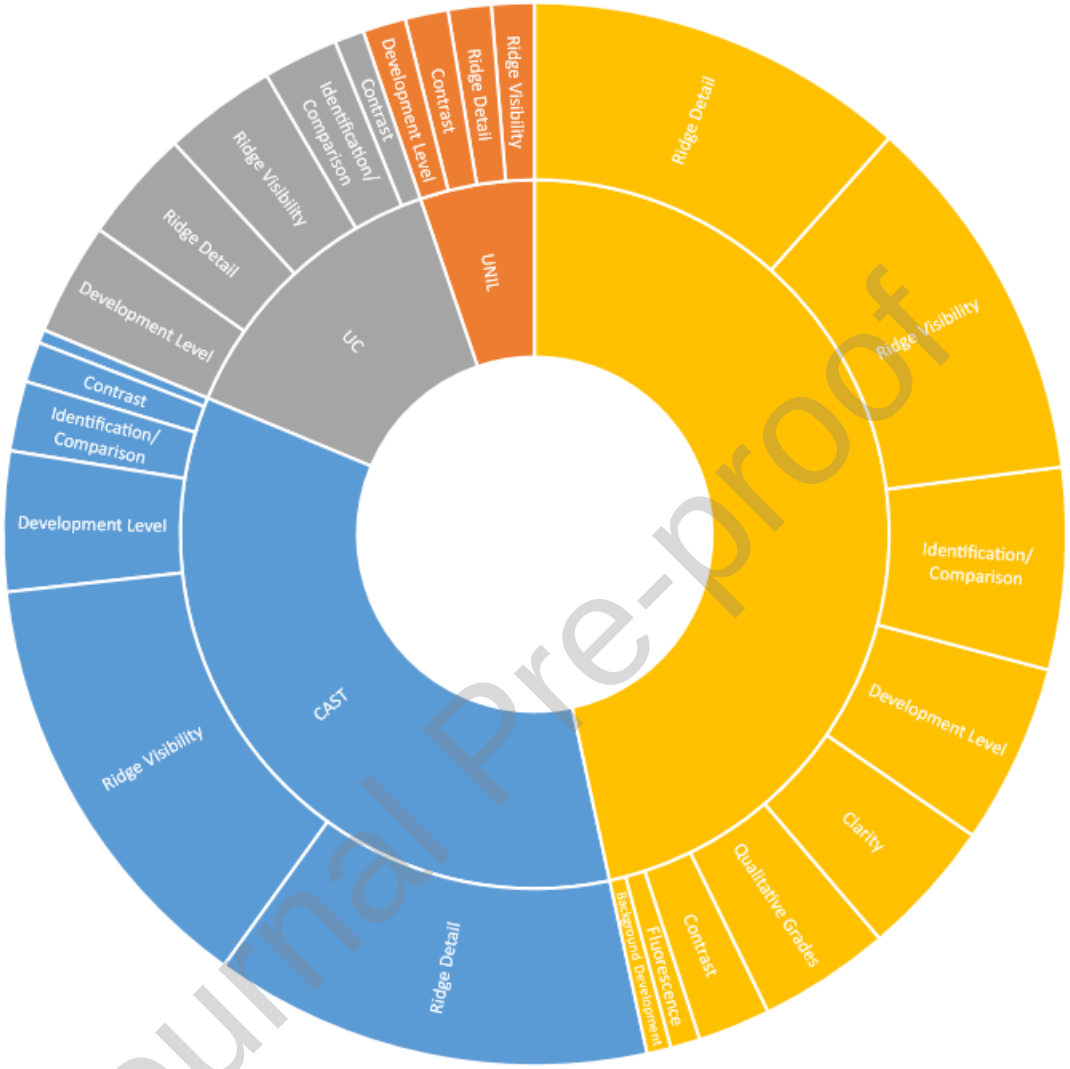

Figure 14: *Sunburst representation of the different quality parameters applied in each scale.*

Ridge detail often involves looking at specific levels of detail without using them as qualifiers for identification purposes. This involves attributing a level of detail, for example level 2 minutiae, as a qualifier for higher grades or scores. On the contrary identification and comparison descriptions use qualifiers of a mark being “suitable for comparison” and “unsuitable for comparison” [30]. Whilst the amount of ridge detail present can indicate if a mark is suitable for comparison, a mark being suitable for comparison cannot always indicate what level of that ridge detail is present. This is also complicated by donor variability, wherein pressure or movement upon deposition creates a mark with visibility of development but ‘fused’ or ‘smudged’ ridges. For example, in **Figure 15** below, the mark on the left could be considered suitable for comparison, and if considered against the scale utilised in Castello et al. [114] score a 3, with an identification possible. However, the additional descriptions of ‘reasonable quality, ridge detail and some characteristics’ are where this mark can be differentiated

from the mark on the right as both show a possibility to be used for identification but they both have very different levels of ridge detail present. Homogeneity complicates these parameters. In example, some assessors may consider a mark with no delta or core of poorer quality, even if the mark without the delta has sufficient and homogenous ridges. Current quality assessment methods are unable to show these distinct differences between marks, especially when considering the number of parameters available to be used within descriptions. This is where the long descriptions using multiple parameters are being introduced. An example of this can be seen in **Table 11** where Thandauthapani et al. [33] utilises not only development level but also ridge flow, ridge detail and distortion to try to represent a marks' overall quality.

3

Reasonable quality, ridge detail & some characteristics visible, identification possible.

5

Excellent quality, full mark very clear, identification assured.

Figure 15: *Representative images showing differences in ridge detail and identification parameters with their score indicated by the scale utilised in Castello et al. [114].*

Table 11: *The fingermark quality scale utilised in Thandauthapani et al. [33]*

Score	Definition
1	No visible ridges or contacted area – Nothing of interest
2	Weak development: evidence of contacted area but no visible ridge details present
3	Partial development; up to 1/3 ridges present including clear evidence of ridge flow and pattern (first level detail) and partial evidence of individual ridge minutiae - bifurcations and ridge endings (second level detail). Significant distortion evident.
4	Strong development; between 1/3 and 2/3 of ridges present including clear evidence of ridge flow and pattern (first level detail), individual ridge minutiae - bifurcations and ridge endings (second level detail) and partial evidence of pore position and shape (third level detail). Minor distortion evident

5	Very strong development; >2/3 of ridges present including clear evidence of ridge flow and pattern (first level detail), individual ridge minutiae - bifurcations and ridge endings (second level detail) and pore position and shape (third level detail). Very minor or no obvious distortion evident.

The issue with the longer description scales is they leave little room for marks that do not fit into any category or fit into multiple ones. Summarising multiple parameters into one description can create a tight fit for some marks, especially those that show poor homogeneity throughout the mark and don't associate with specific ridge characteristics. Using such specific qualifiers makes it so a mark has to reach a certain level of either criterion before it can reach a particular grade. Some authors to alleviate this strain have considered using multiple scales (an example can be noted in **Table 12**) with multiple scores. In this review, 15% of the studies utilised a scale, which included more than one scoring category or description grouping [7, 8, 11, 21, 32, 35, 50, 56, 66, 71, 77, 78, 84, 88, 90, 92, 107, 108, 139, 176, 177, 179, 180, 183, 191, 193, 244, 245, 251, 253-255, 263, 304, 307, 315, 316, 321, 327, 334, 377, 390, 391, 410, 447, 449-452]. However, this can create issues with data extraction whereby one mark has multiple scores associated and is complicated by each parameter requiring a different contribution level to an 'overall' score if these scores are to be combined. There has been some discussion about data representation methods [3], but there is currently no study which critically analyses if multiple scores can be combined and how those scores should be combined.

These scales do bring additional parameters into an already complicated evaluation. The ability to show more than one quality parameter allows for discrepancy between marks to be considered. However, they are slow in implementation. Authors are less likely to use these methods as they are long and extremely time consuming. Research requires a significant number of variables and this in turn creates mass amounts of images. To assess the quality, an assessor has to manually visualise and grade the marks, with the recommendation that two or more people perform the assessment. Adding more than one grade per mark complicates this process. This is also complicated by the studies that use two scales, one to perform whole mark analysis and another to do comparison [21, 35, 36, 50, 249, 287, 291, 316, 318, 324, 357, 375, 391]. It could be the reason behind most scales, novel or otherwise, having a propensity to be one scoring method and simply change the descriptions as necessary. However, the added level of quality these scales are able to determine perhaps outweighs the negatives this may pose. Starting from the fact that assessing fingermark quality is not fully agreed upon or mandated, the initiative of creating multiple scales to try and encompass quality as a whole certainly goes in the correct direction. It should however not alter the fact that single score scales can be used in research, especially if only one parameter is required (as per identification/comparison definitions in casework implementation studies). It could simply be that some phases of research may benefit from using more than one scale at once, especially where they wished to determine the quality of multiple variables.

3.6.1 Classification of Parameters (Fingermark Quality vs Image Quality)

Having all of these parameters and being able to represent them individually is a complex issue. Initially, those definitions of minutiae counting were 'classified' as scales used to show fingermark quality, but as this definition becomes more complex research has introduced additional parameters for measurement. Some of these parameters can be grouped into classifications: fingermark quality and image quality. Fingermark quality: those meaning, the variables involved within the fingermark, which associates with visibility of ridges and their characteristics (such as levels of detail present). Correspondingly, image quality parameters are those found from detection techniques and can also

be indicators of how well a technique is working minus any specific mark quality factors. Examples of which include background development and contrast.

Expectedly, the most represented variables within all scale's descriptions come from mark quality parameters. The only image quality parameters consistently used in all four scale categories is development level. Although, this is the one category that can be interchanged between image and mark quality as it can represent development by technique or development of ridges. Considering studies within this field involve a level of understanding development success, this alongside contrast and background development are thought to be an easier measurement of quality as they don't require proficiency in determining suitability for comparison or identification. However, it's not established whether development level of ridges or of technique equate to the same level of quality. Often the qualifiers of both are subjective in nature, one uses "full development" [235] and the other "over 2/3 clear ridge detail" [18] .

Here is where some level of subjectivity is noted, those performing grading if given a specific description will often exchange these parameters subconsciously. If told to measure level of ridge detail, one can assume an assessor would also consider if the mark had too much contrast or background development as this could obscure the ridges. Some authors endeavour to investigate how proficient an assessor needs to be to perform this grading without subconscious bias [7, 8]. However, no matter their level of expertise the scale that is given will influence how one subjectively interprets the quality. If an assessor is given one parameter of ridge detail (as seen within the CAST scale) they interpret the image quality based upon their own knowledge. Contrasting this, if a scale shows only image quality characteristics [37, 39, 45, 48, 85, 102, 158, 176], an assessor will then analyse the ridges based upon their own assumed knowledge of ridge characteristics. This could be why the UNIL scale is never tailored to suit a study. It utilises both mark and image quality parameters equally. However, the use of these scales in comparison to each other would need to be performed to fully understand the comparison. This is further noted in the study by Fritz et al. [7] where variability in assessors is investigated to understand how reliable the CAST grading is performed. However, the scale utilised actually tailored the CAST scale by adding an image quality parameter, "contrast of ridge detail and background" (**Table 12**). As a consequence, it is currently difficult to assess the proficiency level of assessors for any scale other than the one represented within the study. An interesting route of study would be to investigate the level of agreement between assessors these scales would have, especially those that utilise different quality parameters. However, the aim of proficiency and agreement testing deviates from the evaluation methods themselves and has subsequently not been extensively studied in this article, especially under the consideration that there are minimal studies associated with this concept [7, 8].

Table 12: *The fingermark quality scale utilised in Fritz et al. [7]*

Grade	**0**	**1**	**2**	**3**	**4**
Friction Ridge Detail Development	No development	Signs of contact, has less than 1/3 of fingermark continuous ridges	½-2/3 of fingermark continuous ridges	More than 2/3 of fingermark continuous ridges, but not quite a "perfect" mark	Full development; whole fingermark continuous ridges

Contrast of Ridge Detail and Background	No contrast	Poor contrast	Moderate contrast	Good contrast	Very good contrast

4. Recommendations

Fingermark quality and its assessment methods is a worthwhile area to be explored. If assessment methods are aimed at answering a specific definition of quality whilst being refined and allowing for cross-collaboration, research could quickly identify limitations of techniques, compare methods, and give definitive conclusions. The current limitations in research relate to the wide variety of methods that are thought to achieve this. Even with the 'common practice' methods from the IFRG, authors are still creating new assessment protocols and even tailoring those that already exist. It could be said that the guidelines are not standardized to where they should be. Addressing this limitation comes from our inability to conclusively agree upon a definition of quality. Moreover, gaining knowledge about how authors interpret these scales and officially understanding the proficiency level required to perform these grading's may alleviate some of the subjectivity associated.

Contrary to this, not having a strict quality scoring method could pose some advantages. Simply, the ability for a person to adapt a scale based upon their aims is easy and can allow fit-for-purpose investigation. This may also assist wherein a person can measure quality based upon their own interpretation, which could possibly eliminate some of the issues with assessors interpreting descriptions based upon their own knowledge or experience when utilising current practice scales. Mandating a process may also cause issues where each phase, or even technique requires subtle changes to descriptions (for example fluorescence in methods that do or do not fluoresce). However, each evaluation phase faces differing challenges, introducing new aims and evaluation methods could create hundreds of scales that cannot be directly compared. In the same way, science is not necessarily a collection of opinions. There needs to be a refutable aspect to each conclusion, with a clear point or argument in order to refute those conclusions. This is especially true where each scale creates a different argument or conclusion that is difficult to counter unless those exact methods are applied in comparison.

Throughout this article it is clear to note that one of the main issues revolves around the wide variety of scales, both recommended as common practice and not, that are in circulation. This point alone constitutes the need for a more reformed process for quality evaluation and that the current scales in circulation may not be best suited for this as authors are choosing their own methods beyond those recommended. It is recommended that research firstly evaluates the quality parameters necessary to evaluate fingermark development, especially in consideration to the phases of research. Here some general and informative conclusions can be made about the parameters currently being utilised by studies. These parameters and any additional that may not come from the scales themselves but personal knowledge from assessors should be combined to determine the parameters necessary to determine a marks overall quality. Only then can a scale with universal and definitive descriptions be created. Ultimately, this would need to associate with a refined definition of what fingermark quality is. This in turn will minimise the creation of novel scales and tailoring of those that are recommended. It is hoped that development of a definition of quality and protocol to perform grading should improve some of the constraints seen within current quality assessment methods.

Some authors suggest that the issues seen with these scales may be alleviated by objective measures [3, 9]. However, throughout this study it was noted that these methods are often used alongside scales [10, 60, 270], and there are minimal publications that only use objective methods beyond the preliminary introduction studies. This is a new and upcoming method of evaluation and is currently being extensively researched and improved [6, 453, 454]. However, currently there is no singular method that is thought to outperform a person performing the analysis. This is also true considering casework is done not only by software (AFIS) but by a human examiner. As research is influenced by the procedures taken in casework, it is self-explanatory that human observation would be favoured to software. Therefore, whilst these methods are currently being tested and applied in research, it is unlikely that it will be used in favour to traditional subjective methods until they can outperform an assessor. Subsequently, as with objective means, subjective methods should also continue to be researched in order to improve their reliability.

5. Conclusions

This critical review aimed to explore all of the subjective fingermark quality assessments. These methods were systematically extracted and analysed from 398 research publications. It was concluded that currently there is no consistent method of assessment, with similar representation from the CAST scale to novel scales. Some methods may be better suited to represent quality, but as such with no current universal definition of what fingermark quality it cannot be confirmed which method can be considered 'best'. The scales indicated for 'common practice' are often tailored in favour of using the novel published methods. It is clear there may not be one such agreed upon approach to measure fingermark quality.

It was observed that the phases of fingermark research may also influence the choice of scale. This is particularly of note as the novel scales showed their highest frequency within Phase 2 and 4 studies. Similarly, the parameters used within the scale descriptions are often influential on scale choice. This is due to the fact that each parameter is assessing different quality areas within an individual mark. It is proposed here that these quality parameters could be grouped to represent both mark quality and image quality parameters. Fingermark quality meaning, the variables involved within the mark, which associates with visibility of ridges and their characteristics. Correspondingly, image quality parameters are those found from detection techniques and can also be indicators of how well a technique is working. Likewise, perhaps there should be investigation into the different scales required within each phase of research.

In research, the number of marks needed within a study alongside donors, depletions, ages, depositions, and repeats has all increased as we determine that fingermarks are variable and as such require an extensive universal method to perform research on them. As we continue to learn more about them, especially their variability, it is only logical that the way we evaluate them would continue to grow as well. However, the 'common practice' methods recommended from the IFRG have not changed. Likewise, neither have the novel scales, which often utilise the same versions of quality the IFRG scales use as well as the outdated methods from initial studies. Until more is known about what quality actually means and how best to determine it, the current scales being used will suffer from the same issues time and time again. Research would benefit from understanding what parameters are required to determine a marks overall quality, especially with the variable level of detail that comes with producing large numbers of fingermarks at once.

Appendix

Appendix Table 1: *The fingermark quality scale utilised in Sherriffs et al. [325]*

Classification	Definition
0	No mark has been developed
1	An empty mark has been developed
2	Some ridges have been developed with up to 1/3 of the mark having been developed
3	Between 1/3 and 2/3 of the ridges of the mark have been developed
4	From 2/3 to a full mark has been developed

Appendix Table 2: *The fingermark quality scale utilised in Bisotti et al. [139]*

Value	Scale
-	Fingermarks developed with Lumicyano Kit have a lower quality than the ones revealed with Lumicyano
0	The quality of the fingermark developed with Lumicyano Kit is equivalent to that of the trace revealed with Lumicyano
+	Fingermarks developed with Lumicyano Kit have a better quality than the ones revealed with Lumicyano
++	Quality of the fingermarks developed with Lumicyano Kit is greatly superior to that of the traces revealed with Lumicyano

Appendix Table 3: *Half-grades indicated for the CAST and UNIL scales used within Beerman et al. [334]*

Score	Description
+	Clearly more visible ridges, but not enough to be a higher grade
±	Ridges that are slightly visible but no sufficient to be a + or next full grade
-	Less detail than a full grade

Appendix Table 4: *Fingermark quality scale utilised in Castello et al. [114] to showcase identification descriptors in novel grading scales*

Grade	Description
0	No visible print
1	Poor quality, very few visible ridges
2	Poor quality, some ridge detail visible or partial mark with limited characteristics
3	Reasonable quality, ridge detail & some characteristics visible, identification possible
4	Good quality print, ridge detail and characteristics visible, probable identification
5	Excellent quality, full mark very clear, identification assured

References

1. Ulery, B.T., Hicklin, R.A., Kiebuzinski, G.I., Roberts, M.A., and Buscaglia, J., *Understanding the Sufficiency of Information for Latent Fingerprint Value Determinations.* Forensic Science International, 2013. **230**(1): p. 99-106. DOI: https://doi.org/10.1016/j.forsciint.2013.01.012.
2. International Fingerprint Research Group, *Guidelines for the Assessment of Fingermark Detection Techniques.* Journal of Forensic Identification, 2014. **64**(2): p. 174-197.
3. Hockey, D., Dove, A., and Kent, T., *Guidelines for the Use and Statistical Analysis of the Home Office Fingermark Grading Scheme for Comparing Fingermark Development Techniques.* Forensic Science International, 2021. **318**: p. 110604. DOI: https://doi.org/10.1016/j.forsciint.2020.110604.
4. Evett, I.W. and Williams, R.L., *A Review of the Sixteen Point Fingerprint Standard in England and Wales.* Journal of Forensic Identification, 1995. **46**(1).
5. Yao, Z., Le Bars, J.-M., Charrier, C., and Rosenberger, C., *Literature Review of Fingerprint Quality Assessment and Its Evaluation.* IET Biometrics, 2016. **5**(3): p. 243-251. DOI: https://doi.org/10.1049/iet-bmt.2015.0027.
6. Swofford, H., Champod, C., Koertner, A., Eldridge, H., and Salyards, M., *A Method for Measuring the Quality of Friction Skin Impression Evidence: Method Development and Validation.* Forensic Science International, 2021. **320**: p. 110703. DOI: https://doi.org/10.1016/j.forsciint.2021.110703.
7. Fritz. P, Frick A.A, Bronswijk. W. van, S.W. Lewis. S.W, Beaudoin. A, Bleay. S, and Lennard, C., *Variability and Subjectivity in the Grading Process for Evaluating the Performance of Latent Fingermark Detection Techniques.* Journal of Forensic Identification, 2015. **65**(5): p. 851-867.
8. Fieldhouse, S. and Gwinnett, C., *The Design and Implementation of a Proficiency Test for Assessors of Fingermark Quality, to Facilitate Collaborative Practise in Fingermark Research.* Science & Justice, 2016. **56**(4): p. 231-240. DOI: https://doi.org/10.1016/j.scijus.2016.03.001.
9. Humphreys, J.D., Porter, G., and Bell, M., *The Quantification of Fingerprint Quality Using a Relative Contrast Index.* Forensic Science International, 2008. **178**(1): p. 46-53. DOI: https://doi.org/10.1016/j.forsciint.2008.02.003.
10. Williams, S.F., Pulsifer, D.P., Lakhtakia, A., and Shaler, R.C., *Visualization of Partial Bloody Fingerprints on Nonporous Substrates Using Columnar Thin Films.* Canadian Society of Forensic Science Journal, 2015. **48**(1): p. 20-35. DOI: 10.1080/00085030.2014.987464.
11. Williams, S.F., Pulsifer, D.P., Shaler, R.C., Ramotowski, R.S., Brazelle, S., and Lakhtakia, A., *Comparison of the Columnar-Thin-Film and Vacuum-Metal-Deposition Techniques to Develop Sebaceous Fingermarks on Nonporous Substrates.* J Forensic Sci, 2015. **60**(2): p. 295-302. DOI: 10.1111/1556-4029.12648.
12. Godsell, J.W., Vincent P.G., Lloyd D.W., *Home Office Police Scientific Development Branch Technical Memorandum*.
13. Cuthbertson, F., *The Chemistry of Fingerprints Awre-O13-69*, ed. A.W.R. Establishment. 1969, Aldermaston.
14. Kent, T., Thomas, G.L., Reynoldson, T.E., and East, H.W., *A Vacuum Coating Technique for the Development of Latent Fingerprints on Polythene.* Journal of the Forensic Science Society, 1976. **16**(2): p. 93-101. DOI: https://doi.org/10.1016/S0015-7368(76)71040-5.
15. Morris, J.R., *The Detection of Latent Fingerprints on Wet Paper Samples*, in *SSCD Memorandum 367, April*. 1975, Aldermaston: Atomic Weapons Research Establishment.
16. Knowles, A.M., Jones, R.J., and Clark, L.S., *Development of Latent Fingerprints on Patterned Papers and on Papers Subjected to Wetting: An Evaluation of a New Reagent System – 35-Spd. Phase 1 Results*, in *PSDB Technical Memorandum 6/76*. 1976: London: Home Office.

17. Bleay, S., Sears, V.G., Downham, R.P., Bandey, H.L., Gibson, A.P., Bowman, V.J., Fitzgerald, L., Ciuksza, T.M., Ramadani, J., and Selway, C., *Fingerprint Source Book V2.0 (Second Edition)*. 2017: Home Office.
18. Bandey, H.L. and Gibson, A.P., *The Powders Process, Study 2: Evaluation of Fingerprint Powders on Smooth Surfaces*, in *Fingerprint Development and Imaging Newsletter*. 2006.
19. Becue, A., Moret, S., Champod, C., and Margot, P., *Use of Quantum Dots in Aqueous Solution to Detect Blood Fingermarks on Non-Porous Surfaces.* Forensic Science International, 2009. **191**(1): p. 36-41. DOI: https://doi.org/10.1016/j.forsciint.2009.06.005.
20. McLaren, C., Lennard, C., and Stoilovic, M., *Methylamine Pretreatment of Dry Latent Fingermarks on Polyethylene for Enhanced Detection by Cyanoacrylate Fuming.* Journal of Forensic Identification, 2010. **60**(2): p. 199-222.
21. Fitzi, T., Fischer, R., Moret, S., and Bécue, A., *Fingermark Detection on Thermal Papers: Proposition of an Updated Processing Sequence.* Journal of Forensic Identification, 2014. **64**(4): p. 329-350.
22. Meuwly, D.M., P. *Presented in Part at the 13th Interpol Forensic Science Symposium*. October 16-19 2001. Lyon (France).
23. Champod, C.E., N. Margot, P. *Presented in Part at the 14th Interpol Forensic Science Symposium*. October 19-22 2004. Lyon (France).
24. Becue, A.C., C. Margot, P. *Presented in Part at the 15th Interpol Forensic Science Symposium*. October 23-26 2007. Lyon (France).
25. Becue, A.E., N. Champod, C. Margot, P. *Presented in Part at the 16th Interpol Forensic Science Symposium*. October 5–8 2010. Lyon (France).
26. Egli, E.M., S. Becue, A. Champod, C. *Presented in Part at the 17th Interpol Forensic Science Symposium*. October 8-10 2013. Lyon (France).
27. Becue, A.C., C. *Presented in Part at the 18th Interpol Forensic Science Symposium*. October 11-13 2016. Lyon (France).
28. Bécue, A., Eldridge, H., and Champod, C., *Interpol Review of Fingermarks and Other Body Impressions 2016–2019.* Forensic Science International: Synergy, 2020. DOI: https://doi.org/10.1016/j.fsisyn.2020.01.013.
29. Becue, A.C., C. *Fingermarks and Other Body Impressions – a Review (July 2019 – June 2022)*. in *20th International Forensic Science Manager Symposium*. 08-10 November 2022. Lyon (France).
30. Chadwick, S., Moret, S., Jayashanka, N., Lennard, C., Spindler, X., and Roux, C., *Investigation of Some of the Factors Influencing Fingermark Detection.* Forensic Science International, 2018. **289**: p. 381-389. DOI: https://doi.org/10.1016/j.forsciint.2018.06.014.
31. Barnes, B., Clark, J., Kadane, J., Priestley, M., Tator, D., and Wauthier, D., *Processing Stamp Bags for Latent Prints: Impact of Rubric Selection and Gray-Scaling on Experimental Results.* Journal of Forensic Identification, 2019. **69**(4): p. 469-485.
32. Farrugia, K., Hunter, D., Wilson, C., Hay, S., Sherriffs, P., and Deacon, P., *Further Pseudo-Operational Trials with the Lumicyano Double- and Co-Fuming Process for the Detection of Latent Fingermarks.* Journal of Forensic Sciences, 2020. **65**. DOI: 10.1111/1556-4029.14140.
33. Thandauthapani, T.D., Reeve, A.J., Long, A.S., Turner, I.J., and Sharp, J.S., *Exposing Latent Fingermarks on Problematic Metal Surfaces Using Time of Flight Secondary Ion Mass Spectroscopy.* Science & Justice, 2018. **58**(6): p. 405-414. DOI: https://doi.org/10.1016/j.scijus.2018.08.004.
34. Dove, A., *A Further Evaluation of the Electrodeposition of Gun Blue (Egb): Part 1- Fingermarks.* Journal of Forensic Identification, 2020. **70**(4): p. 465-496.
35. Nizam, F., Knaap, W., and Stewart, J.D., *Development of Fingerprints Using Electrolysis: A Technical Report into the Development of Fingerprints on Fired Brass Cartridge Cases.* Journal of Forensic Identification, 2012. **62**(2): p. 129-142.

36. Wang, W., Xing, J., and Ge, Z., *Evaluation of Nile Red-Loaded Mesoporous Silica Nanoparticles for Developing Water-Soaked Fingerprints on Thermal Paper.* Journal of Forensic Sciences, 2019. **64**(3): p. 717-727. DOI: https://doi.org/10.1111/1556-4029.13959.
37. Burns, D.T., Brown, J.K., Dinsmore, A., and Harvey, K.K., *Base-Activated Latent Fingerprints Fumed with a Cyanoacrylate Monomer. A Quantitative Study Using Fourier-Transform Infra-Red Spectroscopy.* Analytica Chimica Acta, 1998. **362**(2): p. 171-176. DOI: https://doi.org/10.1016/S0003-2670(98)00070-1.
38. Klasey, D.R. and Barnum, C.A., *Development and Enhancement of Latent Prints on Firearms by Vacuum and Atmospheric Cyanoacrylate Fuming.* Journal of Forensic Identification, 2000. **50**(6): p. 572-580.
39. Sears, V.G., Butcher, C.P.G., and Prizeman, T.M., *Enhancement of Fingerprints in Blood--Part 2: Protein Dyes.* Journal of Forensic Identification, 2001. **51**(1): p. 28-38.
40. Bailey, J.A., *An Evaluation of Magnetic and Nonmagnetic Fingerprint Powders on Ceramic Materials.* Journal of Forensic Identification, 2003. **53**(2): p. 162.
41. Stoilovic, M., Lennard, C., Wallace-Kunkel, C., and Roux, C., *Evaluation of a 1,2-Indanedione Formulation Containing Zinc Chloride for Improved Fingermark Detection on Paper.* Journal of Forensic Identification, 2007. **57**(1): p. 4-18.
42. Bessman, C.W., Nelson, E., Lipert, R.J., Coldiron, S., and Herrman, T.R., *A Comparison of Cyanoacrylate Fuming in a Vacuum Cabinet to a Humidity Fuming Chamber.* Journal of Forensic Identification, 2005. **55**(1): p. 10-27.
43. De Alcaraz-Fossoul, J., Barrot-Feixat, C., Zapico, S.C., Mancenido, M., Broatch, J., Roberts, K.A., Carreras-Marin, C., and Tasker, J., *Ridge Width Correlations between Inked Prints and Powdered Latent Fingerprints.* J Forensic Sci, 2018. **63**(4): p. 1085-1091. DOI: 10.1111/1556-4029.13656.
44. Wang, Y.F., Yang, R.Q., Shi, Z.X., Liu, J.J., Zhao, K., and Wang, Y.J., *The Effectiveness of Cdse Nanoparticle Suspension for Developing Latent Fingermarks.* Journal of Saudi Chemical Society, 2014. **18**(1): p. 13-18. DOI: https://doi.org/10.1016/j.jscs.2011.05.007.
45. Zampa, F., Mancini, L., and Caligiore, G., *Fingermark Visualization Exploiting Electrostatic Detection Apparatus (Esda): The Effect of the Composition and Age of the Latent Deposit.* Journal of Forensic Sciences, 2021. **66**(3): p. 1094-1103. DOI: https://doi.org/10.1111/1556-4029.14679.
46. Philipson, D. and Bleay, S., *Alternative Metal Processes for Vacuum Metal Deposition.* Journal of Forensic Identification, 2007. **57**(2): p. 252-273.
47. Bialek, I., Brzozowski, J., and Lukasik, A., *Comparison of the Effectiveness of Selected Methods of Contrasting of Fingerprints in Blood.* Problems in Forensic Science, 2004. **59**: p. 50-65.
48. Hoile, R., Walsh, S.J., and Roux, C., *Bioterrorism: Processing Contaminated Evidence, the Effects of Formaldehyde Gas on the Recovery of Latent Fingermarks*.* Journal of Forensic Sciences, 2007. **52**(5): p. 1097-1102. DOI: https://doi.org/10.1111/j.1556-4029.2007.00539.x.
49. Jasuja, O.P., Toofany, M.A., Singh, G., and Sodhi, G.S., *Dynamics of Latent Fingerprints: The Effect of Physical Factors on Quality of Ninhydrin Developed Prints — a Preliminary Study.* Science & Justice, 2009. **49**(1): p. 8-11. DOI: https://doi.org/10.1016/j.scijus.2008.08.001.
50. Marriott, C., Lee, R., Wilkes, Z., Comber, B., Spindler, X., Roux, C., and Lennard, C., *Evaluation of Fingermark Detection Sequences on Paper Substrates.* Forensic Science International, 2014. **236**: p. 30-37. DOI: https://doi.org/10.1016/j.forsciint.2013.12.028.
51. Hicklin, R.A., Buscaglia, J., and Roberts, M.A., *Assessing the Clarity of Friction Ridge Impressions.* Forensic Science International, 2013. **226**(1): p. 106-117. DOI: https://doi.org/10.1016/j.forsciint.2012.12.015.
52. Morimoto, S.-i., Kaminogo, A., and Hirano, T., *A New Method to Enhance Visualization of Latent Fingermarks by Sublimating Dyes, and Its Practical Use with a Combination of Cyanoacrylate Fuming.* Forensic Science International, 1998. **97**(2): p. 101-108. DOI: https://doi.org/10.1016/S0379-0738(98)00129-7.

53. Smith, K. and Kauffman, C., *Enhancement of Latent Prints on Metal Surfaces.* Journal of Forensic Identification, 2001. **51**(1): p. 9-15.
54. Wallace-Kunkel, C., Lennard, C., Stoilovic, M., and Roux, C., *Optimisation and Evaluation of 1,2-Indanedione for Use as a Fingermark Reagent and Its Application to Real Samples.* Forensic Science International, 2007. **168**(1): p. 14-26. DOI: https://doi.org/10.1016/j.forsciint.2006.06.006.
55. Jagjeet Singh, S., Sodhi, G.S., and Garg, R.K., *Evaluation of Fingerprint Powders.* Journal of Forensic Identification, 2006. **56**(2): p. 186-197.
56. Kent, T., *Standardizing Protocols for Fingerprint Reagent Testing.* Journal of Forensic Identification, 2010. **60**(3): p. 371-379.
57. Almog, J., Sears, V., Springer, E., Hewlett, D., Walker, S., Wiesner, S., Lidor, R., and Bahar, E., *Reagents for the Chemical Development of Latent Fingerprints: Scope and Limitations of Benzo[F]Ninhydrin in Comparison to Ninhydrin.* Journal of Forensic Sciences, 2000. **45**(3): p. 538-544. DOI: 10.1520/JFS14726J.
58. Russell, S.E., John, G.L., and Naccarato, S.L., *Modifications to the 1,2-Indanedione/Zinc Chloride Formula for Latent Print Development.* Journal of Forensic Identification, 2008. **58**(2): p. 182-192.
59. King, W.R., *The Effects of Differential Cyanoacrylate Fuming Times on the Development of Fingerprints on Skin.* Journal of Forensic Identification, 2009. **59**(5): p. 537-544.
60. Salama, J., Aumeer-Donovan, S., Lennard, C., and Roux, C., *Evaluation of the Fingermark Reagent Oil Red O as a Possible Replacement for Physical Developer.* Journal of Forensic Identification, 2008. **58**(2): p. 203-237.
61. Wood, M.A. and James, T., *Oro. The Physical Developer Replacement?* Science & Justice, 2009. **49**(4): p. 272-276. DOI: https://doi.org/10.1016/j.scijus.2009.02.006.
62. Swofford, H.J., *The Efficacy of Commercial Vs Noncommercial Physical Developer Solutions and the Sequential Enhancement of Friction Ridge Impressions Using Potassium Iodide.* Journal of Forensic Identification, 2010. **60**(1): p. 19-33.
63. Trapecar, M. and Balazic, J., *Fingerprint Recovery from Human Skin Surfaces.* Science & Justice, 2007. **47**(3): p. 136-140. DOI: https://doi.org/10.1016/j.scijus.2007.01.002.
64. Trapecar, M. and Vinkovic, M.K., *Techniques for Fingerprint Recovery on Vegetable and Fruit Surfaces Used in Slovenia — a Preliminary Study.* Science & Justice, 2008. **48**(4): p. 192-195. DOI: https://doi.org/10.1016/j.scijus.2008.05.003.
65. Jasuja, O.P., Singh, G.D., and Sodhi, G.S., *Small Particle Reagents: Development of Fluorescent Variants.* Science & Justice, 2008. **48**(3): p. 141-145. DOI: https://doi.org/10.1016/j.scijus.2008.04.002.
66. Patton, E., Brown, D., and Lewis, S., *Detection of Latent Fingermarks on Thermal Printer Paper by Dry Contact with 1,2-Indanedione.* Analytical methods, 2010. **2**. DOI: 10.1039/C0AY00121J.
67. Molina, D., *The Use of Un-Du to Separate Adhesive Materials.* Journal of Forensic Identification, 2007. **57**(5): p. 688-696.
68. De Alcaraz-Fossoul, J., Barrot Feixat, C., C. Zapico, S., McGarr, L., Carreras-Marin, C., Tasker, J., and Gené Badia, M., *Latent Fingermark Aging Patterns (Part Iv): Ridge Width as One Indicator of Degradation.* Journal of Forensic Sciences, 2019. **64**(4): p. 1057-1066. DOI: https://doi.org/10.1111/1556-4029.14018.
69. Bergeron, J.W., *Use of Liquid Nitrogen to Separate Adhesive Tapes.* Journal of Forensic Identification, 2009. **59**(1): p. 7-25.
70. Bergeron, J., *Development of Bloody Prints on Dark Surfaces with Titanium Dioxide and Methanol.* Journal of Forensic Identification, 2003. **53**(2): p. 149.
71. Baran, M., *Lifting Fingerprints from Skin Using Silicone.* Canadian Society of Forensic Science Journal, 2009. **42**: p. 121-131. DOI: 10.1080/00085030.2009.10757601.

72. Trapecar, M., *Lifting Techniques for Finger Marks on Human Skin Previous Enhancement by Swedish Black Powder — a Preliminary Study.* Science & Justice, 2009. **49**(4): p. 292-295. DOI: https://doi.org/10.1016/j.scijus.2009.01.018.
73. Eveleigh, G., *Development of Latent Fingerprints on Reptile Skin.* Journal of Forensic Identification, 2009. **59**(3): p. 285-296.
74. Snyder, C., *Methods for Developing and Preserving Prints in Petroleum Jelly.* Journal of Forensic Identification, 2009. **59**(2): p. 152-171.
75. Lin, A.C., Hsieh, H.M., Tsai, L.C., Linacre, A., and Lee, J.C., *Forensic Applications of Infrared Imaging for the Detection and Recording of Latent Evidence.* J Forensic Sci, 2007. **52**(5): p. 1148-50. DOI: 10.1111/j.1556-4029.2007.00502.x.
76. Almog, J., Sheratzki, H., Elad-Levin, M., Sagiv, A.E., Singh, G.D., and Jasuja, O.P., *Moistened Hands Do Not Necessarily Allude to High Quality Fingerprints: The Relationship between Palmar Moisture and Fingerprint Donorship.* J Forensic Sci, 2011. **56 Suppl 1**: p. S162-5. DOI: 10.1111/j.1556-4029.2010.01587.x.
77. Fieldhouse, S., *Consistency and Reproducibility in Fingermark Deposition.* Forensic Science International, 2011. **207**(1): p. 96-100. DOI: https://doi.org/10.1016/j.forsciint.2010.09.005.
78. Holt, D., *Determining the Quality and Sustainability of Friction Ridge Deposits on Envelopes Sent through the Postal System.* Journal of Forensic Identification, 2013. **63**(3): p. 247-253.
79. Smith, S., Sebetan, I.M., and Stein, P., *Development of Aged Latent Prints on Envelopes.* Journal of Forensic Identification, 2011. **61**(4): p. 363-372.
80. Lam, R. and Wilkinson, D., *Forensic Light Source and Environmental Effects on the Performance of 1,2-Indanedione-Zinc Chloride and 1,8-Diazafluoren-9-One for the Recovery of Latent Prints on Porous Substrates.* Journal of Forensic Identification, 2011. **61**(6): p. 607-620.
81. Hahn, W. and Ramotowski, R., *Evaluation of a Novel One-Step Fluorescent Cyanoacrylate Fuming Process for Latent Print Visualization.* Journal of Forensic Identification, 2012. **62**(3): p. 279-298.
82. Thiburce, N., Becue, A., Champod, C., and Crispino, F., *Design of a Control Slide for Cyanoacrylate Polymerization: Application to the Ca-Bluestar Sequence.* Journal of Forensic Identification, 2011. **61**(3): p. 232-249.
83. Schwarz, L. and Hermanowski, M.-L., *The Effect of Humidity on Long-Term Storage of Evidence Prior to Using Cyanoacrylate Fuming for the Detection of Latent Fingerprints.* Journal of Forensic Identification, 2012. **62**(3): p. 227-233.
84. Fieldhouse, S.J., *An Investigation into the Use of a Portable Cyanoacrylate Fuming System (Superfume®) and Aluminum Powder for the Development of Latent Fingermarks.* J Forensic Sci, 2011. **56**(6): p. 1514-20. DOI: 10.1111/j.1556-4029.2011.01847.x.
85. McMullen, L. and Beaudoin, A., *Application of Oil Red O Following Dfo and Ninhydrin Sequential Treatment: Enhancing Latent Fingerprints on Dry, Porous Surfaces.* Journal of Forensic Identification, 2013. **63**(4): p. 387-423.
86. Soars, D., *Comparison of the Cotton Wool Powdering Technique to Conventional Powdering with a Squirrel-Hair Brush.* Journal of Forensic Identification, 2012. **62**(5): p. 430-463.
87. Swofford, H.J. and Kovalchick, A.T., *Fingerprint Powders: Aerosolized Application Revisited.* Journal of Forensic Identification, 2012. **62**(2): p. 109-128.
88. Nag, K., Liu, X., Scott, A., and Sandling, G., *Production and Evaluation of a Dark Magnetic Flake Powder for Latent Fingerprint Development.* Journal of Forensic Identification, 2010. **60**(4): p. 395-407.
89. Ferguson, S., Nicholson, L., Farrugia, K., Bremner, D., and Gentles, D., *A Preliminary Investigation into the Acquisition of Fingerprints on Food.* Science & Justice, 2013. **53**(1): p. 67-72. DOI: https://doi.org/10.1016/j.scijus.2012.08.001.
90. Lodhi, K.M., Davis, S.A., Grier, R.L., and Saxon, A.B., *The Identification of Cell Phone Users from Latent Fingerprints.* Journal of Forensic Identification, 2013. **63**(1): p. 41-45.

91. Trapecar, M., *Finger Marks on Glass and Metal Surfaces Recovered from Stagnant Water.* Egyptian Journal of Forensic Sciences, 2012. **2**(2): p. 48-53. DOI: https://doi.org/10.1016/j.ejfs.2012.04.002.
92. Trapecar, M., *Fingerprint Recovery from Wet Transparent Foil.* Egyptian Journal of Forensic Sciences, 2012. **2**(4): p. 126-130. DOI: https://doi.org/10.1016/j.ejfs.2012.08.001.
93. Becue, A., Scoundrianos, A., and Moret, S., *Detection of Fingermarks by Colloidal Gold (Mmd/Smd) – Beyond the Ph 3 Limit.* Forensic Science International, 2012. **219**(1): p. 39-49. DOI: https://doi.org/10.1016/j.forsciint.2011.11.024.
94. Moret, S., Bécue, A., and Champod, C., *Cadmium-Free Quantum Dots in Aqueous Solution: Potential for Fingermark Detection, Synthesis and an Application to the Detection of Fingermarks in Blood on Non-Porous Surfaces.* Forensic Science International, 2013. **224**(1): p. 101-110. DOI: https://doi.org/10.1016/j.forsciint.2012.11.009.
95. Bissonnette, M., Knaap, W., and Forbes, S.L., *Steam Development of Latent Fingerprints on Thermal Paper.* Journal of Forensic Identification, 2010. **60**(6): p. 619-638.
96. Bouwmeester, M. and Kroos, J., *The Influence of Cyanoacrylate on the Efficiency of the Fingermark Detection Technique Amido Black.* Journal of Forensic Identification, 2020. **70**(3): p. 311-322.
97. Wightman, G. and O'Connor, D., *The Thermal Visualisation of Latent Fingermarks on Metallic Surfaces.* Forensic Science International, 2011. **204**(1): p. 88-96. DOI: https://doi.org/10.1016/j.forsciint.2010.05.007.
98. Bailey, J.A. and Crane, J.S., *Use of Nitrogen Cryogun for Separating Duct Tape and Recovery of Latent Fingerprints with a Powder Suspension Method.* Forensic Science International, 2011. **210**(1): p. 170-173. DOI: https://doi.org/10.1016/j.forsciint.2011.03.004.
99. Wilson, H.D., *Ray Dye Stain Versus Gentian Violet and Alternate Powder for Development of Latent Prints on the Adhesive Side of Tape.* Journal of Forensic Identification, 2010. **60**(5): p. 510-523.
100. Färber, D., Seul, A., Weisser, H.J., and Bohnert, M., *Recovery of Latent Fingerprints and DNA on Human Skin.* J Forensic Sci, 2010. **55**(6): p. 1457-61. DOI: 10.1111/j.1556-4029.2010.01476.x.
101. Fraser, J., Sturrock, K., Deacon, P., Bleay, S., and Bremner, D.H., *Visualisation of Fingermarks and Grab Impressions on Fabrics. Part 1: Gold/Zinc Vacuum Metal Deposition.* Forensic Science International, 2011. **208**(1): p. 74-78. DOI: https://doi.org/10.1016/j.forsciint.2010.11.003.
102. Garrett, H.J. and Bleay, S.M., *Evaluation of the Solvent Black 3 Fingermark Enhancement Reagent: Part 1 — Investigation of Fundamental Interactions and Comparisons with Other Lipid-Specific Reagents.* Science & Justice, 2013. **53**(2): p. 121-130. DOI: https://doi.org/10.1016/j.scijus.2012.11.006.
103. Daniel, R., *Pretreatment Processing for Nonporous Items Coated with Gasoline.* Journal of Forensic Identification, 2013. **63**(2): p. 165-173.
104. Downham, R.P., Mehmet, S., and Sears, V.G., *A Pseudo-Operational Investigation into the Development of Latent Fingerprints on Flexible Plastic Packaging Films.* Journal of Forensic Identification, 2012. **62**(6): p. 661-682.
105. Jasuja, O.P., Singh, G., and Almog, J., *Development of Latent Fingermarks by Aqueous Electrolytes.* Forensic Science International, 2011. **207**(1): p. 215-222. DOI: https://doi.org/10.1016/j.forsciint.2010.10.011.
106. Prete, C., Galmiche, L., Quenum-Possy-Berry, F.-G., Allain, C., Thiburce, N., and Colard, T., *Lumicyano(Tm): A New Fluorescent Cyanoacrylate for a One-Step Luminescent Latent Fingermark Development.* Forensic Science International (Online), 2013. **233**(1-3): p. 104-112. DOI: https://doi.org/10.1016/j.forsciint.2013.07.008.
107. Farrugia, K.J., Deacon, P., and Fraser, J., *Evaluation of Lumicyano™ Cyanoacrylate Fuming Process for the Development of Latent Fingermarks on Plastic Carrier Bags by Means of a*

Pseudo Operational Comparative Trial. Science & Justice, 2014. **54**(2): p. 126-132. DOI: https://doi.org/10.1016/j.scijus.2013.10.003.

108. Farrugia, K.J., Fraser, J., Calder, N., and Deacon, P., *Pseudo-Operational Trials of Lumicyano Solution and Lumicyano Powder for the Detection of Latent Fingermarks on Various Substrates.* Journal of Forensic Identification, 2014. **64**(6): p. 556-582.
109. Honig, M. and Yoak, J., *Oil Red O: A Comparative Performance Study.* Journal of Forensic Identification, 2016. **66**(2): p. 118-135.
110. Low, W.Z., Khoo, B.E., Aziz, Z.B.A., Low, L.W., Teng, T.T., and Abdullah, A.F.L.b., *Application of Acid-Modified Imperata Cylindrica Powder for Latent Fingerprint Development.* Science & Justice, 2015. **55**(5): p. 347-354. DOI: https://doi.org/10.1016/j.scijus.2015.04.008.
111. Moore-Davies, S., Christophe, D.P., and Morris, T.L., *Determining the Effects of Surface, Age, and Depletion on Latent Prints Processed with Aerosolized Powder Puff Fingerprint Powder.* Journal of Forensic Identification, 2016. **66**(3): p. 233-237,240-243.
112. Weston-Ford, K.A., Moseley, M.L., Hall, L.J., Marsh, N.P., Morgan, R.M., and Barron, L.P., *The Retrieval of Fingerprint Friction Ridge Detail from Elephant Ivory Using Reduced-Scale Magnetic and Non-Magnetic Powdering Materials.* Science & Justice, 2016. **56**(1): p. 1-8. DOI: https://doi.org/10.1016/j.scijus.2015.10.003.
113. Rohatgi, R., Sodhi, G.S., and Kapoor, A.K., *Small Particle Reagent Based on Crystal Violet Dye for Developing Latent Fingerprints on Non-Porous Wet Surfaces.* Egyptian Journal of Forensic Sciences, 2015. **5**(4): p. 162-165. DOI: https://doi.org/10.1016/j.ejfs.2014.08.005.
114. Castelló, A., Francés, F., and Verdú, F., *Solving Underwater Crimes: Development of Latent Prints Made on Submerged Objects.* Science & Justice, 2013. **53**(3): p. 328-331. DOI: https://doi.org/10.1016/j.scijus.2013.04.002.
115. Rohatgi, R. and Kapoor, A.K., *Development of Latent Fingerprints on Wet Non-Porous Surfaces with Spr Based on Basic Fuchsin Dye.* Egyptian Journal of Forensic Sciences, 2016. **6**(2): p. 179-184. DOI: https://doi.org/10.1016/j.ejfs.2015.05.007.
116. Knighting, S., Fraser, J., Sturrock, K., Deacon, P., Bleay, S., and Bremner, D.H., *Visualisation of Fingermarks and Grab Impressions on Dark Fabrics Using Silver Vacuum Metal Deposition.* Science & Justice, 2013. **53**(3): p. 309-314. DOI: https://doi.org/10.1016/j.scijus.2013.01.002.
117. Fraser, J., Deacon, P., Bleay, S., and Bremner, D.H., *A Comparison of the Use of Vacuum Metal Deposition Versus Cyanoacrylate Fuming for Visualisation of Fingermarks and Grab Impressions on Fabrics.* Science & Justice, 2014. **54**(2): p. 133-140. DOI: https://doi.org/10.1016/j.scijus.2013.11.005.
118. Levin-Elad, M. and Bentolila, A., *Using Alginate Gel Followed by Chemical Enhancement to Recover Blood-Contaminated Fingermarks from Fabrics.* Journal of Forensic Identification, 2015. **66**.
119. James, R.M. and Altamimi, M.J., *The Enhancement of Friction Ridge Detail on Brass Ammunition Casings Using Cold Patination Fluid.* Forensic Science International, 2015. **257**: p. 385-392. DOI: https://doi.org/10.1016/j.forsciint.2015.10.004.
120. Jasuja, O.P., Singh, K., Sodhi, P., and Singh, G., *Development of Latent Fingermarks by Aqueous Electrolytes on Metallic Surfaces: Further Studies.* Canadian Society of Forensic Science Journal, 2015. **48**: p. 1-15. DOI: 10.1080/00085030.2015.1051316.
121. Petretei, D. and Angyal, M., *Recovering Bloody Fingerprints from Skin.* Journal of Forensic Identification, 2015. **65**(5): p. 813-827.
122. Luo, Y.-P., Zhao, Y.-B., and Liu, S., *Evaluation of Dfo/Pvp and Its Application to Latent Fingermarks Development on Thermal Paper.* Forensic Science International, 2013. **229**(1): p. 75-79. DOI: https://doi.org/10.1016/j.forsciint.2013.03.045.
123. Ponschke, M. and Hornickel, M., *A Limited Validation and Comparison of 1,2-Indanedione and Thermanin for Latent Print Development on Thermal Paper.* Journal of Forensic Identification, 2016. **66**(3): p. 245-258.

124. Gardner, S.J., Cordingley, T.H., and Francis, S.C., *An Investigation into Effective Methodologies for Latent Fingerprint Enhancement on Items Recovered from Fire.* Science & Justice, 2016. **56**(4): p. 241-246. DOI: https://doi.org/10.1016/j.scijus.2016.02.003.
125. Dhall, J.K., Sodhi, G.S., and Kapoor, A.K., *A Novel Method for the Development of Latent Fingerprints Recovered from Arson Simulation.* Egyptian Journal of Forensic Sciences, 2013. **3**(4): p. 99-103. DOI: https://doi.org/10.1016/j.ejfs.2013.03.002.
126. McCarthy, D., *Sulfosalicylic Acid and Rhodamine 6g as a Fixing and Development Solution for the Enhancement of Blood Impressions.* Journal of Forensic Identification, 2014. **64**(4): p. 351-374.
127. Mattson, P. and Bilous, P., *Coomassie Brilliant Blue: An Excellent Reagent for the Enhancement of Faint Bloody Fingerprints.* Journal of the Canadian Society of Forensic Science, 2014. **47**: p. 20-36. DOI: 10.1080/00085030.2014.885728.
128. Cadd, S., Li, B., Beveridge, P., O'Hare, W.T., Campbell, A., and Islam, M., *The Non-Contact Detection and Identification of Blood Stained Fingerprints Using Visible Wavelength Reflectance Hyperspectral Imaging: Part 1.* Science & Justice, 2016. **56**(3): p. 181-190. DOI: https://doi.org/10.1016/j.scijus.2016.01.004.
129. Cadd, S., Li, B., Beveridge, P., O'Hare, W.T., Campbell, A., and Islam, M., *The Non-Contact Detection and Identification of Blood Stained Fingerprints Using Visible Wavelength Hyperspectral Imaging: Part Ii Effectiveness on a Range of Substrates.* Sci Justice, 2016. **56**(3): p. 191-200. DOI: 10.1016/j.scijus.2016.01.005.
130. Soltyszewski, I., Moszczynski, J., Pepinski, W., Jastrzebowska, S., Makulec, W., Zbiec, R., and Janica, J., *Fingerprint Detection and DNA Typing on Objects Recovered from Water.* Journal of Forensic Identification, 2007. **57**(5): p. 681-687.
131. Stow, K.M. and McGurry, J., *The Recovery of Finger Marks from Soot-Covered Glass Fire Debris.* Science & Justice, 2006. **46**(1): p. 3-14. DOI: https://doi.org/10.1016/S1355-0306(06)71562-3.
132. Maslanka, D.S., *Latent Fingerprints on a Nonporous Surface Exposed to Everyday Liquids.* Journal of Forensic Identification, 2016. **66**(2): p. 137-154.
133. Jasuja, O.P., Kumar, P., and Singh, G., *Development of Latent Fingermarks on Surfaces Submerged in Water: Optimization Studies for Phase Transfer Catalyst (Ptc) Based Reagents.* Science & Justice, 2015. **55**(5): p. 335-342. DOI: https://doi.org/10.1016/j.scijus.2015.03.001.
134. Hefetz, I., Cohen, A., Cohen, Y., and Chaikovsky, A., *Development of Latent Fingermarks from Rocks and Stones.* J Forensic Sci, 2014. **59**(5): p. 1226-30. DOI: 10.1111/1556-4029.12438.
135. Plazibat, S.L., Swiontek, S.E., Lakhtakia, A., and Roy, R., *White-Light Vs. Short-Wavelength Ultraviolet Illumination of Fingerprints Developed with Columnar Thin Films of Alq3.* Canadian Society of Forensic Science Journal, 2015. **48**: p. 190 - 199.
136. De Alcaraz-Fossoul, J., Barrot Feixat, C., Carreras-Marin, C., Tasker, J., Zapico, S.C., and Gené Badia, M., *Latent Fingermark Aging Patterns (Part Iii): Discontinuity Index as One Indicator of Degradation.* J Forensic Sci, 2017. **62**(5): p. 1180-1187. DOI: 10.1111/1556-4029.13438.
137. Levin-Elad, M., Liptz, Y., Bar-Or, K.L., and Almog, J., *1,2-Indanedione — a Winning Ticket for Developing Fingermarks: A Validation Study.* Forensic Science International, 2017. **271**: p. 8-12. DOI: https://doi.org/10.1016/j.forsciint.2016.12.007.
138. Casault, P., Gilbert, N., and Daoust, B., *Comparison of Various Alkyl Cyanoacrylates for Fingerprint Development.* Canadian Society of Forensic Science Journal, 2016. **50**: p. 1-22. DOI: 10.1080/00085030.2016.1223438.
139. Bisotti, A., Allain, C., Georges, J.-L., Guichard, F., Audebert, P., Barbosa, I., and Galmiche, L., *New Lumicyano Kit: Comparison Studies with the First Generation and Effectiveness on Nonporous Substrates.* Journal of Forensic Identification, 2016. **66**(6): p. 560-575.
140. Korzeniewski, P. and Svensson, M., *Longevity of Tween 20-Based Physical Developer.* Journal of Forensic Identification, 2018. **68**(4): p. 557-566.

141. Li, H., Guo, X., Liu, J., and Li, F., *A Synthesis of Fluorescent Starch Based on Carbon Nanoparticles for Fingerprints Detection.* Optical Materials, 2016. **60**: p. 404-410. DOI: https://doi.org/10.1016/j.optmat.2016.08.010.
142. Kim, A., Ryu, S.-J., Lee, J., and Jung, H., *Development of Latent Fingermarks on Nonporous and Semiporous Substrates Using Photoluminescent Eu(Phen) 2 Complex Intercalated Clay Hybrids with Enhanced Adhesion.* Journal of Forensic Sciences, 2018. **63**. DOI: 10.1111/1556-4029.13766.
143. Xu, J., Zhang, Z., Zheng, X., and Bond, J.W., *A Modified Electrostatic Adsorption Apparatus for Latent Fingerprint Development on Unfired Cartridge Cases.* J Forensic Sci, 2017. **62**(3): p. 776-781. DOI: 10.1111/1556-4029.13344.
144. Dove, A., *Fingerprint Development on Cartridge Cases through the Electrodeposition of Gun Blue.* Journal of Forensic Identification, 2017. **67**(3): p. 391-409.
145. Dove, A., *Follow-Up: Fingermark Development on Fired Cartridge Cases through the Electrodeposition of Gun Blue.* Journal of Forensic Identification, 2018. **68**(4): p. 567-587.
146. Morrissey, J., Larrosa, J., and Birkett, J.W., *A Preliminary Evaluation of the Use of Gun Bluing to Enhance Friction Ridge Detail on Cartridge Casings.* Journal of Forensic Identification, 2017. **67**(3): p. 313-322.
147. Jonas, A., Rubner, I., and Oetken, M., *Development of Latent Fingerprints on Thermal Paper by Immersion in Hot Water.* Journal of Forensic Identification, 2019. **69**(2): p. 141-162.
148. Rairden, A. and Castillo, A., *Developing Latent Fingerprints on Thermal Paper by Fuming with Hydrochloric Acid.* Journal of Forensic Identification, 2017. **67**(2): p. 243-257.
149. Pettolina, M., Rainey, J., and Sanchez, R., *Using Bluestar Forensic to Detect Latent Bloodstains under Coats of Paint.* Journal of Forensic Identification, 2017. **67**(3): p. 341-353.
150. Johnson, S., *Examining the Effectiveness of Processing Fired Cartridge Cases for Latent Evidence.* Journal of Forensic Identification, 2019. **69**(1): p. 27-34.
151. Barnes, B., Clark, J., Kadane, J., Priestley, M., Spencer, N., Tator, D., Wauthier, D., and Yohannan, J., *Latent Print Processing of Glassine Stamp Bags Containing Suspected Heroin: The Search for an Efficient and Safe Method.* Journal of Forensic Identification, 2018. **68**(4): p. 588-606.
152. Madkour, S., sheta, A., El Dine Fatma, B., Elwakeel, Y., and AbdAllah, N., *Development of Latent Fingerprints on Non-Porous Surfaces Recovered from Fresh and Sea Water.* Egyptian Journal of Forensic Sciences, 2017. **7**(1). DOI: https://doi.org/10.1186/s41935-017-0008-8.
153. Cai, N., Zou, Y., Almog, J., Wang, G., and Mi, Z., *Inherent Fluorescence Detection of Latent Fingermarks by Homemade Shortwave Ultraviolet Laser.* J Forensic Sci, 2017. **62**(1): p. 209-212. DOI: 10.1111/1556-4029.13239.
154. Akiba, N., Kuroki, K., Kurosawa, K., and Tsuchiya, K., *Visualization of Aged Fingerprints with an Ultraviolet Laser.* J Forensic Sci, 2018. **63**(2): p. 556-562. DOI: 10.1111/1556-4029.13588.
155. Sorum, E.D., *Performance Review of the Ff-1.0 Forensic Filter and the Expose Curved Barrier Filter by Arrowhead Forensics.* Journal of Forensic Identification, 2019. **69**(1): p. 35-48.
156. Fieldhouse, S., Oravcova, E., and Walton-Williams, L., *The Effect of DNA Recovery on the Subsequent Quality of Latent Fingermarks.* Forensic Science International, 2016. **267**: p. 78-88. DOI: https://doi.org/10.1016/j.forsciint.2016.08.003.
157. Feine, I., Shpitzen, M., Geller, B., Salmon, E., Peleg, T., Roth, J., and Gafny, R., *Acetone Facilitated DNA Sampling from Electrical Tapes Improves DNA Recovery and Enables Latent Fingerprints Development.* Forensic Science International, 2017. **276**: p. 107-110. DOI: https://doi.org/10.1016/j.forsciint.2017.04.023.
158. Florence, G. and Gee, W., *Harnessing Volatile Luminescent Lanthanide Complexes to Visualise Latent Fingermarks on Nonporous Surfaces.* The Analyst, 2018. **143**. DOI: 10.1039/C8AN01150H.

159. Arbeli, T., Liptz, Y., Bengiat, R., and Levin-Elad, M., *Development of Fingermarks on Latex Gloves: The Solution to a Challenging Surface.* Forensic Science International, 2017. **280**: p. 147-152. DOI: https://doi.org/10.1016/j.forsciint.2017.09.015.
160. Azoury, M., Rozen, E., Yannay, U., and Peleg-Shironi, Y., *Old Latent Prints Developmed with Powder: A Rare Phenomenon?* Journal of Forensic Identification, 2004. **54**(5): p. 534-541.
161. Mi Jung, C., McDonagh, A.M., Maynard, P.J., Wuhrer, R., and et al., *Preparation and Evaluation of Metal Nanopowders for the Detection of Fingermarks on Nonporous Surfaces.* Journal of Forensic Identification, 2006. **56**(5): p. 756-768.
162. Rawji, A. and Beaudoin, A., *Oil Red O Versus Physical Developer on Wet Papers: A Comparative Study.* Journal of Forensic Identification, 2006. **56**(1): p. 33-54.
163. Singh, G.d., Sodhi, G.S., and Jasuja, O.P., *Detection of Latent Fingerprints on Fruits and Vegetables.* Journal of Forensic Identification, 2006. **56**(3): p. 374-381.
164. Guigui, K. and Beaudoin, A., *The Use of Oil Red O in Sequence with Other Methods of Fingerprint Development.* Journal of Forensic Identification, 2007. **57**(4): p. 550-581.
165. Williams, N.H. and Elliott, K.T., *Development of Latent Prints Using Titanium Dioxide (Tio^Sub 2^) in Small Particle Reagent, White (Spr-W) on Adhesives.* Journal of Forensic Identification, 2005. **55**(3): p. 292-305.
166. Marchant, B. and Tague, C., *Developing Fingerprints in Blood: A Comparison of Several Chemical Techniques.* Journal of Forensic Identification, 2007. **57**(1): p. 76-93.
167. Sears, V.G., Butcher, C.P.G., and Fitzgerald, L.A., *Enhancement of Fingerprints in Blood Part 3: Reactive Techniques, Acid Yellow 7, and Process Sequences.* Journal of Forensic Identification, 2005. **55**(6): p. 741-786.
168. Fieldhouse, S., Parsons, R., Bleay, S., and Walton-Williams, L., *The Effect of DNA Recovery on the Subsequent Quality of Latent Fingermarks: A Pseudo-Operational Trial.* Forensic Science International, 2020. **307**: p. 110076. DOI: https://doi.org/10.1016/j.forsciint.2019.110076.
169. Exall, A., Goddard, I., and Bandey, H., *Preliminary Investigations Using Recover Latent Fingerprint Technology on Unfired Ammunition and Fired Cartridge Cases.* Science & Justice, 2022. **62**(5): p. 556-568. DOI: https://doi.org/10.1016/j.scijus.2022.08.001.
170. Steiner, R., Moret, S., and Roux, C., *Evaluation of the Use of Chemical Pads to Mimic Latent Fingermarks for Research Purposes.* Forensic Science International, 2020. **314**: p. 110411. DOI: https://doi.org/10.1016/j.forsciint.2020.110411.
171. Bengiat, R., Liptz, Y., Rajs, N., Bentolila, A., and Levin-Elad, M., *Time Is Money or Money Is Time? A Rapid Operational Sequence for Detecting Fingermarks on Polymer Banknotes.* J Forensic Sci, 2020. **65**(5): p. 1465-1473. DOI: 10.1111/1556-4029.14479.
172. Monson, K., Kyllonen, K., Leggitt, J., Edmiston, K., Justus, C., Kavlick, M., Phillip, M., Roberts, M., Shegogue, C., and Watts, G., *Blast Suppression Foam, Aqueous Gel Blocks, and Their Effect on Subsequent Analysis of Forensic Evidence*: Evidence Effects of Foam and Gel Blocks.* Journal of Forensic Sciences, 2020. **65**. DOI: 10.1111/1556-4029.14536.
173. Cai, K., Yang, R., Wang, Y., Yu, X., and Liu, J., *Super Fast Detection of Latent Fingerprints with Water Soluble Cdte Quantum Dots.* Forensic Science International, 2013. **226**(1): p. 240-243. DOI: https://doi.org/10.1016/j.forsciint.2013.01.035.
174. Thomas-Wilson, A., Guo, Z.Y., Luck, R., Hussey, L.J., Harmsworth, M., Coulston, J.L., Hillman, A.R., and Sears, V.G., *Replacing Synperonic® N in the Physical Developer Fingermark Visualisation Process: Reformulation ☆.* Forensic Science International (Online), 2021. **323**. DOI: https://doi.org/10.1016/j.forsciint.2021.110786.
175. Jones, C., Fraser, J., Deacon, P., Lindsay, M., Carlysle-Davies, F., and Farrugia, K.J., *An Assessment of a Portable Cyanoacrylate Fuming System (Lumifume™) for the Development of Latent Fingermarks.* Forensic Science International, 2019. **305**: p. 109966. DOI: https://doi.org/10.1016/j.forsciint.2019.109966.
176. Zampa, F., Hilgert, M., and Mattei, A., *Fingermark Visualisation on Compostable Polymers – a Comparison among Different Procedures as an Outcome of the 2020 Collaborative Exercise of*

the Enfsi Fingerprint Working Group. Forensic Science International, 2022. **335**: p. 111276. DOI: https://doi.org/10.1016/j.forsciint.2022.111276.

177. Bouzin, J.T., Merendino, J., Bleay, S.M., Sauzier, G., and Lewis, S.W., *New Light on Old Fingermarks: The Detection of Historic Latent Fingermarks on Old Paper Documents Using 1,2-Indanedione/Zinc.* Forensic Science International: Reports, 2020. **2**: p. 100145. DOI: https://doi.org/10.1016/j.fsir.2020.100145.
178. Shalhoub, R., Quinones, I., Ames, C., Multaney, B., Curtis, S., Seeboruth, H., Moore, S., and Daniel, B., *The Recovery of Latent Fingermarks and DNA Using a Silicone-Based Casting Material.* Forensic Science International, 2008. **178**(2): p. 199-203. DOI: https://doi.org/10.1016/j.forsciint.2008.04.001.
179. De Alcaraz-Fossoul, J. and Li, S., *Evaluation of an Inkless Method for Fingerprint Recordings Using Hand Sanitizer Gel on Thermal Paper.* Forensic Science International, 2021. **323**: p. 110787. DOI: https://doi.org/10.1016/j.forsciint.2021.110787.
180. De Alcaraz-Fossoul, J., Tully-Doyle, R., Weber, A.R., Barrot Feixat, C., Zapico, S.C., Rivera Cardenas, N., Sirard, M.J., and Graber, R.P., *A Small Population Study on Friction Skin Ridges: Differences in Ridge Widths between Latent and Inked Fingerprints.* Journal of Forensic Sciences, 2020. **65**(2): p. 620-626. DOI: https://doi.org/10.1111/1556-4029.14210.
181. Amith Yadav, H.J., Eraiah, B., Basavaraj, R.B., Nagabhushana, H., Darshan, G.P., Sharma, S.C., Daruka Prasad, B., Nithya, R., and Shanthi, S., *Rapid Synthesis of C-Dot@Tio2 Core-Shell Composite Labeling Agent: Probing of Complex Fingerprints Recovery in Fresh Water.* Journal of Alloys and Compounds, 2018. **742**: p. 1006-1018. DOI: https://doi.org/10.1016/j.jallcom.2017.12.251.
182. Azman, A.R., Zulkifli, S.N., Mahat, N.A., Ahmad, W.A., Hamzah, H.H., and Wahab, R.A., *Visualisation of Latent Fingerprints on Non-Porous Object Immersed in Stagnant Tap Water Using Safranin-Tinted Candida Rugosa Lipase Reagent.* Malaysian Journal of Fundamental and Applied Sciences, 2019. **15**: p. 781-783.
183. Kumari, V., Thakar, M.K., Mondal, B., and Pal, S.K., *Effects of Oils, Lotions, Hand Sanitizers, and Mehendi on Fingerprints Captured through Digital Fingerprint Scanner.* Egyptian Journal of Forensic Sciences, 2021. **11**(1): p. 8. DOI: 10.1186/s41935-021-00222-w.
184. Harush-Brosh, Y., Hefetz, I., Hauzer, M., Mayuoni-Kirshenbaum, L., Mashiach, Y., Faerman, M., and Levin-Elad, M., *Clean and Clear (out): A Neat Method for the Recovery of Latent Fingermarks from Crime-Scenes.* Forensic Science International, 2020. **306**: p. 110049. DOI: https://doi.org/10.1016/j.forsciint.2019.110049.
185. Lam, R., Hockey, D., Williamson, J., and Hearns, N.G.R., *Latent Fingermark Development on Fired and Unfired Brass Ammunition under Controlled and Blind Conditions.* Forensic Science International, 2022. **337**: p. 111369. DOI: https://doi.org/10.1016/j.forsciint.2022.111369.
186. Kapoor, N., Ahmed, S., Shukla, R.K., and Badiye, A., *Development of Submerged and Successive Latent Fingerprints: A Comparative Study.* Egyptian Journal of Forensic Sciences, 2019. **9**(1): p. 44. DOI: 10.1186/s41935-019-0147-1.
187. Nagar, V., Tripathi, K., Aseri, V., Mavry, B., Chopade, R.L., Verma, R., Singh, A., Singh Sankhla, M., Pritam, P.P., and Parihar, K., *Latent Friction Ridge Analysis of Developed Fingerprints after Treatment with Various Liquid Materials on Porous Surface.* Materials Today: Proceedings, 2022. **69**: p. 1532-1539. DOI: https://doi.org/10.1016/j.matpr.2022.04.619.
188. Rajan, R., Zakaria, Y., Shamsuddin, S., and Hassan, N.F.N., *Nanocarbon Powder for Latent Fingermark Development: A Green Chemistry Approach.* Egyptian Journal of Forensic Sciences, 2018. **8**(1): p. 60. DOI: 10.1186/s41935-018-0091-5.
189. De Alcaraz-Fossoul, J., Einfalt, M.R., and Kammrath, B.W., *The Influence of Biological Sex on Latent Fingermark Aging as Examined by the Color Contrast Technique.* Journal of Forensic Sciences, 2022. **67**(4): p. 1476-1489. DOI: https://doi.org/10.1111/1556-4029.15035.
190. Finigan, A., McCarthy, D., and Krosch, M.N., *Preliminary Assessment of Fingermark Development Techniques for Recovering Faint Ridge Impressions from Persons with*

Ectodermal Dysplasia. Australian Journal of Forensic Sciences, 2021: p. 1-11. DOI: 10.1080/00450618.2021.2002406.

191. Salmeron, L.C. and De Alcaraz-Fossoul, J., *Evaluation of the Loss of Fingermark Ridge Clarity as a Function of Biological Sex.* Journal of Forensic Sciences, 2022. **67**(6): p. 2444-2452. DOI: https://doi.org/10.1111/1556-4029.15138.
192. Li, K., Li, S., and Yang, J., *Optimum Conditions and Application of One-Step Fluorescent Cyanoacrylate Fuming Method for Fingermark Development Based on Polycyano Uv.* Forensic Sciences Research, 2022. **7**(3): p. 550-559. DOI: 10.1080/20961790.2022.2049153.
193. Zampa, F., Hilgert, M., and Mattei, A., *Fingermark Visualisation on Thermal Paper – a Comparison among Different Procedures as an Outcome of the 2018 Collaborative Exercise of the Enfsi Fingerprint Working Group.* Forensic Science International, 2020. **316**: p. 110479. DOI: https://doi.org/10.1016/j.forsciint.2020.110479.
194. Vanderheyden, N., Verhoeven, E., Vermeulen, S., and Bekaert, B., *Survival of Forensic Trace Evidence on Improvised Explosive Devices: Perspectives on Individualisation.* Scientific Reports, 2020. **10**(1): p. 12813. DOI: 10.1038/s41598-020-69385-1.
195. Yong, Y., Zakaria, Y., and Nik Hassan, N.F., *Recovery of Latent Fingermarks from Burial Environments.* Egyptian Journal of Forensic Sciences, 2020. **10**. DOI: 10.1186/s41935-020-00206-2.
196. Deepthi, N.H., Darshan, G.P., Basavaraj, R.B., Prasad B, D., Sharma, S.C., D, K., and Nagabhushana, H., *Nanostructured Stannic Oxides for White Light Emitting Diodes Provides Authentication for Latent Fingerprints Visualization under Diverse Environmental Conditions.* ACS Sustainable Chemistry & Engineering, 2019. **7**(1): p. 578-591. DOI: 10.1021/acssuschemeng.8b04109.
197. Peng, D., Liu, X., Huang, M., and Liu, R., *Characterization of a Novel Co 2 Tio 4 Nanopowder for the Rapid Identification of Latent and Blood Fingerprints.* Analytical Letters, 2017. **51**. DOI: 10.1080/00032719.2017.1391827.
198. Huang, W., Li, X., Wang, H., Xu, X., Liu, H., and Wang, G., *Synthesis of Amphiphilic Silica Nanoparticles for Latent Fingerprint Detection.* Analytical Letters, 2015. **48**. DOI: 10.1080/00032719.2014.984195.
199. Yang, R. and Lian, J., *Studies on the Development of Latent Fingerprints by the Method of Solid–Medium Ninhydrin.* Forensic Science International, 2014. **242**: p. 123-126. DOI: https://doi.org/10.1016/j.forsciint.2014.06.036.
200. Kupferschmid, E., Schwarz, L., and Champod, C., *Development of Standardized Test Strips as a Process Control for the Detection of Latent Fingermarks Using Physical Developers.* Journal of Forensic Identification, 2010. **60**(6): p. 639-655.
201. Blotta, E. and Moler, E., *Fingerprint Image Enhancement by Differential Hysteresis Processing.* Forensic Science International, 2004. **141**(2): p. 109-113. DOI: https://doi.org/10.1016/j.forsciint.2004.01.014.
202. Magora, A., Azoury, M., and Geller, B., *Treatment of Cocaine Contaminated Polythene Bags Prior to Fingerprint Development by Cyanoacrylate Fuming.* Journal of Forensic Identification, 2002. **52**(2): p. 159-167.
203. Colella, O., Miller, M., Boone, E., Buffington-Lester, S., Curran III, F.J., and Simmons, T., *The Effect of Time and Temperature on the Persistence and Quality of Latent Fingerprints Recovered from 60-Watt Incandescent Light Bulbs.* Journal of Forensic Sciences, 2020. **65**(1): p. 90-96. DOI: https://doi.org/10.1111/1556-4029.14133.
204. Eksinitkun, G., Pansiw, S., and Phutdhawong, W., *Simple Improvement in Latent Fingerprint Detection with Ninhydrin/Water Glue on Thermal Paper.* Journal of Physics: Conference Series, 2019. **1380**(1): p. 012122. DOI: 10.1088/1742-6596/1380/1/012122.
205. Joy, J., Cox, J.O., Hudson, B.C., Armstrong, J., Miller, M.T., and Cruz, T.D., *Comparison of Cyanoacrylate Fuming Techniques of Bloody and Latent Fingerprints and the Examination of Subsequent DNA Success.* Journal of Forensic Identification, 2020. **70**(2): p. 171-185.

206. Garcia, M. and Gokool, V., *Latent Print Development on the Adhesive Side of Tape.* Journal of Forensic Identification, 2020. **70**(1): p. 103-123.
207. Martinez, T.M., *The Effects of Cyanoacrylate Fuming and Rhodamine 6g on the Adhesive Side of Tape When Processing with Adhesive-Side Powders.* Journal of Forensic Identification, 2020. **70**(1): p. 23-35.
208. Casault, P., Camiré, A., Morin, R., and Daoust, B., *Comparison of Various Alkyl Cyanoacrylates Applied to Fingerprint Development in a Commercial Fuming Chamber.* Journal of Forensic Identification, 2020. **70**(3): p. 365-384.
209. Shipman, J., *Evaluation of Vacuum Metal Deposition: Fingerprint Development on Plastic, Gloves, Handguns, and Live Ammo.* Journal of Forensic Identification, 2021. **71**(2): p. 119-141.
210. Nugroho, D., Keawprom, C., Chanthai, S., Oh, W.C., and Benchawattananon, R., *Highly Sensitive Fingerprint Detection under Uv Light on Non-Porous Surface Using Starch-Powder Based Luminol-Doped Carbon Dots (N-Cds) from Tender Coconut Water as a Green Carbon Source.* Nanomaterials (Basel), 2022. **12**(3). DOI: 10.3390/nano12030400.
211. Brown, J. and Clutter, S., *Fingerprinting Different Food Surfaces at Crime Scenes.* Journal of Forensic Identification, 2019. **69**(3): p. 271-279.
212. Ho, M. and George, M., *The Use of Liquid Latex as a Pretreatment to Remove Debris Off the Exterior Surface of Vehicles for Fingerprint Recovery.* Journal of Forensic Identification, 2019. **69**(3): p. 329-337.
213. Christofidis, G., Morrissey, J., and Birkett, J.W., *Using Gun Blue to Enhance Fingermark Ridge Detail on Ballistic Brass.* Journal of Forensic Identification, 2019. **69**(4): p. 431-449.
214. Kusenthiran, S.G.V., Rogers, T., and Knaap, W., *Latent Fingerprint Detection on Thermal Paper Using Vacuum Metal Deposition and Steam.* Journal of Forensic Identification, 2010. **60**(1): p. 34-44.
215. Cramer, D. and Glass, K., *Developing Latent Fingerprints on the Adhesive Side of Tape Using a Freezing Technique.* Journal of Forensic Identification, 2008. **58**(4): p. 419-423.
216. Jasuja, O.P. and Singh, K., *The Next Level Aqueous Electrolyte Reagent (Aer) for Development of Latent Fingermarks.* Canadian Society of Forensic Science Journal, 2019. **52**(1): p. 33-52. DOI: 10.1080/00085030.2019.1581691.
217. !!! INVALID CITATION !!! [3, 10, 18, 30, 35, 50, 217-373].
218. Bandey, H.L., *The Powders Process, Study 1: Evaluation of Fingerprint Brushes for Use with Aluminium Powder*, in *Fingerprint Development and Imaging Newsletter: Special Edition*. 2004.
219. Bandey, H.L. and Hardy, T., *The Powders Process Study 3: Evaluation of Fingerprint Powders on Textured Surfaces and U-Pvc*, in *Fingerprint and Footwear Forensics Newsletter: Special Edition*. 2006.
220. Sears, V., Batham, R., and Bleay, S., *The Effectiveness of 1,2-Indandione-Zinc Formulations and Comparison with Hfe-Based 1,8-Diazafluoren-9-One for Fingerprint Development.* Journal of Forensic Identification, 2009. **59**(6): p. 654-678.
221. Lee, J.L., Bleay, S., Sears, V.G., Mehmet, S., and Croxton, R., *Evaluation of the Dimethylaminocinnamaldeyhde Contact Transfer Process and Its Application to Fingerprint Development on Thermal Papers.* Journal of Forensic Identification, 2009. **59**: p. 545-568.
222. Daéid, N.N., Carter, S., and Laing, K., *Comparison of Vacuum Metal Deposition and Powder Suspension for Recovery of Fingerprints on Wetted Nonporous Surfaces.* Journal of Forensic Identification, 2008. **58**(5): p. 600-613.
223. Paterson, E., Bond, J.W., and Robert Hillman, A., *A Comparison of Cleaning Regimes for the Effective Removal of Fingerprint Deposits from Brass.* Journal of Forensic Sciences, 2010. **55**(1): p. 221-224. DOI: https://doi.org/10.1111/j.1556-4029.2009.01219.x.
224. Sears, V.G., Bleay, S.M., Bandey, H.L., and Bowman, V.J., *A Methodology for Finger Mark Research.* Science & Justice, 2012. **52**(3): p. 145-160. DOI: https://doi.org/10.1016/j.scijus.2011.10.006.

225. Porpiglia, N., Bleay, S., Fitzgerald, L., and Barron, L., *An Assessment of the Effectiveness of 5-Methylthioninhydrin within Dual Action Reagents for Latent Fingerprint Development on Paper Substrates.* Science & Justice, 2012. **52**(1): p. 42-48. DOI: https://doi.org/10.1016/j.scijus.2011.04.006.
226. Mao, N.-h., Zhao, Y.-B., and Luo, Y., *A New Dfo Method for Developing Latent Fingermarks on Thermal Paper.* Journal of Forensic Identification, 2014. **2**(4).
227. Paine, M., Bandey, H.L., Bleay, S.M., and Willson, H., *The Effect of Relative Humidity on the Effectiveness of the Cyanoacrylate Fuming Process for Fingermark Development and on the Microstructure of the Developed Marks.* Forensic Science International, 2011. **212**(1): p. 130-142. DOI: https://doi.org/10.1016/j.forsciint.2011.06.003.
228. Nixon, C., Almond, M.J., Baum, J.V., and Bond, J.W., *Enhancement of Aged and Denatured Fingerprints Using the Cyanoacrylate Fuming Technique Following Dusting with Amino Acid-Containing Powders.* J Forensic Sci, 2013. **58**(2): p. 508-12. DOI: 10.1111/1556-4029.12052.
229. Frick, A.A., Fritz, P., Lewis, S.W., and van Bronswijk, W., *A Modified Oil Red O Formulation for the Detection of Latent Fingermarks on Porous Substrates.* Journal of Forensic Identification, 2012. **62**(6): p. 623-641.
230. Frick, A.A., Fritz, P., Lewis, S.W., and van Bronswijk, W., *Sequencing of a Modified Oil Red O Development Technique for the Detection of Latent Fingermarks on Paper Surfaces.* Journal of Forensic Identification, 2013. **63**(4): p. 369-385.
231. Sauzier, G., Frick, A.A., and Lewis, S.W., *Investigation into the Performance of Physical Developer Formulations for Visualizing Latent Fingerprints on Paper.* Journal of Forensic Identification, 2013. **63**(1): p. 70-89.
232. Bleay, S.M., Bandey, H.L., Black, M., and Sears, V.G., *The Gelatin Lifting Process: An Evaluation of Its Effectiveness in the Recovery of Latent Fingerprints.* Journal of Forensic Identification, 2011. **61**(6): p. 581-606.
233. Bond, J.W., *Development of Latent Fingerprints on Thermal Paper by the Controlled Application of Heat.* J Forensic Sci, 2013. **58**(3): p. 767-71. DOI: 10.1111/1556-4029.12132.
234. Bond, J.W., *Effect That the Relative Abundance of Copper Oxide and Zinc Oxide Corrosion Has on the Visualization of Fingerprints Formed from Fingerprint Sweat Corrosion of Brass.* J Forensic Sci, 2011. **56**(4): p. 999-1002. DOI: 10.1111/j.1556-4029.2011.01759.x.
235. Bond, J.W., Eliopulos, L.N., and Brady, T.F., *Visualization of Latent Fingermark Corrosion of Brass, Climatic Influence in a Comparison between the U.K. And Iraq.* J Forensic Sci, 2011. **56**(2): p. 506-9. DOI: 10.1111/j.1556-4029.2010.01680.x.
236. Sykes, S. and Bond, J.W., *A Comparison of Fingerprint Sweat Corrosion of Different Alloys of Brass.* J Forensic Sci, 2013. **58**(1): p. 138-41. DOI: 10.1111/j.1556-4029.2012.02300.x.
237. Meekins, A., Bond, J.W., and Chaloner, P., *Effect of Chloride Ion Concentration on the Galvanic Corrosion of A Phase Brass by Eccrine Sweat.* J Forensic Sci, 2012. **57**(4): p. 1070-4. DOI: 10.1111/j.1556-4029.2012.02063.x.
238. Alcaraz-Fossoul, J. and Javer, D., *Evaluation of 3d and 2d Chronomorphometrics for Latent Fingermark Aging Studies.* Journal of Forensic Sciences, 2022. **67**. DOI: 10.1111/1556-4029.15095.
239. Beresford, A.L., Brown, R.M., Hillman, A.R., and Bond, J.W., *Comparative Study of Electrochromic Enhancement of Latent Fingerprints with Existing Development Techniques.* J Forensic Sci, 2012. **57**(1): p. 93-102. DOI: 10.1111/j.1556-4029.2011.01908.x.
240. Brown, R.M. and Hillman, A.R., *Electrochromic Enhancement of Latent Fingerprints by Poly(3,4-Ethylenedioxythiophene).* Physical Chemistry Chemical Physics, 2012. **14**(24): p. 8653-8661. DOI: 10.1039/C2CP40733G.
241. Dominick, A.J., Daéid, N.N., and Bleay, S.M., *The Recoverability of Fingerprints on Nonporous Surfaces Exposed to Elevated Temperatures.* Journal of Forensic Identification, 2011. **61**(5): p. 520-536.

242. Bouwmeester, M., Gorré, S., Rodriguez, C., and de Puit, M., *A Comparison of Reagents for the Visualization of Blood Prints on Knives with Black Handles.* Journal of Forensic Identification, 2011. **61**(4): p. 353-362.
243. Au, C., Jackson-Smith, H., Quinones, I., Jones, B.J., and Daniel, B., *Wet Powder Suspensions as an Additional Technique for the Enhancement of Bloodied Marks.* Forensic Science International, 2011. **204**(1): p. 13-18. DOI: https://doi.org/10.1016/j.forsciint.2010.04.044.
244. Gaskell, C., Bleay, S.M., Willson, H., and Park, S., *The Enhancement of Fingermarks on Grease-Contaminated, Nonporous Surfaces: A Comparative Assessment of Processes for Light and Dark Surfaces.* Journal of Forensic Identification, 2013. **63**(3): p. 286-319.
245. Cadd, S.J., Bleay, S.M., and Sears, V.G., *Evaluation of the Solvent Black 3 Fingermark Enhancement Reagent: Part 2 — Investigation of the Optimum Formulation and Application Parameters.* Science & Justice, 2013. **53**(2): p. 131-143. DOI: https://doi.org/10.1016/j.scijus.2012.11.007.
246. Gaskell, C., Bleay, S.M., and Ramadani, J., *Natural Yellow 3: A Novel Fluorescent Reagent for Use on Grease-Contaminated Fingermarks on Nonporous Dark Surfaces.* Journal of Forensic Identification, 2013. **63**(3): p. 274-285.
247. Gibson, A.P., Bannister, M., and Bleay, S.M., *A Comparison of Three Ultraviolet Searching and Imaging Systems for the Recovery of Fingerprints.* Journal of Forensic Identification, 2012. **62**(4): p. 349-367.
248. Ferguson, L., Bradshaw, R., Wolstenholme, R., Clench, M., and Francese, S., *Two-Step Matrix Application for the Enhancement and Imaging of Latent Fingermarks.* Anal Chem, 2011. **83**(14): p. 5585-91. DOI: 10.1021/ac200619f.
249. Azman, A.R., Mahat, N.A., Wahab, R.A., Ahmad, W.A., Puspanadan, J.K., Huri, M.A.M., Kamaluddin, M.R., and Ismail, D., *Box–Behnken Design Optimisation of a Green Novel Nanobio-Based Reagent for Rapid Visualisation of Latent Fingerprints on Wet, Non-Porous Substrates.* Biotechnology Letters, 2021. **43**(4): p. 881-898. DOI: 10.1007/s10529-020-03052-3.
250. Payne, I.C., McCarthy, I., Almond, M.J., Baum, J.V., and Bond, J.W., *The Effect of Light Exposure on the Degradation of Latent Fingerprints on Brass Surfaces: The Use of Silver Electroless Deposition as a Visualization Technique.* J Forensic Sci, 2014. **59**(5): p. 1368-71. DOI: 10.1111/1556-4029.12524.
251. Zadnik, S., van Bronswijk, W., Frick, A.A., Fritz, P., and Lewis, S.W., *Fingermark Simulants and Their Inherent Problems: A Comparison with Latent Fingermark Deposits.* Journal of Forensic Identification, 2013. **63**(5): p. 593-608.
252. Mangle, M.F., Xu, X., and de Puit, M., *Performance of 1,2-Indanedione and the Need for Sequential Treatment of Fingerprints.* Science & Justice, 2015. **55**(5): p. 343-346. DOI: https://doi.org/10.1016/j.scijus.2015.04.002.
253. Fritz, P., van Bronswijk, W., Patton, E., and Lewis, S.W., *Variability in Visualization of Latent Fingermarks Developed with 1,2-Indanedione-Zinc Chloride.* Journal of Forensic Identification, 2013. **63**(6): p. 698-713.
254. Fritz, P., van Bronswijk, W., and Lewis, S.W., *A New P-Dimethylaminocinnamaldehyde Reagent Formulation for the Photoluminescence Detection of Latent Fingermarks on Paper.* Forensic Science International, 2015. **257**: p. 20-28. DOI: https://doi.org/10.1016/j.forsciint.2015.07.037.
255. Farrugia, K.J., Fraser, J., Friel, L., Adams, D., Attard-Montalto, N., and Deacon, P., *A Comparison between Atmospheric/Humidity and Vacuum Cyanoacrylate Fuming of Latent Fingermarks.* Forensic Science International, 2015. **257**: p. 54-70. DOI: https://doi.org/10.1016/j.forsciint.2015.07.035.
256. Sonnex, E., Almond, M.J., and Bond, J.W., *Enhancement of Latent Fingerprints on Fabric Using the Cyanoacrylate Fuming Method Followed by Infrared Spectral Mapping.* J Forensic Sci, 2016. **61**(4): p. 1100-6. DOI: 10.1111/1556-4029.13065.

257. Bouwmeester, M., Leegwater, J., and de Puit, M., *Comparison of the Reagents Spr-W and Acid Yellow 7 for the Visualization of Blood Marks on a Dark Surface.* Journal of Forensic Identification, 2016. **66**(4): p. 289-302.
258. Charlton, D., Bleay, S., and Sears, V., *Evaluation of the Multimetal Deposition Process for Fingermark Enhancement in Simulated Operational Environments.* Analytical Methods, 2013. **5**: p. 5411. DOI: 10.1039/c3ay40533h.
259. Wightman, G., Emery, F., Austin, C., Andersson, I., Harcus, L., Arju, G., and Steven, C., *The Interaction of Fingermark Deposits on Metal Surfaces and Potential Ways for Visualisation.* Forensic Science International, 2015. **249**: p. 241-254. DOI: https://doi.org/10.1016/j.forsciint.2015.01.035.
260. Liu, S., Pflug, M., Hofstetter, R., and Taylor, M., *The Effect of Ph on Electrolyte Detection of Fingermarks on Cartridge Cases and Subsequent Microscopic Examination.* J Forensic Sci, 2015. **60**(1): p. 186-92. DOI: 10.1111/1556-4029.12620.
261. Bond, J.W., *Comparison of Chemical and Heating Methods to Enhance Latent Fingerprint Deposits on Thermal Paper.* J Forensic Sci, 2014. **59**(2): p. 485-9. DOI: 10.1111/1556-4029.12339.
262. Thomas, P. and Farrugia, K., *An Investigation into the Enhancement of Fingermarks in Blood on Paper with Genipin and Lawsone.* Science & Justice, 2013. **53**(3): p. 315-320. DOI: https://doi.org/10.1016/j.scijus.2013.04.006.
263. Cadd, S., Li, B., Beveridge, P., O'Hare, W.T., Campbell, A., and Islam, M., *A Comparison of Visible Wavelength Reflectance Hyperspectral Imaging and Acid Black 1 for the Detection and Identification of Blood Stained Fingerprints.* Science & Justice, 2016. **56**(4): p. 247-255. DOI: https://doi.org/10.1016/j.scijus.2015.12.007.
264. Simmons, R., Deacon, P., and Farrugia, K., *Water-Soaked Porous Evidence: A Comparison of Processing Methods.* Journal of Forensic Identification, 2014. **64**: p. 157-173.
265. Fritz, P., Frick, A.A., van Bronswijk, W., Lewis, S.W., Beaudoin, A., Bleay, S., and Lennard, C., *Variability and Subjectivity in the Grading Process for Evaluating the Performance of Latent Fingermark Detection Techniques.* Journal of Forensic Identification, 2015. **65**(5): p. 851-867.
266. Davis, L. and Fisher, R., *Fingermark Recovery from Riot Debris: Bricks and Stones.* Science & Justice, 2015. **55**(2): p. 97-102. DOI: https://doi.org/10.1016/j.scijus.2015.01.006.
267. McMorris, H., Farrugia, K., and Gentles, D., *An Investigation into the Detection of Latent Marks on the Feathers and Eggs of Birds of Prey.* Science & Justice, 2015. **55**(2): p. 90-96. DOI: https://doi.org/10.1016/j.scijus.2014.12.004.
268. Piekny, J. and Knaap, W., *The Use of a Dry Chemical Fire Extinguisher for the Development of Latent Fingerprints in Marijuana Grow Operations.* Journal of Forensic Identification, 2016. **66**(2): p. 92-105.
269. Zuidberg, M.C., van Woerkom, T., de Bruin, K.G., Stoel, R.D., and de Puit, M., *Effects of Cbrn Decontaminants in Common Use by First Responders on the Recovery of Latent Fingerprints--Assessment of the Loss of Ridge Detail on Glass.* J Forensic Sci, 2014. **59**(1): p. 61-9. DOI: 10.1111/1556-4029.12281.
270. Williams, S.F., Pulsifer, D.P., Lakhtakia, A., and Shaler, R.C., *Columnar-Thin-Film-Assisted Visualization of Depleted Sebaceous Fingermarks on Nonporous Metals and Hard Plastics.* J Forensic Sci, 2015. **60**(1): p. 179-85. DOI: 10.1111/1556-4029.12599.
271. Williams, S., Pulsifer, D., Shaler, R., Ramotowski, R., Brazelle, S., and Lakhtakia, A., *Comparison of the Columnar-Thin-Film and Vacuum-Metal-Deposition Techniques to Develop Sebaceous Fingermarks on Nonporous Substrates,†‡.* Journal of Forensic Sciences, 2014. **60**. DOI: 10.1111/1556-4029.12648.
272. Boudreault, A. and Beaudoin, A., *Pseudo-Operational Study on the Efficiency of Various Fingermark Development Techniques During the Aging Process.* Journal of Forensic Identification, 2017. **67**(1): p. 85-117.

273. Agapie, C.M., Sampson, M., Gee, W., , *Tropolone-Based Treatments for Visualising Latent Fingermarks on Porous Surfaces.* ChemRxiv, 2019. DOI: 10.26434/chemrxiv.7892870.v2.
274. Nicolasora, N., Downham, R., Hussey, L., Luscombe, A., Mayse, K., and Sears, V., *A Validation Study of the 1,2-Indandione Reagent for Operational Use in the Uk: Part 1 — Formulation Optimization.* Forensic Science International, 2018. **292**: p. 242-253. DOI: https://doi.org/10.1016/j.forsciint.2018.04.046.
275. Nicolasora, N., Downham, R., Dyer, R.-M., Hussey, L., Luscombe, A., and Sears, V., *A Validation Study of the 1,2-Indandione Reagent for Operational Use in the Uk: Part 2 — Optimization of Processing Conditions.* Forensic Science International, 2018. **288**: p. 266-277. DOI: https://doi.org/10.1016/j.forsciint.2018.04.044.
276. Luscombe, A. and Sears, V., *A Validation Study of the 1,2-Indandione Reagent for Operational Use in the Uk: Part 3—Laboratory Comparison and Pseudo-Operational Trials on Porous Items.* Forensic Science International, 2018. **292**: p. 254-261. DOI: https://doi.org/10.1016/j.forsciint.2018.04.042.
277. Olszowska, I., Deacon, P., Lindsay, M., Leśniewski, A., Niedziółka-Jönsson, J., and Farrugia, K., *An Alternative Carrier Solvent for Fingermark Enhancement Reagents.* Forensic Science International, 2018. **284**: p. 53-64. DOI: https://doi.org/10.1016/j.forsciint.2017.12.012.
278. Mayse, K., Sears, V.G., Nicolasora, N., and Bleay, S., *An Evaluation of the Effect of Incorporating Metal Salts into 1,8 Diazafluoren-9-One (Dfo) Formulations for Fingermark Enhancement.* Science & Justice, 2019. **59**(3): p. 349-358. DOI: https://doi.org/10.1016/j.scijus.2019.01.002.
279. Cappiello, P., Zampa, F., Siciliano, M., Amata, B., Di Palma, R., Modica, M., and Lazzaro, A.P., *Visualization of Fingermarks Deposits on Untreated Thermal Paper Exploiting the near Infrared Luminescence.* J Forensic Sci, 2020. **65**(1): p. 238-247. DOI: 10.1111/1556-4029.14071.
280. Davis, L., Kelly, P., and Bleay, S., *Assessing Phosphomolybdic Acid as a Fingermark Enhancement Reagent.* Journal of Forensic Identification, 2018. **68**.
281. Fritz, P., Frick, A., Bronswijk, W., Beaudoin, A., Bleay, S., Lennard, C., and Lewis, S., *Investigations into the Influence of Donor Traits on the Performance of Fingermark Development Reagents. Part 1:1,2-Indanedione-Zinc Chloride.* Journal of Forensic Identification, 2017. **67**: p. 410-425.
282. Zhao, Y.-B., Ma, Y.-j., Song, D., Liu, Y., Luo, Y., Lin, S., and Liu, C., *New Luminescent Nanoparticles Based on Carbon Dots/Sio2 for the Detection of Latent Fingermarks.* Anal. Methods, 2017. **9**. DOI: 10.1039/C7AY01316G.
283. Boateng, J.O., Jasra, P.K., Cowper, D., and Jasra, S.K., *Using Dry Fire Extinguisher to Develop Latent Fingerprints and Its Comparison with Other Methods of Fingerprint Development.* Journal of Forensic Identification, 2016. **66**(5): p. 395-404.
284. McMorris, H., Sturrock, K., Gentles, D., Jones, B.J., and Farrugia, K.J., *Environmental Effects on Magnetic Fluorescent Powder Development of Fingermarks on Bird of Prey Feathers.* Science & Justice, 2019. **59**(2): p. 117-124. DOI: https://doi.org/10.1016/j.scijus.2018.09.004.
285. Downham, R.P., Ciuksza, T.M., Desai, H.J., and Sears, V.G., *Black Iron (Ii/Iii) Oxide Powder Suspension (2009 Cast Formulation) for Fingermark Visualization, Part 1: Formulation Component and Shelf-Life Studies.* Journal of Forensic Identification, 2017. **67**(1): p. 118-143.
286. Downham, R.P., Ciuksza, T.M., Desai, H.J., and Sears, V.G., *Black Iron (Ii/Iii) Oxide Powder Suspension (2009 Cast Formulation) for Fingermark Visualization, Part 2: Surfactant Solution Component Investigations.* Journal of Forensic Identification, 2017. **67**(1): p. 145-167.
287. Azman, A.R., Mahat, N.A., Abdul Wahab, R., Ahmad, W.A., Mohamed Huri, M.A., Abdul Hamid, A.A., Adamu, A., and Mat Saat, G.A., *Characterisation and Computational Analysis of a Novel Lipase Nanobio-Based Reagent for Visualising Latent Fingerprints on Water-Immersed Glass Slides.* Process Biochemistry, 2020. **96**: p. 102-112. DOI: https://doi.org/10.1016/j.procbio.2020.05.033.
288. Azman, A.R., Mahat, N.A., Abdul Wahab, R., Abdul Razak, F.I., and Hamzah, H.H., *Novel Safranin-Tinted Candida Rugosa Lipase Nanoconjugates Reagent for Visualizing Latent*

Fingerprints on Stainless Steel Knives Immersed in a Natural Outdoor Pond. Int J Mol Sci, 2018. **19**(6). DOI: 10.3390/ijms19061576.

289. Deepthi, N.H., Basavaraj, R.B., Sharma, S.C., Revathi, J., Ramani, Sreenivasa, S., and Nagabhushana, H., *Rapid Visualization of Fingerprints on Various Surfaces Using Zno Superstructures Prepared Via Simple Combustion Route.* Journal of Science: Advanced Materials and Devices, 2018. **3**(1): p. 18-28. DOI: https://doi.org/10.1016/j.jsamd.2018.01.007.
290. Newland, T.G., Moret, S., Bécue, A., and Lewis, S.W., *Further Investigations into the Single Metal Deposition (Smd Ii) Technique for the Detection of Latent Fingermarks.* Forensic Science International, 2016. **268**: p. 62-72. DOI: https://doi.org/10.1016/j.forsciint.2016.09.004.
291. Bouzin, J.T., Horrocks, A.J., Sauzier, G., Bleay, S.M., and Lewis, S.W., *Comparison of Three Active 1,2-Indanedione-Zinc Formulations for Fingermark Detection in the Context of Limited Resources and Supply Chain Risks in Seychelles.* Forensic Chemistry, 2022. **30**: p. 100439. DOI: https://doi.org/10.1016/j.forc.2022.100439.
292. Downham, R.P., Brewer, E.R., King, R.S.P., Luscombe, A.M., and Sears, V.G., *Fingermark Visualisation on Uncirculated £5 (Bank of England) Polymer Notes: Initial Process Comparison Studies.* Forensic Science International, 2017. **275**: p. 30-43. DOI: https://doi.org/10.1016/j.forsciint.2017.02.026.
293. Downham, R.P., Brewer, E.R., King, R.S.P., and Sears, V.G., *Sequential Processing Strategies for Fingermark Visualisation on Uncirculated £10 (Bank of England) Polymer Banknotes.* Forensic Science International, 2018. **288**: p. 140-158. DOI: https://doi.org/10.1016/j.forsciint.2018.04.018.
294. Scotcher, K. and Bradshaw, R., *The Analysis of Latent Fingermarks on Polymer Banknotes Using Maldi-Ms.* Scientific Reports, 2018. **8**. DOI: 10.1038/s41598-018-27004-0.
295. Zhang, Y., Zhang, M., Wei, Q., Gao, Y., Guo, L., and Zhang, X., *Latent Fingermarks Enhancement in Deep Eutectic Solvent by Co-Electrodepositing Silver and Copper Particles on Metallic Substrates.* Electrochimica Acta, 2016. **211**: p. 437-444. DOI: https://doi.org/10.1016/j.electacta.2016.05.200.
296. Jasuja, O.P. and Singh, K., *Visualizing Latent Fingermarks by Aqueous Electrolyte Gel on Fixed Aluminum and Steel Surfaces.* Canadian Society of Forensic Science Journal, 2017. **50**(4): p. 181-196. DOI: 10.1080/00085030.2017.1371435.
297. Hong, S. and Han, A., *Development of Fingermark on the Surface of Fired Cartridge Casing Using Amino Acid Sensitive Reagents: Change of Viewpoint.* Forensic Science International, 2016. **266**: p. 86-90. DOI: https://doi.org/10.1016/j.forsciint.2016.05.010.
298. Challinger, S.E., Baikie, I.D., Flannigan, G., Halls, S., Laing, K., Daly, L., and Nic Daeid, N., *Comparison of Scanning Kelvin Probe with Sem/Epma Techniques for Fingermark Recovery from Metallic Surfaces.* Forensic Science International, 2018. **291**: p. 44-52. DOI: https://doi.org/10.1016/j.forsciint.2018.07.025.
299. Ahmad, A.A.L., Alawadhi, A.H., Park, J., Abdou, H.E., and Mohamed, A.A., *Evaluation of Diazonium Gold(Iii) Salts in Forensic Chemistry: Latent Fingerprint Development on Metal Surfaces.* Forensic Chemistry, 2019. **13**: p. 100144. DOI: https://doi.org/10.1016/j.forc.2019.100144.
300. Cooper-Dunn, A., Jones, O., and Bond, J.W., *The Effect of Varying the Composition of Fingerprint Sweat Deposits on the Corrosion of Brass and Fingerprint Visibility.* J Forensic Sci, 2017. **62**(5): p. 1314-1319. DOI: 10.1111/1556-4029.13427.
301. Girelli, C.M.A., Vieira, M.A., Singh, K., Cunha, A.G., Freitas, J.C.C., and Emmerich, F.G., *Recovery of Latent Fingermarks from Brass Cartridge Cases: Evaluation of Developers, Analysis of Surfaces and Internal Ballistic Effects.* Forensic Science International, 2018. **290**: p. 258-278. DOI: https://doi.org/10.1016/j.forsciint.2018.07.026.

302. Pitera, M., Sears, V.G., Bleay, S.M., and Park, S., *Fingermark Visualisation on Metal Surfaces: An Initial Investigation of the Influence of Surface Condition on Process Effectiveness.* Science & Justice, 2018. **58**(5): p. 372-383. DOI: https://doi.org/10.1016/j.scijus.2018.05.005.
303. Zheng, X., Li, K., Xu, J., and Lin, Z., *The Effectiveness and Practicality of Using Simultaneous Superglue & Iodine Fuming Method for Fingermark Development on 'Low Yield' Leather Surfaces: A Feasibility Study.* Forensic Science International, 2017. **281**: p. 152-160. DOI: https://doi.org/10.1016/j.forsciint.2017.10.043.
304. Avissar, Y.Y., Hefetz, I., Grafit, A., Kimchi, S., and Muller, D., *The Effect of Ignitable Liquid Analysis on Latent Fingermark Development 1.* Journal of Forensic Identification, 2019. **69**(2): p. 207-221.
305. Bouwmeester, M. and Siem-Gorré, S., *Determination of Detection Sequence for Optimal Visualization of Blood Fingermarks on a Dark Surface.* Journal of Forensic Identification, 2018. **68**(3): p. 389-402.
306. Mutter, N., Deacon, P., and Farrugia, K., *The Effect of Cyanoacrylate Fuming on Subsequent Protein Stain Enhancement of Fingermarks in Blood.* Journal of Forensic Identification, 2018. **68**: p. 545-556.
307. McCook, S.J., Tate, D.P., and Eller, J.B., *Recovery of Latent Prints from Nonporous Objects Exposed to Snow.* Journal of Forensic Identification, 2016. **66**(6): p. 577-590.
308. Forchelet, S. and Bécue, A., *Impact of Anti-Fingerprint Coatings on the Detection of Fingermarks.* Journal of Forensic Identification, 2018. **68**(3): p. 348-368.
309. Chadwick, S., Neskoski, M., Spindler, X., Lennard, C., and Roux, C., *Effect of Hand Sanitizer on the Performance of Fingermark Detection Techniques.* Forensic Science International, 2017. **273**: p. 153-160. DOI: https://doi.org/10.1016/j.forsciint.2017.02.018.
310. Attard, C. and Lennard, C., *Use of Gelatin Lifters and Episcopic Coaxial Illumination for the Recovery and Imaging of Latent Fingermarks from Various Surfaces.* Journal of Forensic Identification, 2018. **68**(2): p. 171-185.
311. Rajan, R., Zakaria, Y., Shamsuddin, S., and Nik Hassan, N.F., *Robust Synthesis of Mono-Dispersed Spherical Silica Nanoparticle from Rice Husk for High Definition Latent Fingermark Development.* Arabian Journal of Chemistry, 2020. **13**(11): p. 8119-8132. DOI: https://doi.org/10.1016/j.arabjc.2020.09.042.
312. Kumari Sharma, K., Kannikanti, G.H., Baggi, T.R.R., and Vaidya, J.R., *Fixing Transient Iodine on Developed Latent Fingermarks.* Journal of Forensic Sciences, 2019. **64**(6): p. 1859-1866. DOI: https://doi.org/10.1111/1556-4029.14139.
313. Bleay, S.M., Kelly, P.F., King, R.S.P., and Thorngate, S.G., *A Comparative Evaluation of the Disulfur Dinitride Process for the Visualisation of Fingermarks on Metal Surfaces.* Science & Justice, 2019. **59**(6): p. 606-621. DOI: https://doi.org/10.1016/j.scijus.2019.06.011.
314. Moret, S., Lee, P.L.T., de la Hunty, M., Spindler, X., Lennard, C., and Roux, C., *Single Metal Deposition Versus Physical Developer: A Comparison between Two Advanced Fingermark Detection Techniques.* Forensic Science International, 2019. **294**: p. 103-112. DOI: https://doi.org/10.1016/j.forsciint.2018.10.032.
315. D'Uva, J.A., Brent, N., Boseley, R.E., Ford, D., Sauzier, G., and Lewis, S.W., *Preliminary Investigations into the Use of Single Metal Deposition Ii (Smd Ii) to Visualise Latent Fingermarks on Polyethylene 'Zip-Lock' Bags in Western Australia.* Forensic Chemistry, 2020. **18**: p. 100229. DOI: https://doi.org/10.1016/j.forc.2020.100229.
316. Lam, R., Hofstetter, O., Lennard, C., Roux, C., and Spindler, X., *Evaluation of Multi-Target Immunogenic Reagents for the Detection of Latent and Body Fluid-Contaminated Fingermarks.* Forensic Science International, 2016. **264**: p. 168-175. DOI: https://doi.org/10.1016/j.forsciint.2016.04.014.
317. Jones, B.J., Cammidge, J.W., Evans, C., Scott, G., Sherriffs, P.B., Breen, F., Andersen, P.M.B., Popov, K.T., and O'Hara, J., *Degradation of Polymer Banknotes through Handling, and Effect*

on Fingermark Visualisation. Science & Justice, 2022. **62**(5): p. 644-656. DOI: https://doi.org/10.1016/j.scijus.2022.08.007.

318. Choi, G.-W. and Kim, C.-W., *Influence of Adhesive Force of Lifter on the Quality of Powdered Fingermark.* The Journal of the Korea Contents Association, 2019. **19**(5).
319. Bradshaw, G., Bleay, S., Deans, J., and Daéid, N., *Recovery of Fingerprint from Arson Scenes: Part 1 - Latent Fingerprints.* Journal of Forensic Identification, 2008. **58**: p. 54-82.
320. Dominick, A.J., NicDaéid, N., and Bleay, S.M. *The Recoverability of Fingerprints on Paper Exposed to Elevated Temperatures - Part 1: Comparison of Enhancement Techniques*. 2010.
321. Moore, J., Bleay, S., Deans, J., and NicDaeid, N., *Recovery of Fingerprints from Arson Scenes: Part 2 - Fingerprints in Blood.* Journal of Forensic Identification, 2008. **58**(1): p. 83-108.
322. Bond, J.W., *Visualization of Latent Fingerprint Corrosion of Metallic Surfaces.* J Forensic Sci, 2008. **53**(4): p. 812-22. DOI: 10.1111/j.1556-4029.2008.00738.x.
323. Brewer, E.R., *Visualization of Latent Fingermark Detail on Fired Handgun Casings Using Forensic Vmd.* Journal of Forensic Identification, 2020. **70**(3): p. 323-345.
324. Braasch, K., de la Hunty, M., Deppe, J., Spindler, X., Cantu, A.A., Maynard, P., Lennard, C., and Roux, C., *Nile Red: Alternative to Physical Developer for the Detection of Latent Fingermarks on Wet Porous Surfaces?* Forensic Science International, 2013. **230**(1): p. 74-80. DOI: https://doi.org/10.1016/j.forsciint.2013.03.041.
325. Sherriffs, P.B., Farrugia, K.J., Fraser, J.M., and Jones, B.J., *The Optimisation of Fingermark Enhancement by Vmd and Lumicyano™ on Thermal Paper.* Science & Justice, 2020. **60**(2): p. 160-168. DOI: https://doi.org/10.1016/j.scijus.2019.10.004.
326. Tan, T.T.F., Law, P.P.K., Kwok, S.W.K., Yeung, W.W.L., Ho, W.-C., Chung, W.-K., and Au, B.-C., *A Novel Solvent-Based Method to Separate Duct Tape from Porous Surface for Fingerprint Development.* Journal of Forensic Sciences, 2020. **65**(1): p. 73-83. DOI: https://doi.org/10.1111/1556-4029.14146.
327. Dawkins, J., Gautam, L., Bandey, H., Armitage, R., and Ferguson, L., *The Effect of Paint Type on the Development of Latent Fingermarks on Walls.* Forensic Science International (Online), 2020. **309**. DOI: https://doi.org/10.1016/j.forsciint.2020.110186.
328. Illston-Baggs, G., Deacon, P., Ivanova, J., Nichols-Drew, L., Armitage, R., and Farrugia, K.J., *An Investigation into the Detection of Latent Fingermarks on Eco-Friendly Soft Plastics Packaging.* Forensic Chemistry, 2022. **29**: p. 100427. DOI: https://doi.org/10.1016/j.forc.2022.100427.
329. You, W., Zhao, Y.-B., Xu, S.-L., and Tian, S.-S., *Visualization of Latent Fingermarks on Fabric Using Multi-Metal Deposition (Mmd)—a Preliminary Study.* Forensic Science International, 2021. **327**: p. 110981. DOI: https://doi.org/10.1016/j.forsciint.2021.110981.
330. Berkil Akar, K., *Evaluation of Alizarin and Purpurin Dyes for Their Ability to Visualize Latent Fingermark on Porous Surfaces.* Science & Justice, 2021. **61**(2): p. 130-141. DOI: https://doi.org/10.1016/j.scijus.2020.11.006.
331. Zhao, Y.-B., Wang, L.-X., Li, W.-J., You, W., and Farrugia, K., *Effect of Carrier Solvent in 1,2-Indanedione Formulation on the Development of Fingermarks on Porous Substrates.* Forensic Science International, 2021. **318**: p. 110589. DOI: https://doi.org/10.1016/j.forsciint.2020.110589.
332. Chang, I., Stone, A.C.A., Hanney, O.C., and Gee, W.J., *Volatilised Pyrene: A Phase 1 Study Demonstrating a New Method of Visualising Fingermarks with Comparisons to Iodine Fuming.* Forensic Science International, 2019. **305**: p. 109996. DOI: https://doi.org/10.1016/j.forsciint.2019.109996.
333. Moorat, G., Reed, J., Bleay, S., Amaral, M.A., Chappell, B., Pamment, N., Plowman, C., and Smith, P.A., *The Visualisation of Fingermarks on Pangolin Scales Using Gelatine Lifters.* Forensic Science International, 2020. **313**: p. 110221. DOI: https://doi.org/10.1016/j.forsciint.2020.110221.

334. Beerman, N., Savage, A., Dennany, L., and Fraser, J., *Evaluation of the One-Step Lumicyano™ Used in the Visualisation of Fingermarks on Fabrics.* Science & Justice, 2019. **59**(5): p. 486-497. DOI: https://doi.org/10.1016/j.scijus.2019.06.001.
335. Downham, R.P., Sears, V.G., Hussey, L., Chu, B.-S., and Jones, B.J., *Fingermark Visualisation with Iron Oxide Powder Suspension: The Variable Effectiveness of Iron (Ii/Iii) Oxide Powders, and Tween® 20 as an Alternative to Triton™ X-100.* Forensic Science International, 2018. **292**: p. 190-203. DOI: https://doi.org/10.1016/j.forsciint.2018.09.012.
336. Reed, H., Stanton, A., Wheat, J., Kelley, J., Davis, L., Rao, W., Smith, A., Owen, D., and Francese, S., *The Reed-Stanton Press Rig for the Generation of Reproducible Fingermarks: Towards a Standardised Methodology for Fingermark Research.* Science & Justice, 2016. **56**(1): p. 9-17. DOI: https://doi.org/10.1016/j.scijus.2015.10.001.
337. Rae, L., Gentles, D., and Farrugia, K.J., *An Investigation into the Enhancement of Fingermarks in Blood on Fruit and Vegetables.* Science & Justice, 2013. **53**(3): p. 321-327. DOI: https://doi.org/10.1016/j.scijus.2013.05.002.
338. Croxton, R., Kent, T., Littlewood, A., and Smith, M., *An Evaluation of Inkjet Printed Amino Acid Fingerprint Test Targets for Ninhydrin Process Monitoring – and Some Observations.* Forensic Science International, 2021. **321**: p. 110741. DOI: https://doi.org/10.1016/j.forsciint.2021.110741.
339. Pollitt, J.N., Christofidis, G., Morrissey, J., and Birkett, J.W., *Vacuum Metal Deposition Enhancement of Friction Ridge Detail on Ballistic Materials.* Forensic Science International, 2020. **316**: p. 110551. DOI: https://doi.org/10.1016/j.forsciint.2020.110551.
340. Chingthongkham, P., Chomean, S., Suppajariyawat, P., and Kaset, C., *Enhancement of Bloody Fingerprints on Non-Porous Surfaces Using Lac Dye (Laccifer Lacca).* Forensic Science International, 2020. **307**: p. 110119. DOI: https://doi.org/10.1016/j.forsciint.2019.110119.
341. Oliver, S., Smale, T., and Arthur, I., *The Use of Ortho-Phenylenediamine and Zar-Pro™ Strips for the Development of Bloodmarks on a Dark-Coloured, Non-Porous Surface.* Forensic Science International, 2018. **288**: p. 97-106. DOI: https://doi.org/10.1016/j.forsciint.2018.04.021.
342. Dhall, J.K. and Kapoor, A.K., *Development of Latent Prints Exposed to Destructive Crime Scene Conditions Using Wet Powder Suspensions.* Egyptian Journal of Forensic Sciences, 2016. **6**(4): p. 396-404. DOI: https://doi.org/10.1016/j.ejfs.2016.06.003.
343. Poletti, T., Berneira, L.M., Passos, L.F., da Rosa, B.N., de Pereira, C.M.P., and Mariotti, K.d.C., *Preliminary Efficiency Evaluation of Development Methods Applied to Aged Sebaceous Latent Fingermarks.* Science & Justice, 2021. **61**(4): p. 378-383. DOI: https://doi.org/10.1016/j.scijus.2021.03.007.
344. Hong, S., Kim, M., and Yu, S., *Latent Fingermark Development on Thermal Paper Using 1,2-Indanedione/Zinc and Polyvinylpyrrolidone.* Journal of Forensic Sciences, 2018. **63**(2): p. 548-555. DOI: https://doi.org/10.1111/1556-4029.13585.
345. Girelli, C.M.A. and Segatto, B.R., *Identification of a Suspect in a Murder Case through Recovery of Fingermarks from a Fired Cartridge Case.* Journal of Forensic Sciences, 2019. **64**(5): p. 1520-1522. DOI: https://doi.org/10.1111/1556-4029.14045.
346. Fairley, C., Bleay, S.M., Sears, V.G., and NicDaeid, N., *A Comparison of Multi-Metal Deposition Processes Utilising Gold Nanoparticles and an Evaluation of Their Application to 'Low Yield' Surfaces for Finger Mark Development.* Forensic Science International, 2012. **217**(1): p. 5-18. DOI: https://doi.org/10.1016/j.forsciint.2011.09.018.
347. Vadivel, R., Nirmala, M., and Anbukumaran, K., *Commonly Available, Everyday Materials as Non-Conventional Powders for the Visualization of Latent Fingerprints.* Forensic Chemistry, 2021. **24**: p. 100339. DOI: https://doi.org/10.1016/j.forc.2021.100339.
348. Passos, L.F., Berneira, L.M., Poletti, T., Mariotti, K.d.C., Carreño, N.L.V., Hartwig, C.A., and Pereira, C.M.P., *Evaluation and Characterization of Algal Biomass Applied to the Development of Fingermarks on Glass Surfaces.* Australian Journal of Forensic Sciences, 2021. **53**(3): p. 337-346. DOI: 10.1080/00450618.2020.1715478.

349. Prakash, O. and Singh, K., *Aqueous Electrolytes: Retrieving Latent Fingermarks from Crumpled Aluminum Foil.* Research & Reports in forensic Medical Sciences, 2016. **Volume 6**. DOI: 10.2147/RRFMS.S121577.
350. Hefetz, I., Einot, N., Faerman, M., Horowitz, M., and Almog, J., *Touch DNA: The Effect of the Deposition Pressure on the Quality of Latent Fingermarks and Str Profiles.* Forensic Science International: Genetics, 2019. **38**: p. 105-112. DOI: https://doi.org/10.1016/j.fsigen.2018.10.016.
351. Nagachar, N., Tiedge, T.M., Lakhtakia, A., McCormick, M.N., and Roy, R., *Development of Environmentally Insulted Fingermarks on Nonporous Forensically Relevant Substrates with Conformal Columnar Thin Films.* Canadian Society of Forensic Science Journal, 2020. **53**(4): p. 149-172. DOI: 10.1080/00085030.2020.1799658.
352. Francese, S., Bradshaw, R., and Denison, N., *An Update on Maldi Mass Spectrometry Based Technology for the Analysis of Fingermarks – Stepping into Operational Deployment.* Analyst, 2017. **142**(14): p. 2518-2546. DOI: 10.1039/C7AN00569E.
353. de Lyra, A.C.F., Silva, L.P.A.d., de Lima Neto, J., Costa, C.V., de Assis, A.M.L., de Freitas, J.D., Lima, D.J.P., and Ribeiro, A.S., *Functionalization of Pyrrole Derivatives as a Way to Improve Their Solubility in Aqueous Medium for Applying in Latent Fingerprints Development.* Forensic Chemistry, 2021. **26**: p. 100373. DOI: https://doi.org/10.1016/j.forc.2021.100373.
354. Hong, S. and Kim, C.R., *Use of Squid as an Alternative to Human Skin for Studying Thedevelopment of Hit Marks on Clothes.* Journal of Forensic Research, 2016. **7**: p. 1-8.
355. Zhou, H., Shi, W., Liu, J., Su, G., Cui, S., Zhang, M., and Li, S., *Enhanced Developing Property of Latent Fingerprint Based on Inclusion Complex of B-Cyclodextrin with Natural Berberine Extracted from Coptis Chinensis.* Chemical Papers, 2022. **76**(8): p. 4893-4905. DOI: 10.1007/s11696-022-02216-x.
356. Joannidis, C.A., Haddrill, P.R., and Laing, K., *Determination of the Most Effective Enhancement Process for Latent Fingermarks on Clydesdale Bank and Royal Bank of Scotland £5 and £10 Polymer Banknotes.* Forensic Science International, 2020. **312**: p. 110334. DOI: https://doi.org/10.1016/j.forsciint.2020.110334.
357. Berkil Akar, K., *Novel O-Propyl, S-Propyl, and N-Propyl Substituted 1,4-Naphthoquinones and 1,4-Anthraquinones as Potential Fingermark Development Reagents for Porous Surfaces.* J Forensic Sci, 2021. **66**(1): p. 161-171. DOI: 10.1111/1556-4029.14596.
358. Gülekçi, Y., Tülek, A., Şener, H., and Küçüker, H., *Fingermark Development on Living and Dead Subjects: Analysis of Thermal Paper Transfers with Different Methods.* Australian Journal of Forensic Sciences, 2022: p. 1-12. DOI: 10.1080/00450618.2022.2117412.
359. Radgen-Morvant, I., Kummer, N., Curty, C., and Delémont, O., *Effects of Chemical Warfare Agent Decontaminants on Trace Survival: Impact on Fingermarks Deposited on Glass.* J Forensic Sci, 2022. **67**(6): p. 2267-2277. DOI: 10.1111/1556-4029.15115.
360. De Alcaraz-Fossoul, J. and Li, S., *Evaluation of an Inkless Method for Fingerprint Recordings Using Hand Sanitizer Gel on Thermal Paper (Part Ii): Effect of Time, Temperature, and Biological Sex.* Forensic Science International, 2022. **340**: p. 111423. DOI: https://doi.org/10.1016/j.forsciint.2022.111423.
361. Bond, J.W., *Response Assessment of Thermal Papers from Four Continents to Fingerprint Development by Heat.* J Forensic Sci, 2015. **60**(5): p. 1331-6. DOI: 10.1111/1556-4029.12811.
362. Bond, J.W., *The Thermodynamics of Latent Fingerprint Corrosion of Metal Elements and Alloys.* Journal of Forensic Sciences, 2008. **53**(6): p. 1344-1352. DOI: https://doi.org/10.1111/j.1556-4029.2008.00860.x.
363. Gulekci, Y., Efeoglu Ozseker, P., Cavus Yonar, F., and Daglioglu, N., *Comparison of Methods to Develop Fingerprints on Papers Impregnated with Ab-Pinaca and Ab-Fubinaca.* Journal of Forensic Sciences, 2022. **67**(2): p. 524-533. DOI: https://doi.org/10.1111/1556-4029.14926.
364. Aguayo, K. and Pohl, D., *Evaluation of 1,2-Lndanedione Zinc Chloride Versus Ninhydrin on Cardboard Substrates.* Journal of Forensic Identification, 2021. **71**(2): p. 103-117.

365. Illston-Baggs, G., Deacon, P., Ivanova, J., Nichols-Drew, L., and Farrugia, K.J., *A Pseudo-Operational Trial: An Investigation into the Use of Longwave Reflected Uv Imaging of Cyanoacrylate Developed Fingermarks.* Forensic Science International, 2021. **325**: p. 110871. DOI: https://doi.org/10.1016/j.forsciint.2021.110871.
366. Hong, S., Park, J.H., Park, J.H., Oh, H.B., Choi, E.J., Cho, I.H., and Mok, Y.J., *Development of Latent Fingermarks on Surfaces of Food-a More Realistic Approach.* J Forensic Sci, 2019. **64**(4): p. 1040-1047. DOI: 10.1111/1556-4029.13960.
367. Brewer, E.R., *The Capability of Forensic Vacuum Metal Deposition for Developing Latent Fingermarks on Fired Ammunition: A Preliminary Study Comparing Alternative Metal Processes.* Journal of Forensic Identification, 2019. **69**(3): p. 299-327.
368. Christofidis, G., Morrissey, J., and Birkett, J.W., *A Preliminary Study on Vacuum Metal Deposition as a Standalone Method for Enhancement of Fingermarks on Ballistic Brass Materials.* J Forensic Sci, 2019. **64**(5): p. 1500-1505. DOI: 10.1111/1556-4029.14052.
369. Illston-Baggs, G., Deacon, P., Nichols-Drew, L., and Farrugia, K.J., *Using Vacuum Metal Deposition to Detect Latent Fingermarks on Thermal Paper: A Pseudo-Operational Trial.* Journal of Forensic Identification, 2022. **72**(2): p. 185-199.
370. Cartledge, E.M., Guo, Z.Y., Bleay, S.M., Sears, V.G., and Hussey, L.J., *Replacing Synperonic® N in the Physical Developer Fingermark Visualisation Process: Pseudo-Operational Trial and Parameter Studies.* Forensic Science International, 2021. **326**: p. 110916. DOI: https://doi.org/10.1016/j.forsciint.2021.110916.
371. Krebs, B., Gapinska-Serwin, A., and Knaap, W., *A Novel Technique: Developing Latent Fingerprints Using Fluorescent Starch Powder and a Sandblasting Gun.* Journal of Forensic Identification, 2021. **71**(4): p. 291-308.
372. Kapsa, C., Ho, M., and Libby, M., *The Use of Liquid Latex to Recover Latent Fingerprints That Are Covered in Debris from Exterior Glass Surfaces of Vehicles.* Journal of Forensic Sciences, 2020. **65**(6): p. 1961-1967. DOI: https://doi.org/10.1111/1556-4029.14522.
373. Claveria, S., Clares, N., Fernández, P., Heredia, R., and Godall, A., *Wet Ucio - New Powder Suspension Formula for Fingerprint Development on the Adhesive Side of Tape.* Journal of Forensic Identification, 2022. **72**(2): p. 174-184.
374. Pontone, S., Slaney, J., Power, C., and Oliverio, M., *Using S₂N₂ Recover Latent Fingerprint Technology to Recover Fingerprints from Spent Brass Casings.* Journal of Forensic Identification, 2021. **71**(3): p. 227-248.
375. Bonnaz, B., De Donno, M., Anthonioz, A., and Bécue, A., *Automatic Assessment of Fingermarks Quality: Exploration of the Possible Application in the Context of Detection and Comparison with Human Examiners.* Journal of Forensic Sciences, 2021. **66**(3): p. 879-889. DOI: https://doi.org/10.1111/1556-4029.14667.
376. Azman, A.R., Mahat, N.A., Wahab, R.A., Ahmad, W.A., Puspanadan, J.K., Huri, M.A.M., Kamaluddin, M.R., and Ismail, D., *Box-Behnken Design Optimisation of a Green Novel Nanobio-Based Reagent for Rapid Visualisation of Latent Fingerprints on Wet, Non-Porous Substrates.* Biotechnol Lett, 2021. **43**(4): p. 881-898. DOI: 10.1007/s10529-020-03052-3.
377. Fritz, P., van Bronswijk, W., Dorakumbura, B., Hackshaw, B., and Lewis, S.W., *Evaluation of a Solvent-Free P-Dimethylaminobenzaldehyde Method for Fingermark Visualization with a Low-Cost Light Source Suitable for Remote Locations.* Journal of Forensic Identification, 2015. **65**(1): p. 67-90.
378. Lam, R., Wilkinson, D., Tse, T., and Pynn, B., *Recommended Protocols for Fingerprint Detection on Canadian Polymer Banknotes-Part I: Chemical Development.* Journal of Forensic Identification, 2014. **64**(4): p. 375-401.
379. Perry, H. and Sears, V.G., *The Use of Natural Yellow 3 (Curcumin) for the Chemical Enhancement of Latent Friction Ridge Detail on Naturally Weathered Materials.* Journal of Forensic Identification, 2015. **65**: p. 45-66.

380. Downham, R., Kelly, S., and Sears, V.G., *Feasibility Studies for Fingermark Visualization on Leather and Artificial Leather.* Journal of Forensic Identification, 2015. **65**: p. 138-159.
381. Munro, M., Deacon, P., and Farrugia, K.J., *A Preliminary Investigation into the Use of Alginates for the Lifting and Enhancement of Fingermarks in Blood.* Science & Justice, 2014. **54**(3): p. 185-191. DOI: https://doi.org/10.1016/j.scijus.2013.11.002.
382. Girelli, C.M.A., Lobo, B.J.M., Cunha, A.G., Freitas, J.C.C., and Emmerich, F.G., *Comparison of Practical Techniques to Develop Latent Fingermarks on Fired and Unfired Cartridge Cases.* Forensic Science International, 2015. **250**: p. 17-26. DOI: https://doi.org/10.1016/j.forsciint.2015.02.012.
383. Bond, J.W., *A Noninvasive and Speculative Method of Visualizing Latent Fingerprint Deposits on Thermal Paper.* J Forensic Sci, 2015. **60**(4): p. 1034-9. DOI: 10.1111/1556-4029.12782.
384. Goel, T.L., *Developing Latent Fingermarks on Thermal Paper: Comparison of the 1,2-Indanedione-Zinc Chloride Dry Contact Method to the Hot Print System.* Journal of Forensic Identification, 2015. **65**(1): p. 34-43.
385. Moret, S. and Bécue, A., *Single-Metal Deposition for Fingermark Detection-a Simpler and More Efficient Protocol.* Journal of Forensic Identification, 2015. **65**(2): p. 118-137.
386. Moret, S., Bécue, A., and Champod, C., *Functionalised Silicon Oxide Nanoparticles for Fingermark Detection.* Forensic Science International, 2016. **259**: p. 10-18. DOI: https://doi.org/10.1016/j.forsciint.2015.11.015.
387. Steiner, R. and Bécue, A., *Effect of Water Immersion on Multi- and Mono-Metallic Vmd.* Forensic Science International, 2018. **283**: p. 118-127. DOI: https://doi.org/10.1016/j.forsciint.2017.12.020.
388. Jasuja, O.P. and Singh, K., *Recovery of Latent Fingermarks from Chalk.* Journal of Forensic Identification, 2017. **67**(1): p. 60-69.
389. Venzke, D., Poletti, T., Rosa, B.N., Berneira, L.M., de Lima, N.P.K., de Oliveira, T.F., Carreño, N.L.V., Mariotti, K.d.C., Duarte, L.S., Nobre, S.M., and Pereira, C.M.P., *Preparation of Fluorescent Bisamides: A New Class of Fingermarks Developers.* Chemical Data Collections, 2021. **33**: p. 100680. DOI: https://doi.org/10.1016/j.cdc.2021.100680.
390. Wang, W., Xing, J., and Ge, Z., *Evaluation of Nile Red-Loaded Mesoporous Silica Nanoparticles for Developing Water-Soaked Fingerprints on Thermal Paper.* Journal of Forensic Sciences, 2018. **64**. DOI: 10.1111/1556-4029.13959.
391. Loh, C.N., Chia, W.L.K., Foo, S.C.S., Xu, X., and Tan, W.L.S., *Evaluation of the Performance of Ind/Zn and Dfo on Various Porous Substrates in Singapore Context.* Forensic Science International, 2020. **315**: p. 110440. DOI: https://doi.org/10.1016/j.forsciint.2020.110440.
392. Acherar, O., Truong, M.Q., Robert, S., Crispino, F., Moret, S., and Bécue, A., *Paper Characteristics and Their Influence on the Ability of Single Metal Deposition to Detect Fingermarks.* Forensic Chemistry, 2019. **12**: p. 8-24. DOI: https://doi.org/10.1016/j.forc.2018.11.005.
393. Hallez, F., Ledroit, P., Henrot, D., Malo, M., and Tamisier, L., *Optimization of the Development of Latent Fingermarks on Thermal Papers.* Forensic Science International, 2019. **298**: p. 20-33. DOI: https://doi.org/10.1016/j.forsciint.2019.02.055.
394. Rousseau, M., Ledroit, P., Malo, M., Henrot, D., and Guille, H., *Fingermarks Development on Gloves: Relative Efficiency of 1,2 Indanedione/Zncl2, Ninhydrin and Wet Powder.* Science & Justice, 2020. **60**(5): p. 473-479. DOI: https://doi.org/10.1016/j.scijus.2020.07.002.
395. Berdejo, S., Rowe, M., and Bond, J., *Latent Fingermark Development on a Range of Porous Substrates Using Ninhydrin Analogs-a Comparison with Ninhydrin and 1,8-Diazofluoren.* Journal of forensic sciences, 2011. **57**: p. 509-14. DOI: 10.1111/j.1556-4029.2011.01972.x.
396. Montgomery, L., Spindler, X., Maynard, P., Lennard, C., and Roux, C., *Pretreatment Strategies for the Improved Cyanoacrylate Development of Dry Latent Fingerprints on Nonporous Surfaces.* Journal of Forensic Identification, 2012. **62**(5): p. 517-542.

397. Chadwick, S., Maynard, P., Kirkbride, P., Lennard, C., Spindler, X., and Roux, C., *Use of Styryl 11 and Star 11 for the Luminescence Enhancement of Cyanoacrylate-Developed Fingermarks in the Visible and near-Infrared Regions.* J Forensic Sci, 2011. **56**(6): p. 1505-13. DOI: 10.1111/j.1556-4029.2011.01846.x.
398. Chadwick, S., Maynard, P., Kirkbride, P., Lennard, C., McDonagh, A., Spindler, X., and Roux, C., *Styryl Dye Coated Metal Oxide Powders for the Detection of Latent Fingermarks on Non-Porous Surfaces.* Forensic Science International, 2012. **219**(1): p. 208-214. DOI: https://doi.org/10.1016/j.forsciint.2012.01.006.
399. Moret, S., Spindler, X., Lennard, C., and Roux, C., *Microscopic Examination of Fingermark Residues: Opportunities for Fundamental Studies.* Forensic Science International, 2015. **255**: p. 28-37. DOI: https://doi.org/10.1016/j.forsciint.2015.05.027.
400. Khuu, A., Chadwick, S., Spindler, X., Lam, R., Moret, S., and Roux, C., *Evaluation of One-Step Luminescent Cyanoacrylate Fuming.* Forensic Science International, 2016. **263**: p. 126-131. DOI: https://doi.org/10.1016/j.forsciint.2016.04.007.
401. Chadwick, S., Xiao, L., Maynard, P., Lennard, C., Spindler, X., and Roux, C., *Polycyano Uv: An Investigation into a One-Step Luminescent Cyanoacrylate Fuming Process.* Australian Journal of Forensic Sciences, 2014: p. 1-14. DOI: 10.1080/00450618.2014.891654.
402. Richards, D.A. and Thomas, J.R., *Nonporous Fluorescent Dye Stains: A Comparative Analysis.* Journal of Forensic Identification, 2014. **64**(3): p. 239-254.
403. Barros, H.L. and Stefani, V., *A New Methodology for the Visualization of Latent Fingermarks on the Sticky Side of Adhesive Tapes Using Novel Fluorescent Dyes.* Forensic Science International, 2016. **263**: p. 83-91. DOI: https://doi.org/10.1016/j.forsciint.2016.03.053.
404. Mostowtt, T., Ramotowski, R.S., and Morgan, J.P., Jr., *A Comparison of Thermal Fingerprint Development to Current Recommended Chemical Development Techniques on Porous Surfaces *.* Journal of Forensic Identification, 2016. **66**(4): p. 326-348.
405. Yaseen, M., Rasool, N., Farooq, Z., Nazir, D., and Chohan, S., *A Pilot Study for the Use of Coumarin-480 to Enhance the Fingermarks.* Studia Universitatis Babeș-Bolyai Chemia, 2019. **64**: p. 185-196. DOI: 10.24193/subbchem.2019.1.15.
406. Coppes, A., Ramotowski, R.S., Jones, B.A., Manna, M.E., Chervinsky, E.V., and Smith, K.D., *Silver Nitrate Grade and Its Effect on Physical Developer Performance- a Validation Study.* Journal of Forensic Identification, 2018. **68**(1): p. 11-27.
407. Barros, H.L. and Stefani, V., *Micro-Structured Fluorescent Powders for Detecting Latent Fingerprints on Different Types of Surfaces.* Journal of Photochemistry and Photobiology A: Chemistry, 2019. **368**: p. 137-146. DOI: https://doi.org/10.1016/j.jphotochem.2018.09.046.
408. Lee, P.L.T., Kanodarwala, F.K., Lennard, C., Spindler, X., Spikmans, V., Roux, C., and Moret, S., *Latent Fingermark Detection Using Functionalised Silicon Oxide Nanoparticles: Method Optimisation and Evaluation.* Forensic Science International, 2019. **298**: p. 372-383. DOI: https://doi.org/10.1016/j.forsciint.2019.02.038.
409. Wahab, R.A., Puspanadan, J.K., Mahat, N.A., Azman, A.R., and Ismail, D., *Potassium Triiodide Enhanced Multi-Walled Carbon Nanotubes Supported Lipase for Expediting a Greener Forensic Visualization of Wetted Fingerprints.* Chemical Papers, 2021. **75**(4): p. 1401-1412. DOI: 10.1007/s11696-020-01370-4.
410. Zampa, F., Hilgert, M., Malmborg, J., Svensson, M., Schwarz, L., and Mattei, A., *Evaluation of Ninhydrin as a Fingermark Visualisation Method – a Comparison between Different Procedures as an Outcome of the 2017 Collaborative Exercise of the Enfsi Fingerprint Working Group.* Science & Justice, 2020. **60**(2): p. 191-200. DOI: https://doi.org/10.1016/j.scijus.2019.11.003.
411. Poudel, K., Brillhart, M., and Tom, K., *Testing the Effectiveness of Lumicyano™ with Cyano-Shot™ Components: A Novel Heat Solution.* Forensic Science International: Reports, 2021. **3**: p. 100208. DOI: https://doi.org/10.1016/j.fsir.2021.100208.
412. Azman, A.R., Mahat, N.A., Abdul Wahab, R., Ahmad, W.A., and Ismail, D., *Preliminary forensic Assessment of the Visualised Fingerprints on Nonporous Substrates Immersed in Water Using*

the Green and Optimised Novel Nanobio-Based Reagent. Sci Rep, 2022. **12**(1): p. 14780. DOI: 10.1038/s41598-022-18929-8.

413. Chadwick, S., Cvetanovski, M., Ross, M., Sharp, A., and Moret, S., *Comparison of Nir Powders to Conventional Fingerprint Powders.* Forensic Science International, 2021. **328**: p. 111023. DOI: https://doi.org/10.1016/j.forsciint.2021.111023.
414. Klemczak, K., Kozdrój-Miler, K., Siejca, A., Lityński, K., and Leśniewski, A., *Greasy Fingermark Detection on Porous Surfaces Using Oil Red O in a Gas Phase: Comparison with Oil Red O in Solution.* Forensic Science International, 2022. **339**: p. 111417. DOI: https://doi.org/10.1016/j.forsciint.2022.111417.
415. Kanodarwala, F.K., Leśniewski, A., Olszowska-Łoś, I., Spindler, X., Pieta, I.S., Lennard, C., Niedziółka-Jönsson, J., Moret, S., and Roux, C., *Fingermark Detection Using Upconverting Nanoparticles and Comparison with Cyanoacrylate Fuming.* Forensic Science International, 2021. **326**: p. 110915. DOI: https://doi.org/10.1016/j.forsciint.2021.110915.
416. Lee, P.L.T., Kanodarwala, F.K., Lennard, C., Spindler, X., Spikmans, V., Roux, C., and Moret, S., *Latent Fingermark Detection Using Functionalised Silicon Oxide Nanoparticles: Optimisation and Comparison with Cyanoacrylate Fuming.* Forensic Science International, 2020. **315**: p. 110442. DOI: https://doi.org/10.1016/j.forsciint.2020.110442.
417. Masterson, A. and Bleay, S., *The Effect of Corrosive Substances on Fingermark Recovery: A Pilot Study.* Science & Justice, 2021. **61**(5): p. 617-626. DOI: https://doi.org/10.1016/j.scijus.2021.07.004.
418. van Dam, A., Falkena, K., den Daas, S.A., Veldhuizen, I., and Aalders, M.C.G., *Improving the Visualization of Fingermarks Using Multi-Target Immunolabeling.* Forensic Science International, 2021. **324**: p. 110804. DOI: https://doi.org/10.1016/j.forsciint.2021.110804.
419. Ting, C.W., Mahat, N.A., Azman, A.R., Muda, N.W., and Anuar, N., *Performance of the Nanobio-Based Reagent for Visualising Wet Fingerprints Exposed to Different Levels of Water Salinity.* Journal of Clinical and Health Sciences, 2021(1(Special)): p. 32-43%V 6. DOI: 10.24191/jchs.v6i1(Special).13169.
420. Perry, H. and Sears, V.G., *The Use of Natural Yellow 3 (Curcumin) for the Chemical Enhancement of Latent Friction Ridge Detail on Naturally Weathered Materials.* Journal of Forensic Identification, 2015. **65**(1): p. 45-66.
421. Downham, R.P., Kelly, S., and Sears, V.G., *Feasibility Studies for Fingermark Visualization on Leather and Artificial Leather.* Journal of Forensic Identification, 2015. **65**(2): p. 138-159.
422. Alsolmy, E., Abdelwahab, W.M., Martinez, V., Henary, M., and Patonay, G., *Investigation of Benzophenoxazine Derivatives for the Detection of Latent Fingerprints on Porous Surfaces.* Journal of Photochemistry and Photobiology A: Chemistry, 2020. **392**: p. 112416. DOI: https://doi.org/10.1016/j.jphotochem.2020.112416.
423. McCabe, R., Spikmans, V., Wuhrer, R., Spindler, X., and Lennard, C., *Evaluation of Indanedione Application Methods for Fingermark Detection on Paper: Conventional Treatment, Vacuum Development, and Dry-Transfer.* Journal of Forensic Identification, 2020. **70**(1): p. 37-58.
424. Jeanneret, A., Anthonioz, A., and Bécue, A., *Printed Artificial Sweat as Replacement for Natural Fingermarks: Qualitative and Quantitative Approach Considering an Amino Acid Reagent.* Science & Justice, 2021. **61**(3): p. 249-259. DOI: https://doi.org/10.1016/j.scijus.2021.01.004.
425. De Alcaraz-Fossoul, J., Mestres Patris, C., Balaciart Muntaner, A., Barrot Feixat, C., and Gené Badia, M., *Determination of Latent Fingerprint Degradation Patterns—a Real Fieldwork Study.* International Journal of Legal Medicine, 2013. **127**(4): p. 857-870. DOI: 10.1007/s00414-012-0797-0.
426. Rohatgi, R., Sodhi, G.S., and Kapoor, A.K., *Small Particle Reagent Based on Crystal Violet Dye for Developing Latent Fingerprints on Non-Porous Wet Surfaces.* Egyptian Journal of Forensic Sciences, 2014. **34**. DOI: 10.1016/j.ejfs.2014.08.005.

427. Maceo, A.V. and Wertheim, K., *Use of Ninhydrin in the Recovery of Latent Prints on Evidence Involving Adhesive Surfaces Attached to Porous Surfaces.* Journal of Forensic Identification, 2000. **50**(6): p. 581-594.
428. Lennard, C. and Stoilovic, M., *The Detection of Bleached Ninhydrin Developed Fingerprints on Paper.* Journal of Forensic Identification, 2002. **52**(5): p. 537-549.
429. Hollars, M.L., Trozzi, T.A., and Barron, B.L., *Development of Latent Fingerprints on Dark Colored Sticky Surfaces Using Liqui-Drox.* Journal of Forensic Identification, 2000. **50**(4): p. 357-362.
430. Swofford, H.J., Paul, L.S., Steffan, S.M., and Bonar, D., *Development of Latent Fingerprints on Fired Brass Cartridge Cases: Impact of Latent Print Development Using Acidified Hydrogen Peroxide on Forensic Firearm and Toolmark Examinations.* Journal of Forensic Identification, 2013. **63**(4): p. 359-368.
431. Plazibat, S., Swiontek, S., Lakhtakia, A., and Roy, R., *White-Light Vs. Short-Wavelength Ultraviolet Illumination of Fingerprints Developed with Columnar Thin Films of Alq 3.* Canadian Society of Forensic Science Journal, 2015. **48**: p. 1-10. DOI: 10.1080/00085030.2015.1073522.
432. Eldridge, H., De Donno, M., and Champod, C., *Predicting Suitability of Finger Marks Using Machine Learning Techniques and Examiner Annotations.* Forensic Science International, 2021. **320**: p. 110712. DOI: https://doi.org/10.1016/j.forsciint.2021.110712.
433. Fraser-Mackenzie, P.A.F., Dror, I.E., and Wertheim, K., *Cognitive and Contextual Influences in Determination of Latent Fingerprint Suitability for Identification Judgments.* Science & Justice, 2013. **53**(2): p. 144-153. DOI: https://doi.org/10.1016/j.scijus.2012.12.002.
434. Ulery, B.T., Hicklin, R.A., Roberts, M.A., and Buscaglia, J., *Interexaminer Variation of Minutia Markup on Latent Fingerprints.* Forensic Science International, 2016. **264**: p. 89-99. DOI: https://doi.org/10.1016/j.forsciint.2016.03.014.
435. Almog, J., Cohen, Y., Azoury, M., and Hahn, T.R., *Genipin--a Novel Fingerprint Reagent with Colorimetric and Fluorogenic Activity.* J Forensic Sci, 2004. **49**(2): p. 255-7.
436. Fairley, C., Bleay, S.M., Sears, V.G., and NicDaeid, N., *A Comparison of Multi-Metal Deposition Processes Utilising Gold Nanoparticles and an Evaluation of Their Application to 'Low Yield' Surfaces for Finger Mark Development.* Forensic Science International, 2012. **217**(1-3): p. 5.
437. Payne, I.C., McCarthy, I., Almond, M.J., Baum, J.V., and Bond, J.W., *The Effect of Light Exposure on the Degradation of Latent Fingerprints on Brass Surfaces: The Use of Silver Electroless Deposition as a Visualization Technique.* Journal of Forensic Sciences, 2014. **59**(5): p. 1368-1371. DOI: https://doi.org/10.1111/1556-4029.12524.
438. Bond, J.W., *Visualization of Latent Fingerprint Corrosion of Metallic Surfaces.* Journal of Forensic Sciences, 2008. **53**(4): p. 812-822. DOI: 10.1111/j.1556-4029.2008.00738.x.
439. Rae, L., Gentles, D., and Farrugia, K.J., *An Investigation into the Enhancement of Fingermarks in Blood on Fruit and Vegetables.* Sci Justice, 2013. **53**(3): p. 321-7. DOI: 10.1016/j.scijus.2013.05.002.
440. Francese, S., Bradshaw, R., and Denison, N., *An Update on Maldi Mass Spectrometry Based Technology for the Analysis of Fingermarks – Stepping into Operational Deployment.* The Analyst, 2017. **142**. DOI: 10.1039/C7AN00569E.
441. Joannidis, C.A., Haddrill, P.R., and Laing, K., *Determination of the Most Effective Enhancement Process for Latent Fingermarks on Clydesdale Bank and Royal Bank of Scotland £5 and £10 Polymer Banknotes.* Forensic Sci Int, 2020. **312**: p. 110334. DOI: 10.1016/j.forsciint.2020.110334.
442. Montgomery, L., Spindler, X., Maynard, P., Lennard, C., and Roux, C., *Pretreatment Strategies for the Improved Cyanoacrylate Development of Dry Latent Fingerprints on Nonporous Surfaces.* Journal of Forensic Identification, 2012. **62**: p. 517-542.
443. Chadwick, S., Maynard, P., Kirkbride, P., Lennard, C., McDonagh, A., Spindler, X., and Roux, C., *Styryl Dye Coated Metal Oxide Powders for the Detection of Latent Fingermarks on Non-Porous Surfaces.* Forensic Sci Int, 2012. **219**(1-3): p. 208-14. DOI: 10.1016/j.forsciint.2012.01.006.

444. Moore-Davies, S., Christophe, D., and Morris, T., *Determining the Effects of Surface, Age, and Depletion on Latent Prints Processed with Aerosolized Powder Puff Fingerprint Powder.* Journal of Forensic Identification, 2016. **66**: p. 233-243.
445. Ponschke, M. and Hornickel, M., *A Limited Validation and Comparison of 1,2-Lndanedione and Thermanin for Latent Print Development on Thermal Paper.* Journal of Forensic Identification, 2016. **66**: p. 245-258.
446. Bécue, A., *Emerging Fields in Fingermark (Meta)Detection – a Critical Review.* Anal. Methods, 2016. **8**: p. 7983-8003. DOI: 10.1039/C6AY02496C.
447. Hicklin, R.A., Buscaglia, J., Roberts, M.A., Meagher, S.B., Fellner, W., Burge, M.J., Monaco, M., Vera, D., Pantzer, L.R., Yeung, C.C., and Unnikumaran, T.N., *Latent Fingerprint Quality: A Survey of Examiners.* Journal of Forensic Identification, 2011. **61**(4): p. 385-418.
448. Bentolila, A., Reuveny, S.A., Attias, D., and Elad, M.L., *Using Alginate Gel Followed by Chemical Enhancement to Recover Blood-Contaminated Fingermarks from Fabrics.* Journal of Forensic Identification, 2016. **66**(1): p. 13-21.
449. Fritz, P., Frick, A.A., van Bronswijk, W., Beaudoin, A., Bleay, S., Lennard, C., and Lewis, S.W., *Investigations into the Influence of Donor Traits on the Performance of Fingermark Development Reagents. Part 1: 1,2-Indanedione-Zinc Chloride.* Journal of Forensic Identification, 2017. **67**(3): p. 410-425.
450. Prete, C., Galmiche, L., Quenum-Possy-Berry, F.-G., Allain, C., Thiburce, N., and Colard, T., *Lumicyano™: A New Fluorescent Cyanoacrylate for a One-Step Luminescent Latent Fingermark Development.* Forensic Science International, 2013. **233**(1): p. 104-112. DOI: https://doi.org/10.1016/j.forsciint.2013.07.008.
451. Bengiat, R., Liptz, Y., Rajs, N., Bentolila, A., and Levin-Elad, M., *Time Is Money or Money Is Time? A Rapid Operational Sequence for Detecting Fingermarks on Polymer Banknotes*.* Journal of Forensic Sciences, 2020. **65**. DOI: 10.1111/1556-4029.14479.
452. Fieldhouse, S.J., Kalantzis, N., and Platt, A.W.G., *Determination of the Sequence of Latent Fingermarks and Writing or Printing on White Office Paper.* Forensic Science International, 2011. **206**(1): p. 155-160. DOI: https://doi.org/10.1016/j.forsciint.2010.07.032.
453. Oblak, T., Haraksim, R., Peer, P., and Beslay, L., *Fingermark Quality Assessment Framework with Classic and Deep Learning Ensemble Models.* Knowledge-Based Systems, 2022. **250**: p. 109148. DOI: https://doi.org/10.1016/j.knosys.2022.109148.
454. Lanahan, M. and Yoda, M., *Quantitative Evaluation of Latent Fingermarks with Novel Enhancement and Illumination.* Science & Justice, 2021. **61**(5): p. 635-648. DOI: https://doi.org/10.1016/j.scijus.2021.07.006.

Author Contributions

Teneil Hanna: Conceptualization (ideas: formulations of overarching aims); data processing and analysis, writing-original draft (preparation, creation of the published work). Dr Sebastien Moret: Conceptualization (ideas: formulations of overarching aims); writing – review and editing (critical review and revision); supervision/mentorship. Dr Scott Chadwick: Conceptualization (ideas: formulations of overarching aims); writing – review and editing (critical review and revision); supervision/mentorship

Declarations of interest:

none

Highlights

- Critical meta-analysis of subjective fingermark quality evaluation methods in fingermark detection research
- Despite recommended scales, novel scales still dominate
- Scale choice dependent on author and location